The Mighty Micronutrients

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1. Introduction

In mineral nutrition of plants, seven nutrients essential for growth and development are required in very small amounts. Therefore, they are classified as micronutrients. Uptake is measured in ounces per acre rather than pounds per acre. These micronutrients are zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), boron (B), chloride (Cl), and molybdenum (Mo). The specific role of each in the plant is not well defined. However, if any one of these seven is eliminated or removed completely from the soil systems, plant growth will cease and, in some extreme cases, the plant will die.

In Minnesota, the need for micronutrients in a fertilizer program is not universal. Need varies with crop and soil chemistry. Therefore, functions and management of each micronutrient will be discussed separately.

1a. Zinc

In Minnesota, Zn is an important consideration for production of corn and edible beans and, when a need is indicated by the results of a soil test, application in a fertilizer program will increase yield. Application of Zn fertilizers, however, has not increased the yield of soybeans, small grains, or forage crops.

The exact or specific function of Zn in plant nutrition is not known. In general, this micronutrient is essential for enzymes that are involved in many metabolic reactions.

The availability of Zn in soils is related to soil pH; becoming more available as soil pH decreases. Therefore, requirements in a fertilizer program may be more frequent when soil pH is above 7.4. Relative levels of Zn in the soil are important for crop production and are measured by the DTPA laboratory procedure (1). The relative levels and corresponding guidelines for Zn use in Minnesota are listed in Table 1 (7).

Table 1. Relative soil test levels for zinc and guidelines for use of zinc in a fertilizer program for corn and edible bean production.

Soil Test Zinc*	Relative Level	Zinc to Apply	
		Broadcast	Band
ppm		lb. zinc/acre	
0.0 to 0.25	v. low	10	2
0.26 to 0.50	low	10	2
0.51 to 0.75	medium	5	1
0.76 to 1.00	high	0	0
1.01+	very high	0	0

* zinc extracted by the DTPA analytical procedure

With Zn, application of low rates, when needed can produce substantial increases in crop yield. The corn yields provided in Table 2 are an example (5). When applied in a band near the seed at planting, a rate of 0.1 lb. Zn per acre nearly doubled the yield of irrigated corn. This rate of Zn should not be expected to produce a similar response in all fields. This illustration is an extremely rare case.

Table 2. Response of corn to application of Zn in a fertilizer band at planting.

Zn Applied *	Corn Yield
lb./acre	bu./acre
0	62
131	
0.3	137
1.0	140
3.00	142

*Applied in an 8-20-0 suspension fertilizer containing 2.5% clay;
DTPA extractable Zn was 0.3 ppm

Zinc can be supplied, when needed, as a fluid or dry material. The dry sources are zinc sulfate ($ZnS0_4$) and zinc oxide (Zn0). Zinc oxide is insoluble in soils (especially calcareous soils) unless finely ground. The finely ground zinc oxide cannot be blended with other dry fertilizer materials that might be broadcast or used in a starter. So, unless applied in a suspension fertilizer, zinc oxide is not a good choice for the application of Zn.

Zinc sulfate (36% Zn) is the only dry material that is practical to use for crop production in Minnesota. It can be easily blended with other dry fertilizer materials.

There is a wide variety of materials that can be mixed with fluid fertilizers (e.g. 10-34-0). These materials usually fit into one of 3 categories (ammonia complex, citrate, and chelate). These materials have a variety of Zn concentrations.

There are always questions about the effectiveness of the various sources. In the past, there have been advertising claims that one source is more effective than another (often by a factor of 10:1). Research conducted to compare various sources is shown in Table 3 where all treatments were applied in a suspension fertilizer to supply the same rate of Zn per acre (5). All sources had an equal effect on yield.

Table 3. Effect of source of Zn applied in a suspension fertilizer on corn yield.

