90¢

Extension Bulletin E-486, Sept. 1981, File 32.3

Secondary and Micronutrients

FOR VEGETABLES AND FIELD CROPS

COOPERATIVE EXTENSION SERVICE • MICHIGAN STATE UNIVERSITY

Secondary and Micronutrients

FOR VEGETABLES AND FIELD CROPS

By M. L. Vitosh, D. D. Warncke, B. D. Knezek and R. E. Lucas*

Department of Crop and Soil Sciences

*The authors gratefully acknowledge the assistance of D. R. Christenson, B. G. Ellis, L. W. Jacobs, V. Meints and L. S. Robertson, Crop and Soil Sciences Department, in the preparation of this bulletin.

COVER: Manganese-deficient soybeans on organic soil, center. Leaves are mottled between the veins and later turn yellow. Soybeans on either side responded to manganese fertilizer.

GENERAL INFORMATION

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

The information presented here is primarily a result of research conducted in Michigan and may not be applicable to other areas of the United States.

Needs for Secondary and Micronutrients

The extent of both secondary and micronutrient deficiencies in Michigan is not widespread, but a deficiency of any of these elements can cause plant abnormalities, reduced growth or crop failure. The need for these nutrients in crop production has drawn increased attention for the following reasons:

- More information regarding crop responses and availability of the nutrients in different 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 there is less widespread use of animal manures and greater use of high-analysis fertilizers low in impurities (secondary and micronutrients).

- Higher potassium levels in the soil and greater use of nitrogen fertilizer can cause a magnesium imbalance in some plants, creating a potential for hypomagnesia (grass tetany) problems in livestock.

- Higher phosphorus levels in the soil can induce zinc deficiency.

- Reduced sulfur emissions from industry, as a result of air pollution abatement practices, have decreased the amount of sulfur falling to the soil in rain water.

- More attention is being given to crop quality and nutritional value of today's crops.

- Increased attention is being given to elements which might reduce disease and damage from air pollutants.

Identifying Problem Areas

The criteria used to help identify secondary and micronutrient problems are: (1) soil tests (2) plant analyses (3) soil type (4) crop planted (5) plant symptoms and (6) yield goals. A good way to confirm a suspected nutrient deficiency is to obtain plant and soil samples from areas of adjacent 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. The copper test is available for organic soils only. Other laboratories may offer soil tests for sulfur, boron and iron.

Plant tissue analyses by emission spectrographic procedures are available through the MSU Soil Testing Laboratory. Table 1 shows the acceptable or sufficiency nutrient ranges required for high production of several important Michigan crops. The values reported for vegetables are general and should be used only as guidelines. Nutrient levels below those suggested can indicate a deficiency. Values above these ranges may be excessive and even toxic.

When using tissue analysis to diagnose nutrient deficiencies, it is important to know the specific tissue sample, the age, position on the plant, and whether or not deficiency symptoms existed on the plant or tissue sampled.

Secondary and Micronutrient Fertilizers

The addition of secondary and micronutrients to nitrogen, phosphorus and potassium (N-P-K) fertilizers can be accomplished in several ways. 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

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 mid-season	Top fully-developed leaves	Petioles from most recently matured leaf sampled in mid-season
	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

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 primary nutrients, a sticker may be needed to prevent particle size separation which leads to segregation of particle sizes and non-uniform distribution when applied.

Secondary and micronutrients may also be added to liquid or suspension fertilizers. Chelated secondary and micronutrient formulations are generally preferred for mixing with liquid fertilizer since 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 amount of element required per acre. In this bulletin all secondary and micronutrient recommendations are given in *pounds of element* per acre.

Michigan Fertilizer Law

The Michigan Fertilizer Law requires each fertilizer manufacturer who claims secondary and micronutrients in fertilizer to guarantee the minimum composition of these nutrients in the fertilizer. The guaranteed minimum levels of secondary and/or micronutrients which can be claimed in agricultural fertilizers in Michigan are given in Table 3. Many 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 carry sufficient quantities to correct a deficiency. For example, one application of 300 pounds of fertilizer containing 0.05% 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.

Claims may be made by the manufacturer that these elements in premium fertilizers are needed as a maintenance fertility program. Such a claim has merit for some micronutrient elements in very sandy soils. But for most agricultural soils in Michigan, the problem is not the maintenance level, but the maintenance of the nutrients in an available form.

