Secondary Macronutrients

The secondary macronutrients—calcium, magnesium, and sulfur—are generally not limiting to crop production in most Minnesota soils except under certain conditions.

Calcium

Calcium is available to plants as the Ca^{2+} ion. Calcium deficiency due to low soil calcium is rare, but may occur in acid sandy soils. Soils cropped to potatoes for many years may be low in calcium because liming is not recommended for this crop. Soil test results of less than 300 ppm calcium are considered low. For all crops except potatoes and blueberries, calcium needs can be met by liming according to soil pH. For potatoes where maintenance of acidity is desired, calcium needs can be met by applying low rates of lime (approximately 1000 lb/A) during the rotation year. An alternative is to apply calcium as gypsum (calcium sulfate—20% Ca) according to **Table 37**.

Some plants are susceptible to calcium deficiency even when adequate levels of calcium are present in the soil. For physiological disorders related to calcium deficiency (such as blossom end rot in tomatoes; tipburn in lettuce, cabbage, or cauliflower; black heart in celery; or bitter pit in apples) foliar calcium sprays may be beneficial. In soils where pH has been adjusted to 6.0 or above, additional soil applied calcium generally does not correct these physiological disorders. These disorders can often be related to cultivar, excessive ammonium fertilization, and/or excess or lack of water. For foliar sprays, apply 2-4 lb Ca/A. Calcium chloride at the rate of 5-10 lb per 100 gallons per acre or calcium nitrate at the rate of 10-15 lb per 100 gallons per acre should be applied directly to the sensitive tissue. Multiple applications are necessary to increase tissue calcium. Because of precipitation problems, do not mix calcium with sulfate or phosphate compounds.

Table 37. *Calcium recommendations for fruit and vegetable crops.*

Calcium Soil Test	Relative Level	Calcium to Apply
ppm		lb/A
0 - 150	low	200
151 - 299	medium	100
300 +	high	0

Magnesium

Magnesium is available to plants as the Mg^{2+} ion. Magnesium deficiency may occur in acid sandy soils. Soil tests less than 100 ppm magnesium are considered low. Deficiencies can be induced by high rates of potassium fertilizer on sandy soils low in magnesium. If magnesium deficiency is known or suspected, the use of dolomitic limestone is the best long-range approach. Apply low rates (approximately 1000 lb/A) if maintenance of soil acidity is desired. Other more immediately available sources of magnesium include potassium-magnesium sulfate (11% magnesium) or Epsom salts (10% magnesium). Recommended rates of magnesium based on a soil test are presented in **Table 38.** For in-season correction of magnesium deficiency, foliar sprays at the rate of 2-4 lb Mg/A are recommended (20-40 lbs of Epsom salts per acre). Two to three applications are required.

Table 38. *Magnesium recommendations for fruit and vegetable crops.*

Magnesium Soil Test	Relative Level	Magnesium to Apply Broadcast	Row
ppm		---------- lb/A	---------
0 - 49	low	100	20
50 - 99	medium	50	10
100 +	high	0	0

Sulfur

Sulfur is available to plants as the sulfate ion (SO_4^{2-}). Like nitrate, sulfate is susceptible to leaching on sandy soils. Sulfur deficiency is most common on sandy low organic matter soils. Soil tests for sulfur are only accurate for sandy soils. If deficiency is known or suspected, refer to **Table 39** for sulfur soil test recommendations. The sulfate form of sulfur is the preferred form to use as fertilizer.