Zinc Source	**Yield**
	bu./acre
no zinc applied	105
oxide	122
sulfate	122
EDTA (chelate)	123
ammonia complex	132

soil test for Zn = low; Zn rate = 0.3 lb. Zn/acre with 8-20-0 suspension

Reported differences in yield from various sources from research in previous years were probably a consequence of distribution of Zn particles in a band. The chelated materials were very small particles. When small particles are applied in a band, there is a high probability that roots will intercept the Zn. When larger particles were used (zinc sulfate), there was a lower probability that the root would be in contact with the Zn. Thus, differences in yield were probably due to particle distribution in a band rather than the agronomic effectiveness of the various Zn sources. There is a higher probability of roots coming in contact with the Zn if this micronutrient is applied in a band at planting rather than broadcast and incorporated. Therefore, banded applications are suggested for production of corn and edible beans.

There are questions about the safety of Zn fertilizers applied in contact with the seed. Results of recent studies in Minnesota (2) show that when applied at a reasonable rate (0.5 lb. Zn per acre) with 10-34-0 (5 gallons per acre) none of the fluid sources had a negative effect on corn emergence and yield when the Zn fertilizers were placed in contact with the seed (Table 4).

Table 4. Effect of zinc source mixed with 10-34-0 on the emergence of corn and subsequent yield.

Zinc Source	**Placement**			
	Seed Contact		**Above the Seed**	
	Emergence	**Yield**	**Emergence**	**Yield**
	% of control	bu./acre	% of control	bu./acre
Nulex-Zn	95.5	213	96.8	204
Tra-Fix-Zn	94.2	213	88.5	200
Origin-Zn	93.0	201	94.2	217

Control emergence = 33,977 plants/acre; control yield = 209 bu./acre
Renville County, 2005

There was a reduction in emergence when Tra-Fix Zn was placed above the seed (88.5% of control). The reduction in stand resulted in a reduction in yield from 209 to 200 bu./acre.

Similar studies have not been conducted with edible beans. However, this crop is more sensitive, in general, to fertilizer placed close to the seed. Therefore, placement of any fertilizer with or without Zn close to edible beans at planting is not a suggested practice.

Except for situations where excessively high rates of phosphorus (P) are applied, availability of Zn is not affected by the application of other nutrients. In rare situations, application of very high rates of phosphate without zinc has reduced corn yields as in Table 5 (5). The soil test for P was very low and the soil test for Zn was not reported. Considering the low corn yields, soil Zn was also probably very low.

Table 5. Effect of applications of phosphate and zinc on corn yield.

Fertilizer Applied		
Phosphate	**Zinc**	**Yield**
---------------1b./acre--------		bu./acre
40	0	74
160	0	55
320	0	42
320	10	83

Soil test for P = 2 ppm (Olson); pH = 8.3

The very high rates of phosphate would not be used in crop production. These rates might be achieved with repeated use of high rates of manure. However, there is also Zn in manure. Therefore, this interaction should not be observed in routine production systems.

After Zn fertilizers are applied, dissolved and become part of the soil solution, Zn exists as a cation (Zn^{++}). Therefore, it is closely associated with soil and organic matter particles thereby eliminating loss due to leaching. Because of the close association with organic matter, concentration of available Zn decreases with increasing depth.

Foliar applications can only partially correct zinc deficiency in a growing crop. It is a technical mistake to expect dramatic responses with foliar zinc applications after crops get into the rapid vegetative growth stage. The degree of recovery depends on how severe the problem becomes before treatment is started. Stunted plants seldom catch up as the season progresses. Spraying should be started not later than the 3-4 leaf stage. Severe deficiencies will require 2-3 applications spaced 10-14 days apart. Foliar spraying to correct nutrient deficiencies usually allows recovery to 60-80% of normal yields. Soil testing and application of most of the Zn requirement preplant or at planting is the most effective strategy. Use foliar application as a supplemental or rescue treatment only.