Most soils have ample total iron and manganese, but it is 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 which does not accumulate, to a great extent, in sandy soils and therefore cannot be maintained at sufficiently high levels. In other soils, boron may also 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 as well as strength in the plant. It is thought to counteract the effect of alkali salts and organic acids within a plant. Calcium is absorbed as the ion Ca^{++} 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

TABLE 3. Minimum percentages of secondary and micronutrients which must be present in fertilizer to be claimed under Michigan Fertilizer Laws.

Element	Minimum percent required
Secondary	
Calcium (Ca)	1.0%
Magnesium (Mg)	1.0%
Sulfur (S)	1.0%
Micronutrients	
Manganese (Mn)	1.0%
Iron (Fe)	0.10%
Boron (B)	0.125%
Copper (Cu)	0.5% inorganic, 0.10% chelate
Zinc (Zn)	0.5% inorganic, 0.125% chelate
Molybdenum (Mo)	0.04%

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 due to 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, black heart 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 due to insufficient soil calcium levels.

In Michigan, calcium deficiency occurs only on very acid soils (less than pH 5.0) or where excessive quantities of potassium or magnesium have been used. Soils which are adequately limed are high in calcium. Even soils which 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 and not inadequate calcium. In Michigan, calcium deficiency symptoms sometimes occur where the root system has been damaged by nematodes, insects or diseases such that the plant is unable to take up calcium fast enough.

Correcting Calcium Deficiency

Calcium in plants is a relatively non-mobile 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 1-2 pounds of calcium in 30 gallons of water, using either calcium chloride or calcium nitrate. Lime should be used to correct calcium deficiency when it occurs on acid soils.

Calcium Toxicity

Excess levels of calcium are rarely detrimental to plant growth. However, excessive calcium carbonate in the soil may result in other nutritional problems associated with high pH. Band applications of acid forming fertilizers may lower the pH in the band and increase the availability of other nutrients.

Excessive soluble sources of 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 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 the plants, is absorbed as the ion Mg^{++} and can be readily translocated from older to younger plant parts in the event of a deficiency.

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

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 celery, chlorosis starts 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, then brown, causing the leaves to become very brittle.

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 center of the leaflets. The leaves become brown and very brittle during the advanced stages of the deficiency.

Other responsive crops in Michigan are cauliflower, muskmelons, peas and rye. General deficiency symptoms for these crops show that the oldest leaves are mottled or lighter green than normal or new leaves.

Correcting Magnesium Deficiency

Present soil test criteria for recommending magnesium in Michigan are: (1) the exchangeable magnesium level is less than 75 pounds per acre for mineral soils (150 pounds per acre for organic soils) or (2) the equivalents of potassium exceed magnesium (on a weight basis this is about 3 parts of potassium to 1 part magnesium) or (3) the soil magnesium (as a percent of total bases) is less than 3 percent.

On acid soils where magnesium need is indicated, at least 1,000 pounds of dolomitic limestone should be applied. 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 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 of the total exchangeable bases (equivalent basis). These rates are aimed at preventing "grass tetany" disorders in livestock which feed on lush grass. Anyone concerned with "grass tetany" should avoid excessive rates of potassium fertilizer and feed legume hay, which is generally high in magnesium. Some magnesium carriers can be mixed with grain or salt rations; contact your animal feed specialist for amounts and sources.

Magnesium uptake by celery appears to 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 which 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. Even the continued use of dolomitic limestone has not caused magnesium toxicity.

SULFUR

Sulfur is taken up by plants primarily in the form of sulfate ($SO_4^=$) ions and reduced and assembled into organic compounds. Sulfur is a constituent of certain amino acids (cystine, cysteine, glutathione, and methionine) and hence it is in proteins that contain these amino acids. It is found in vitamins, enzymes and co-enzymes.

Sulfur is also present in glycosides which give the characteristic odors and flavors to mustard, onion and garlic plants. It is 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 upon decomposition of organic matter. The available sulfate ($SO_4^=$) ion remains in soil solution, much like the nitrate (NO_3^-) ion, until it is taken up by the plant. In this form it is subject to leaching as well as microbial immobilization. In water-logged soils it may be reduced to elemental sulfur (S) or other unavailable forms. Fertilizer impurities also contribute to the overall supply of available sulfur in soils.