Table 39. *Sulfur recommendations for fruit and vegetable crops.*

Sulfur Soil Test	Relative Level	Sulfur to Apply Broadcast	Row
ppm		----------- lb/A	-----------
0 - 6	low	20-30	10-15
7 - 12	medium	trial only	trial only
12.1 +	high	0	0

Micronutrients

Micronutrients, which include boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc, are required in smaller amounts than the other essential nutrients. Generally, soils contain sufficient levels of micronutrients to meet crop demands; however, in some areas micronutrient shortages occur and may limit yields. Some crops have a higher demand for certain micronutrients than others and should be considered in determining whether a micronutrient fertilizer should be applied. The relative response of various fruit and vegetable crops to micronutrients is presented in **Table 40.**

Boron

Boron is taken up by plant roots as the neutral molecule H_3BO_3. Deficiency of boron is most likely on sandy soils low in organic matter. Excessive rainfall or irrigation may leach boron from sandy soils. A suspected boron deficiency should be confirmed by soil and plant analyses before a boron fertilizer is applied since excessive boron can be highly toxic to plants. Boron recommendations are presented in **Table 41**. For in-season correction of boron deficiency, foliar sprays at the rate of 0.2 to 0.4 lb B/A are recommended. Multiple applications are usually required.

Table 40. *Relative response of fruit and vegetable crops to micronutrients under soil conditions favorable to a deficiency.*[1]

Crop	Relative Response					
	Zinc	Iron	Manganese	Molybdenum	Copper	Boron
Apples	high	–	high	low	medium	high
Asparagus	low	medium	low	low	low	low
Beans, snap	high	high	high	low	low	low
Broccoli	–	high	medium	medium	medium	high
Blueberries	–	high	low	low	medium	low
Cabbage	low	medium	medium	medium	medium	medium
Carrots	low	–	medium	low	high	medium
Cauliflower	–	high	medium	high	medium	high
Celery	–	–	medium	low	medium	high
Cucumber	–	–	high	–	medium	low
Grapes	medium	high	high	low	low	medium
Lettuce	medium	–	high	high	high	medium
Onions	high	–	high	high	high	low
Parsnips	–	–	medium	–	medium	medium
Peas	low	–	high	medium	low	low
Potatoes	medium	–	high	low	low	low
Radishes	medium	–	high	medium	medium	medium
Raspberries	–	high	high	low	–	medium
Spinach	high	high	high	high	high	medium
Strawberries	–	high	high	–	medium	medium
Sweet corn	high	medium	medium	low	medium	low
Tomatoes	medium	high	medium	medium	medium	medium
Turnips	–	–	medium	medium	medium	high

[1] *From R. F. Lucas and B. D. Knezek. 1973.* Climatic and Soil Conditions Promoting Micronutrient Deficiencies in Plants. Micronutrients in Agriculture. *Soil Science Soc. of America.*

Table 41. *Boron recommendations for fruit and vegetable crops.*[1]

Boron Soil Test	Relative Level	Group[2]	Boron to Apply
ppm			lb/A
0.0 - 0.4	low	1	4
		2	2
		3	1
0.5 - 0.9	medium	1	2
		2	1
		3	0
1.0+	high	1	0
		2	0
		3	0

[1] *Rates suggested are for broadcast applications.*
[2] **Group 1:** *cauliflower, celery, broccoli, turnips, table beets, Brussels sprouts, rutabagas, apples*
Group 2: *cabbage, radishes, carrots, onions, tomatoes, spinach, eggplant, parsnips, strawberries, raspberries, grapes*
Group 3: *lettuce, peppers, asparagus, potatoes, squash, watermelon, muskmelon, parsley, mint, endive, rhubarb, green onions, blueberries*
No boron is recommended for fruits or vegetables not listed above.

Table 42. Copper recommendations for fruit and vegetable crops (organic soils only).

Copper Test	Relative Level	Group[1]	Copper to Apply
ppm			lb/A
0.0 - 2.5	low	1	10 broadcast 0.3 foliar[2]
		2	0
2.6 - 5.0	medium	1	6 broadcast 0.1 foliar[3]
		2	0
5.1+	high	1	0
		2	0

[1] **Group 1:** carrots, lettuce, spinach, onions, table beets, radishes, parsnips, turnips, celery, green onions
Group 2: asparagus, broccoli, Brussels sprouts, cabbage, cauliflower, mint, endive, parsley
[2] Some leaf burn may occur if foliar applications of copper exceed 0.15 lb Cu/A. Split the high rate recommended into two or more applications at weekly intervals.
[3] Two or three applications are usually required.