Rainwater supplies a considerable amount of sulfur from the atmosphere. In rural areas of Michigan this amount will generally vary from 8 to 15 pounds per acre annually, depending on proximity to an emission source of atmospheric sulfur. Precipitation within several miles of certain industrial sites may contain 10 to 20 times as much sulfur as 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, the more intensive cropping and the increased use of fertilizers low in sulfur, one might expect sulfur deficiency to be widespread. Field trials, however, have indicated little need for additional sulfur fertilizer. Soil mineral sources and sulfur fallout from the atmosphere are believed to exceed the plant requirements.

Sulfur Deficiency Symptoms

Sulfur deficient plants generally have a light green color which resembles nitrogen deficiency. The most likely crops to show a sulfur deficiency are those grown in the sandy, low organic matter soils in northern Michigan. Legumes, especially those like alfalfa with a high sulfur requirement, will normally be the first crops to respond to sulfur fertilization. Field beans not adequately fertilized with nitrogen have been shown to respond to sulfur fertilizer (Figure 2). 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 appear as an interveinal chlorosis and scorching of the leaf margin which gradually proceeds inward. Irrigation water high in sulfate and/or soluble salts is a potential problem source normally occurring in arid and semi-arid regions. This problem is often remedied by thorough leaching. Excess sulfur in some organic soils and so called "Kett" clay soils can cause extreme acidity when sulfur is oxidized as a result of drainage.

Sulfur dioxide in the atmosphere is an air pollutant and can cause plant injury. Plants which are relatively sensitive to sulfur dioxide injury are soybeans, field 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 only be made after all foliar symptoms and related evidence has been considered.

In general, existing 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 exhibit an ivory or white type of chronic symptom while others show a strong red brown or black coloration. Later symptoms resemble normal senescence.

Acute injury appears as marginal areas of dead tissue which at first have a full grayish-green, water-soaked appearance. Later these areas take on a

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

Figure 3. Manganese-deficient dark red kidney beans. Yellowing between the leaf veins. Veins remain green.

Figure 4. Manganese-deficient celery. Chorosis of the leaves between the dark veins.

Figure 5. Manganese deficiency in cabbage. Interveinal chlorosis of the leaves generally over the entire plant, center. Healthy plant in front.

Figure 6. Manganese deficiency in 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 7. Manganese deficiency in field beans. Yellow mottling between the veins, right. Symptoms occur 3 to 4 weeks after emergence. Normal leaf, left.

bleached ivory color in most plants. In small grains, tip dieback is a common symptom of the injury.

MANGANESE

Manganese deficiency in crops is the most common micronutrient problem in Michigan. The element should not be confused with "magnesium," a secondary element.

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. 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 or alkaline soils, e.g., lake beds, glacial outwashes, peats and mucks. Acid soils which 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 color. The deficiency in crops is seldom found on glacial till or moraine soils.

Crops show differences in response to manganese. The degree of response of crops to fertilizer manganese is given in Table 4.

Manganese Deficiency Symptoms

Most crops deficient in manganese are yellowish to olive-green in color. 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. Corn plants do not show a marked symptom but, when compared with a normal leaf, the deficient leaf is lighter green-colored and has parallel, yellowish stripes (Figure 19).

Manganese deficient plants, such as soybeans, beans, sugar beets, celery, cucumbers and cabbage, show marked yellowing between the leaf veins; the veins themselves remain dark green (Figures 3-7). This pattern is similar to iron deficiency but is more general 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 deficiency is sometimes confused with nitrogen deficiency. To separate the two, make a nitrogen tissue test. Manganese deficient plants usually test higher than normal in nitrate-nitrogen.

Correcting Manganese Deficiency

Manganese deficiency in crops can be prevented by applying manganese fertilizer to the soil, spraying it on the foliage, or making the soil more acidic. Steam or chemical fumigation will also give temporary correction. 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), and 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 materials. These materials, however, do not blend well with other fertilizers because of segregation problems due to differences in particle sizes.

Manganous oxide-manganese-sulfate combinations contain both manganous oxide and manganese sulfate and are considered intermediate in effectiveness unless finely ground.

Manganic oxide (MnO_4), which is marketed in Michigan, is insoluble and ineffective as a manganese fertilizer regardless of mesh size. Chelated manganese materials in general have not been satisfactory 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. For this reason, manganese must be applied every year on a deficient soil. Suggested rates of application based on soil tests are given in Table 5.

Foliar applications of manganese are recommended where: (1) regular fungicide and insecticide sprays are applied or (2) fertilizer is not applied in a band near the seed or (3) deficiency symptoms appear on the foliage. 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 plugging of the nozzles. Some fungicides, such as maneb, contain manganese but the amount of manganese applied is generally not sufficient to correct a deficiency.

Manganese deficiency can be corrected by acidifying the soil with materials such as sulfur and aluminum sulfate. These treatments are more costly 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 the soil farther from the fertilizer band. Some

TABLE 4. Relative response of selected crops to micronutrients.[1]

Crop	Response to Micronutrient					
	Mn	B	Cu	Zn	Mo	Fe
Alfalfa	medium	high	high	low	medium	medium
Asparagus	low	low	low	low	low	medium
Barley	medium	low	medium	medium	low	high
Beans	high	low	low	high	medium	high
Blueberries	low	low	medium			
Broccoli	medium	medium	medium		high	high
Cabbage	medium	medium	medium		medium	medium
Carrots	medium	medium	medium	low	low	
Cauliflower	medium	high	medium		high	high
Celery	medium	high	medium		low	
Clover	medium	medium	medium	low	medium	
Cucumbers	high	low	medium			
Corn	medium	low	medium	high	low	medium
Grass	medium	low	low	low	low	high
Lettuce	high	medium	high	medium	high	
Oats	high	low	high	low	low	medium
Onions	high	low	high	high	high	
Parsnips	medium	medium	medium			
Peas	high	low	low	low	medium	
Peppermint	medium	low	low	low	low	low
Potatoes	high	low	low	medium	low	
Radishes	high	medium	medium		medium	
Rye	low	low	low	low	low	
Sorghum	high	low	medium	high	low	high
Spearmint	medium	low	low	low	low	
Soybeans	high	low	low	medium	medium	high
Spinach	high	medium	high		high	high
Sudan grass	high	low	high	medium	low	high
Sugar beets	medium	high	medium	medium	medium	high
Sweet corn	high	medium	medium	high	low	medium
Table beets	high	high	high	medium	high	high
Tomatoes	medium	medium	medium	medium	medium	high
Turnips	medium	high	medium		medium	
Wheat	high	low	high	low	low	low

[1] The crops listed will respond as indicated to applications of the respective micronutrient when that micronutrient concentration in the soil is low.

TABLE 5. Manganese recommendations for band application of responsive crops grown on mineral and organic soils.

Manganese (0.1 N HCl Extraction)								
	MINERAL SOILS				ORGANIC SOILS			
Soil test ppm Mn	Above pH 6.5		pH 6.0-6.5		Above pH 6.4		pH 5.8-6.4	
	Response	Mn-lbs/A	Response	Mn-lbs/A	Response	Mn-lbs/A	Response	Mn-lbs/A
Below 5	Probable	8	Probable	6	Certain	16	Certain	12
5-10	Probable	6	Possible	4	Certain	12	Probable	8
11-20	Possible	4	None	0	Probable	8	Possible	4
21-40	None	0	None	0	Possible	4	None	0
Above 40	None	0	None	0	None	0	None	0

of the benefit accredited to band placement of fertilizer is due to the release of fixed soil manganese.

Manganese Toxicity

Excess manganese is a problem in extremely acid soils, especially if the soil is steamed or fumigated. A toxic manganese situation may also develop in plants if excess 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, 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 (Figure 8). In potatoes, the symptoms are chlorosis and black specks on the stems and underside of the leaves, followed by death of the lower leaves.

The following crops are sensitive to excess manganese: alfalfa, cabbage, cauliflower, small grain, clover, potato, field bean, sugar beet and tomato.

Plant tissue analysis is helpful in diagnosing manganese status. Values less than 20 ppm (parts per million) 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-managnese 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 the spray program on a limited acreage. Injury can be detected within 48 hours after application.

BORON

Boron primarily regulates the metabolism of carbohydrates 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 with different crops. Rates required for responsive crops such as alfalfa, beets and celery can cause serious damage to small grains, beans, peas and cucumbers. Boron deficiency may occur on both alkaline and acid soils but is more prevalent on the calcareous, alkaline soils. Soil types deficient in boron are usually the sandy loams, dark-colored sandy loams, organic soils and some fine textured lake-bed soils. Boron deficiency develops more frequently during dry periods when soil moisture levels are low.