Chlorine

Chlorine is available to plants as the chloride ion (Cl^-) and is a major component of the potash fertilizer, 0-0-60. Actual plant requirements for chlorine are very low and adequate levels of chlorine to meet plant needs are believed to be present in all Minnesota soils. Excessive levels of chloride can cause salt burn. The need for using supplemental fertilizer applications to provide chlorine for fruit or vegetable crops in Minnesota has not been demonstrated.

Copper

Copper is available to plants as the Cu^{2+} ion. In Minnesota, copper deficiency is most likely on organic soils. Responses to copper by crops on mineral soils (loams, clay loams, etc.) have not been demonstrated; therefore, copper fertilizer is not recommended for crops grown on mineral soils. Soil tests for copper are reliable only for organic soils. Soil or foliar applied copper can be used to correct suspected deficiencies **(Table 42)**. For soil application, apply copper sulfate and mix thoroughly in the top 6 inches before planting. Retest in three years.

Iron

The soil test for iron is not reliable for predicting iron requirements in Minnesota. Therefore, no recommendations based on a soil test are provided. Iron availability is related more to soil pH than it is to soil test iron levels. Alkaline soil conditions (pH greater than 7.2) can render iron unavailable to plant roots. Iron is usually present in the Fe^{3+} (ferric) form and must be converted to the Fe^{2+} (ferrous) form before it can be absorbed by plant roots. If soil pH is above 7.2 and interveinal chlorosis is apparent, then a foliar application of iron chelate may be beneficial. A general recommendation for foliar iron is 0.1 to 0.15 pounds actual iron per acre. Follow label instructions for specific crops and materials applied. Applications made during early stages of growth are more beneficial than later in the season. More than one foliar spray is usually required. Iron chlorosis in many crops can be minimized by selecting iron efficient varieties. Iron chlorosis can be corrected by soil applications of iron chelate, but the large amounts required make the practice uneconomical for most crops. For blueberries, soil pH should be lowered to 5.2 or less to correct iron chlorosis problems (see soil acidification section, **page 8**).

Table 43. Manganese recommendations for fruit and vegetable crops (organic soils only).

Soil pH	Group[1]	Manganese to Apply	
		Foliar[2]	Soil
		lb/A	lb/A
5.7 or less	1	0	0
	2	0	0
5.8 - 6.3	1	0.3	10
	2	0.2	4
6.4 or more	1	0.4	15
	2	0.3	6

[1] **Group 1:** lettuce, onions, potatoes, radishes, spinach, table beets, green onions, raspberries, strawberries, apples, grapes
Group 2: sweet corn, celery, broccoli, cauliflower, cabbage, Brussels sprouts, turnips, carrots, parsley, peppers, tomatoes
No manganese is recommended for crops not listed.
[2] Two or three applications are usually required. Apply with 50 to 100 gallons of water. Chelated manganese sources such as MnEDTA are recommended for foliar sprays.

Manganese

Most manganese in soils is precipitated as manganese oxide or hydroxide. The form available to plants is the Mn^{2+} ion. Manganese availability is related more to soil pH than soil test manganese levels. Manganese recommendations are based on the crop being grown and soil pH. On low pH mineral soils (pH less than 4.8), manganese can be toxic to plants. A few suspected deficiencies have been reported in fruit and vegetable crops grown on alkaline mineral soils. Manganese deficiency problems are most likely to occur on organic soils with a pH greater than 5.8. Soil and foliar application rates of manganese based on crop and soil pH are presented in **Table 43** (organic soils). If crops grown on mineral soils show signs of manganese deficiency or have low tissue manganese levels, a foliar application at the rate of 0.2 lb Mn/A is recommended. Two or three applications are usually required. Apply with 50 to 100 gallons of water per acre. Chelated sources of manganese are recommended for foliar spays.