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 a rosetting of the plant. 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 (Figure 9). Growing tips of alfalfa may die, with regrowth coming after a new shoot is initiated at a lower axil. 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. Often, when the soil is dry and plant growth is retarded, both boron deficiency and leafhopper injury 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 surface or wilting of tops. Later, if the deficiency becomes severe, transverse (crosswise) cracking of petioles, death of the growing point, and heart rot of the root develop.

In celery, the first symptoms are brownish mottling along the margins of the bud leaves and brittle stems with brown strips along the ribs. Later, crosswise cracks appear on the stems (Figure 10).

Acute deficiency in corn appears on the newly-formed leaves as elongated, watery or transparent stripes; later, the leaves become 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 base of the kernels.

Correcting Boron Deficiency

Crops show a wide range of response to boron fertilizers (see Table 4). 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 cauliflower and red beets. The suggested rate for foliage application is 0.3 pound of boron per acre in 30 gallons of water for high responsive crops and 0.1 pound for low to medium responsive crops.

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

Since boron is fairly mobile in soils, the application method can be very flexible. 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 grain because of injury to the grass or small grain. Boron for the legume should be applied as a topdressing after the grass has become well-established or the grain companion crop has been harvested. Care should also be taken when fertilizers containing boron are banded near the seed or plant.

Boron Toxicity

Boron toxicity on Michigan crops is usually limited to situations where boron-containing fertilizers prepared for sugar beets are used as planting time fertilizers for highly sensitive crops such as field beans. Toxicity to crops has also occurred where sensitive crops were planted in the same row where fertilizers containing boron had been used earlier in the season. Similar problems may occur where certain vegetable crops are planted with excessive applications of boron.

Unlike copper, zinc and sometimes 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. Except for some wastewaters which are used for irrigation, high boron levels in irrigation waters are not a problem in Michigan.

Boron toxicity is characterized by yellowing of the leaf tip, interveinal chlorosis, and progressive scorching of the leaf margin (Figure 11). 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.

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, symptoms first appear on younger leaves. Research shows a need for zinc in many areas where field beans are grown. Corn, onions, soybeans, and barley have shown benefits in some locations. Other states report that Sudan grass, sorghum, tomatoes and potatoes have been responsive.

Soil types associated with zinc deficiency are usually neutral to alkaline in reaction. The more alkaline the soil the greater is 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 tilling and spoil-bank leveling. Lake bed soils in the Saginaw Valley and peats show the greatest zinc deficiencies in Michigan. Soil series where zinc deficiencies are most likely to occur are listed in Table 6.

Observations and field tests show that field beans following sugar beets often need zinc. The large quantities of phosphorus fertilizer used for sugar beets and the high zinc uptake are believed to cause the problem.

Zinc deficiency varies from year to year. Wet, cool, cloudy weather during the early growth season increases the deficiency. Considerable trouble 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.

High soil phosphorus levels can induce zinc deficiency, especially in responsive crops (see Figure 12). 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 an acceptable

TABLE 6. Soil series which often have an alkaline reaction and are likely to need zinc fertilizer for responsive crops.

Series	Management Group	Series	Management Group
Alpena	Ga	Hessel	Gbc
Aubarque	2.5b - cd	Houghton[1]	Mc
Aurelius	M/mc	Lupton	Mc
Bach	2.5c - cs	Markey	M/4c
Carlisle[1]	Mc	Martisco	M/mc
Charity	1c - c	Sanilac	2.5b - cs
Chippeny	M/Rc	St. Ignace	Ra
Colonville	L - 2c - c	Tappan	2.5c - c
Edwards	M/mc	Thomas	2.5c - c
Essexville	4/2c - c	Tobico	5c - c
Filion	Gc - cd	Warners	M/mc
Gagetown	2.5a - cs	Wisner	2.5c - c

[1]These soils are not alkaline in reaction but have shown a need for zinc fertilizer.

Figure 8. Manganese toxicity in field beans. Scorching of the leaf margins and leaf cupping.

Figure 11. Boron toxicity in navy beans. Yellowing of the leaf tip followed by interveinal chlorosis and scorching of the leaf margins.