Molybdenum

Molybdenum is available to plants as the MoO_4^{2-} ion. Deficiencies may occur on acid sandy soils and acid peats. Certain vegetable crops such as cauliflower are particularly susceptible to molybdenum deficiency. Soil tests for molybdenum are not reliable for making molybdenum fertilizer recommendations. Liming soils to a pH of 6.0-6.5 is the best method to correct molybdenum deficiency; however, some cauliflower cultivars seem to be susceptible to molybdenum deficiency even in limed soils. Soil applications of 0.25-0.5 pounds per acre of actual molybdenum can be used if molybdenum deficiency is a problem. Foliar applications of 1-2 oz/A of actual molybdenum are suggested for cole crops where a deficiency is known or expected. Do not overapply molybdenum as high rates can be toxic to animals.

Nickel

Nickel has only recently been shown to be an essential nutrient for plants. The form of nickel available to plants is the Ni^{2+} ion. Deficiencies of nickel have not been reported in field soils in Minnesota; however, some plants (for example, river birch) grown in peat based potting media are susceptible to nickel deficiency. High levels of zinc seem to accentuate nickel deficiency. Soil tests for nickel have not yet been calibrated. Actual requirements for nickel are low and adequate levels of nickel are believed to be present in most soils, although further research is necessary to actually determine nickel requirements of field grown crops in Minnesota. For potted plants showing nickel deficiency, drenches with solutions containing 3 to 6 ppm nickel as nickel nitrate, chloride, or sulfate can correct the problem. High levels of nickel can be toxic to plants. Elevated nickel levels are sometimes found in sewage sludge.

Zinc

The form of zinc available to plants is the Zn^{2+} ion. Zinc deficiency can occur on alkaline soils and sandy soils low in organic matter. High levels of phosphorus coupled with low levels of soil zinc may induce zinc deficiency. If zinc deficiency is known or suspected, zinc sulfate can be blended with a dry bulk fertilizer. Application rates of zinc based on a soil test are presented in **Table 44**. Zinc applied in the row should not come in contact with the seed. For crops showing zinc deficiency during the growing season, foliar applications of zinc chelate (2 oz/A actual zinc) are suggested.

Table 44. *Zinc recommendations for all fruit and vegetable crops.*

Soil Zinc Test	Relative Level	Zinc to Apply Broadcast	Zinc to Apply Row
ppm		------------- lb/A	----------------
0 - 0.5	low	10	2
0.6 - 1.0	medium	5	1
1.1+	high	0	0

Pocedures Used in the University of Minnesota Soil Testing Laboratory

The following analyses are offered:

1. Estimated texture category⁺
2. Total organic matter (%)* (loss on ignition), maximum amount measured is 99.9%
3. Soil pH⁺ (1:1, water:soil suspension)
4. Lime requirement⁺ (SMP buffer index)
5. Extractable phosphorus⁺ (Bray-P1 extractant, Olsen-P sodium bicarbonate extractant)
6. Exchangeable potassium⁺ (ammonium acetate extractant)
7. Soluble salts* (electrical conductivity, 1:1 soil suspension, saturation extract)
8. Extractable sulfur* (calcium phosphate extractant)
9. Extractable zinc* (DTPA extractant)
10. Extractable zinc, copper, iron, and manganese* (DTPA extractant)
11. Nitrate-nitrogen* (0.01 *M* $CaSO_4$ extractant)
12. Exchangeable magnesium and calcium* (ammonium acetate extractant)
13. Hot water extractable boron* (0.1% $CaCl_2 \cdot 2H_2O$ extractant)

⁺ Tested routinely
* Tested only on request

Sample Preparation

At the laboratory, each sample is assigned a number, transferred to a paper bag, and then placed in a metal tray. Every 12th sample is a quality control sample, either a check sample of known chemical properties to ensure accuracy, or a duplicate sample to evaluate laboratory precision.

Samples are dried in a cabinet equipped with a heating element and an exhaust fan to remove moisture-laden air. The temperature in the cabinet does not exceed 104°F in order to approximate air-drying conditions.

Samples are crushed with a mechanical grinder equipped with a porcelain mortar and stainless-steel auger. They are subsequently passed through a stainless-steel 10-mesh sieve to remove larger clods and unwanted debris. Crushed and sieved samples are dried overnight before analysis.