Figure 9. Boron-deficient alfalfa. Yellow to reddish-yellow discoloration of the upper leaves, short nodes and few flowers. Often confused with leafhopper damage.

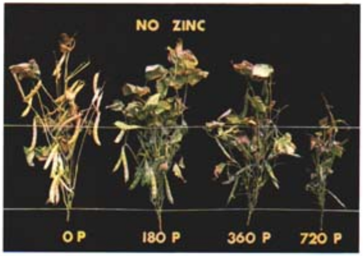

Figure 12. Phosphorus-Zinc interaction in field beans. Brownish leaf discoloration, stunted plants and pods fail to develop. Beans above received increasing rates of phophorus fertilizer without zinc.

Figure 10. Boron-deficient celery. Also known as "crack stem" because brown cracks develop along the stem rib and later across the stem.

Figure 13. Zinc deficiency in field 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. Normal leaf, upper left.

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. Hence, large applications of phosphorus fertilizer may contribute to zinc deficiency in vegetable and field crops.

Zinc Deficiency Symptoms

Bean plants deficient in zinc first become light green. When the deficiency is severe, the area between the veins of the leaves 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 like they have been killed by sun scald (Figure 13). On zinc deficient plants, the terminal blossoms set pods which 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 red streak about one-third of the way from the leaf margin (Figure 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 a stunting, with marked twisting and bending of yellow striped tops (Figure 15). In potatoes, early symptoms are similar to leaf roll. The plants are generally more rigid, with smaller than normal leaves and shorter upper internodes.

Zinc Fertilizer Carriers

A number of zinc compounds can be used to correct a deficiency. Zinc sulfate, zinc oxide, zinc chloride, zinc sulfide and zinc carbonate are common inorganic salts. Organic compounds such as zinc chelates (zinc EDTA and zinc NTA) are about five times more effective than equivalent amounts of zinc found in inorganic salts.

Organic carriers, however, have a lower zinc content ranging from 9 to 14 percent. The zinc content of zinc sulfate ranges from 25 to 36 percent and that of zinc oxide from 70 to 80 percent. In field tests, granular zinc oxide was not as effective as was 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, zinc must be applied early, in moist soil and near the seed. Mixing zinc with a phosphate fertilizer, such as 6-24-24, is acceptable.

Suggested application rates based on soil tests are given in Table 7. Seed treatment with zinc oxide is not recommended. Tests have shown that one pound of zinc per acre, from zinc oxide applied on bean seed, reduced emergence and yields in most locations.

Applications of zinc have not been very effective when sidedressed after the crop has emerged. If a zinc deficiency problem is diagnosed after emergence of the crop, spray the foliage with 0.5 to 1.0 pound of zinc per acre. This amount can be found in 1.5 to 3.0 pounds of zinc sulfate. The solution should not exceed 5 pounds of the salt per hundred gallons of water. This is about 1/2 percent solution. 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 in a vigorous state of growth. Plants with waxy leaves, such as onions, may need a wetting agent in the water to obtain good foliage cover.

Conflicting results have been obtained from spraying crops such as corn, onions, and potatoes. The reason for inadequate results may be poor transfer of zinc into the roots which also need the element to perform their functions. If foliage sprays are used, they should be applied early to obtain best results.

Zineb, Dithane M-45, tank-mix nabam and zinc sulfate are fungicides which contain zinc. Used as a foliar treatment, these fungicides may help correct zinc defi-

TABLE 7. Zinc recommendations for band application on mineral and organic soils.[1]

Soil Test ppm Zn	Zinc for Mineral and Organic Soils (0.1 N HCl Extraction)					
	Above pH 7.5		pH 6.7 to 7.4		Below pH 6.7	
	Response	Zn-lbs/A	Response	Zn-lbs/A	Response	Zn-lbs/A
Below 2	Certain	5	Probable	3	Possible	2
3-5	Probable	3	Possible	3	None	0
5-10	Probable	3	Possible	2	None	0
11-15	Possible	2	None	0	None	0
Above 15	None	0	None	0	None	0

[1]Recommended rates are for inorganic salts such as zinc sulfate. Use one-fourth this rate for chelated materials.

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

Figure 15. Zinc-deficient onions. Yellow striping, twisting and bending of the tops.

Figure 16. Molybdenum deficiency in cauliflower. Yellow mottling between the leaf veins, rolling or curling upward and crinkling of the leaves. Symptoms resemble nitrogen deficiency.

Figure 17. Copper-deficient onion. Tip dieback of the tops. Poor pigmentation of the bulb.

Figure 18. Copper deficiency in Sudan grass. Wilting and eventual death of the leaf tips. Symptoms may resemble frost damage.

Figure 19. Manganese deficient corn grown on organic soil. Leaves are light green with yellowish stripes.

ciency; however, they should not be relied on entirely if a deficiency exists because the amount of zinc applied in fungicides is very small.

Zinc Carryover

Residual carryover of available zinc varies from slight to moderate amounts, increasing as soils become less calcareous (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 by banding annually, the rate of zinc application can often be reduced or eliminated.

Soil and Plant Tissue Tests for Zinc

Plant tests can help diagnose a critical or near critical level of zinc. Tissues containing less than 20 ppm of zinc are often deficient, values of 30 to 100 ppm are normal and values over 200 ppm are considered excessive or toxic. Zinc response and suggested rates of banded zinc for soil test levels are presented in Table 7. Recommendations are based on soil pH as well as available zinc level.

Zinc Toxicity

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

High levels of available soil zinc that result in 100 to 400 ppm zinc in corn leaf tissue seldom result in zinc toxicity in corn, which is a very zinc-tolerant crop. But, if the soil levels result in 40 to 50 ppm or more of zinc in Sanilac white bean or Charlevoix red kidney bean leaf tissue, toxicity may occur because these are zinc sensitive crops. Other varieties of field beans may be more tolerant to zinc toxicity. Soybeans and most small grains fall somewhere between the zinc tolerances of corn and field beans. Vegetable crops generally tend to be sensitive to high zinc, while grasses are usually tolerant of 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—400 ppm or more. Since plant tolerance to zinc toxicity varies greatly, specific soil extractable levels which indicate toxicity have not been established.

MOLYBDENUM

Molybdenum functions largely in the enzyme systems of nitrogen fixation and nitrate reduction. Plants which can neither fix nitrogen nor incorporate nitrate into their metabolic system because of inadequate molybdenum 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 minute amounts. Normal tissues usually contain between 0.8 and 5.0 ppm; some plants may contain as high as 15 ppm. Deficient plants usually contain less than 0.5 ppm. Certain nonresponsive crops such as grass and corn may contain as low as 0.1 ppm. The responsive crops are 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 16). In later growth stages, the deficiency shows up as "whiptail" especially in the younger leaves. Older leaves show marked yellow mottling between the veins and a crinkling of the leaves. In onions, molybdenum deficiency shows up as a dying of the leaf tips. Below the dead tip, the leaf shows an inch or two of wilting and flabby formation. As the deficiency progresses, the wilting and dying advances down the leaves. In severe cases the plant dies.

Correcting Molybdenum Deficiency

Molybdenum deficiency can best be corrected by seed treatment. Dissolve 1/2 ounce of the molybdenum compound in 3 tablespoons of water and mix with sufficient seed to plant 1 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. Suppliers of the molybdate compound often sell the product in 2-ounce packages which will treat enough seed for 4 acres.

Foliar sprays may be used by applying 2 to 3 ounces of the compound per acre. Use wetting agents in the spray when applying the solution to cauliflower or onions.

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 molybdenum content of cauliflower was increased 5-fold by liming from pH 4.9 to pH 6.7. In a Houghton muck, the content of molybdenum increased over 3-fold when the pH was raised from 5.4 to 7.2. Liming severely deficient soils, however, will not completely correct the deficiency.

Molybdenum Toxicity

Plants appear quite tolerant of high soil molybdenum levels. 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.

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 while deficient plants usually contain less than 6 ppm. In each ton of dry hay there is about 0.002 pounds of copper.

Without copper all crops fail to grow. Fortunately, most Michigan soils have sufficient copper. Peaty soils low in ash are about the only ones with a deficiency. If the problem does appear in mineral soils, it will most likely be on acid sandy soil which has been cropped heavily and liberally supplied with N-P-K fertilizers. Copper applied to soil is not easily leached, nor is it extensively used by the crop. For this reason, 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 high-responsive crops.

Copper Deficiency Symptoms

Copper deficiency in many plants shows up as wilting or lack of turgor and development of a bluish-green shade before leaf tips become chlorotic and die (Figures 17 and 18). In grain, the leaves are yellowish in color and the leaf tips show a disorder similar to frost damage. Carrot roots, wheat grain and onion bulbs show poor pigmentation. Table 4 shows the variations in crop response to copper fertilizer. Alfalfa, lettuce, oats, onion, spinach, Sudan grass, table beets, and wheat are the most responsive crops on organic soils.

TABLE 8. Copper recommendations for band application of crops grown on organic soils as indicated by soil tests 1.0 N HCl extractable).

Soil Test	Crop Response		
	Low	Medium	High
ppm		pounds cu/acre	
Below 9	3	4	6
10-20	1.5	2	3
21+	0	0	0

Correcting Copper Deficiency

Application rates for organic soils based on soil tests are given in Table 8. Rates of copper commonly used in highly responsive crops are 3 to 6 pounds per acre, depending of the soil test level. These rates should be doubled on fields that have never received copper.

Common carriers of copper are the sulfate and the oxide. Copper sulfate is blue and easily identified in most fertilizers. It has a copper content of 22.5 percent. Copper oxide, a brown material, has a copper content 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 since copper is applied annually for some vegetables, either as a soil amendment or a component of some fungicides. Copper toxicity often results in a stunting of plant growth, a bluish tint to leaf color, and a cupping of leaves before chlorosis or necrosis begins. When copper concentration exceeds 20 ppm in mature leaf tissue, toxicity due to excessive copper content may be a problem. Accumulative copper applications of 100 pounds per acre have reduced cucumber and snapbean yields on sandy soils.

Copper is tightly absorbed by most soils and will not leach out. Therefore, once a copper toxicity problem develops, it is virtually impossible to alleviate.

IRON

Iron is a constituent of many organic compounds in plants. It is essential for the synthesis of chlorophyll, which causes the green pigmentation of plants. Iron deficiency can be induced by high levels of manganese. High iron can also cause manganese deficiency.

Iron Deficiency Symptoms

A lack or iron in plant tissue cannot be predicted on the basis of concentration. Deficiency symptoms, however, are marked and show up first in terminal leaves as a light yellowing. The symptoms are very similar to those of manganese deficiency. A lack of iron in field and vegetable crops is not common in soils with pH below 7.0.

Iron deficiency is a common problem in the western states where the soils contain considerable sodium and calcium. In Michigan, woody plants such as pines, pin oaks, roses, and certain ornamentals as well as 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 for longer periods of time. For bedding plant production, use 1 to 2 ounces of elemental iron per cubic yard of soil mix.

To help prevent an iron problem do not use 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 has not been common under natural soil conditions. Toxic situations occur primarily when excess soluble iron salts have been applied as foliar sprays or soil amendments. First symptoms or iron toxicity appear as necrotic spots on the leaves.

A secondary 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 that allows excessive iron to reduce manganese uptake by plants due to an interaction between the iron and manganese in the soil. The symptoms observed on the plants are of manganese deficiency, but the low plant uptake of manganese is due to 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. It results in more iron availability and does not solve the manganese deficiency problem.

TABLE 9. Suggested rates and sources of secondary and micronutrients for foliar application.[1]

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

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

FOLIAR APPLICATION OF SECONDARY AND MICRONUTRIENTS

Nutrients can be absorbed through plant leaves from foliar applications. 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 which develop in mid-season.

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 9. 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. However, chelates are more compatible when mixed with other spray materials.

For a preventive spray program, spray the crop about four weeks after emergence or transplanting. Since 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 on a 10-day schedule 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 of the foliage and may increase absorption, especially for 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 cause injury. When in doubt, spray only a limited acreage until compatibility is established. Any injury will usually appear within 48 hours. Table 10 may be used as 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 quantities present in these materials may or may not be sufficient.

Additional information concerning specific nutrients may be found in the respective sections.

TABLE 10. Pounds of secondary or micronutrient carrier needed to obtain the desired amount of the element per acre.[1]

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

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

MICHIGAN STATE UNIVERSITY
CES
COOPERATIVE
EXTENSION
SERVICE

Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8, and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Gordon E. Guyer, Director, Cooperative Extension Service, Michigan State University, E. Lansing, MI 48824.

1P-3R-7.5M, TP-LW, Price 10¢
Single Copy Free to Michigan Residents