1b. Iron

In Minnesota, iron (Fe) is an important consideration in soybean production. Iron Deficiency Chlorosis (IDC) is a serious problem for many soils with a pH in excess of 7.4. High pH values do not assure a problem with IDC. However, the probability of yield limiting IDC increases when higher-than-normal levels of soluble salts are combined with high percentages of free calcium carbonate.

Minnesota soils contain adequate amounts of Fe. In fact, Fe is the fourth most abundant element in the earth's crust. Reduced rates of plant uptake of iron is the major factor in fields where IDC is a serious problem with the soybean crop. There will be more discussion about Fe uptake later in this lesson.

In plants, Fe is essential for the maintenance of chlorophyll. When Fe is deficient, soybean plants turn yellow as a consequence of the lack of chlorophyll. Iron is not a component of the chlorophyll molecule, but it is directly involved in chlorophyll synthesis. Iron is also an essential component of the hemoglobin molecule. In soybean plants, hemoglobin is a component of the nodules. This may explain the lack of nodulation in field situations where IDC is a serious problem.

Iron exists in soils as Fe^{++} (ferrous form) and Fe^{+++} (ferric form). Ferric –Fe must be reduced to Fe^{++} before iron is utilized by plants. Whether the reduction reaction takes place in the soil or in the plant is not defined. But, it is necessary before Fe can be utilized by plants.

Since IDC is a major concern for many soybean growers in Minnesota, considerable research in recent years has focused on management practices that might be used to reduce the severity of the problem. Coating the seed with a Fe containing chelate, foliar application of chelates and placement of various Fe products close to the seed at planting have been effective in certain situations. None of these practices, however, has been consistent from year to year.

In searching for an answer to the IDC problem we reviewed previous research (3). Some studies showed that high concentrations of nitrate-nitrogen (NO_3-N) in leaf tissue inhibited the conversion of ferric (Fe^{+++}) to ferrous (Fe^{++}) iron. This research was conducted in growth chambers and applicability to field situations is not known.

A survey of fields where soybeans in wheel tracks were green showed that chlorosis was associated with high concentrations of NO_3-N in the leaf tissue. Therefore, use of a management practice that would reduce concentrations of soil NO_3-N appeared to be promising. Planting of a small grain crop subsequently killed with glyphosate had been reported by some growers to be successful so field trials were conducted to verify the idea. Three rates of fertilizer N (0, 100, 200 lb per acre) were established. Soybeans were planted within each N level with and without oats as a competition crop. Soybeans remained green when planted with oats, which were apparently absorbing NO_3-N from the soil. Analysis of oat plants showed that at a height of 10 to 14 inches, the oat crop could absorb about 100 lb. N per acre if not hindered by drought.

The yields measured in this research are listed in Table 6. Soil moisture was limited at the Chippewa County site. Use of soil moisture by the oat crop apparently limited soybean yield. As a result, yields without the competition crop were higher than with the competition crop. Without limited moisture (Yellow Medicine County), soybean yields were higher with oats inter-planted.

Table 6. The effect of oats as a competition crop on the yield of soybeans.

	Chippewa County		**Yellow Medicine County**	
N Applied	**no oats**	**oats**	**no oats**	**oats**
lb./acre	- - - - - - - -	- - - - - - - - - bu./acre-	- - - - - - - -	- - - -
0	42.1	22.5	52.0	52.4
100	28.6	20.5	32.2	42.6
200	25.3	18.9	19.1	25.9

The results from this study are encouraging. Use of an inexpensive practice such as seeding a small grain crop with the soybeans may pay big dividends. There are, however, many questions to be answered if this management practice is to be used routinely.

Currently, suggested management practices for reduction of IDC are summarized as follows:

- Select a variety rated as being tolerant to IDC
- Minimize excessive rates of N applied to the preceding corn or small grain crop
- Plant small grain as a competition crop, then apply glyphosate when this crop reaches a height of 10 to 14 inches

1c. Manganese

Manganese (Mn) is an important consideration for soybean production in localized areas of the Corn Belt. Addition of Mn to fertilizer programs has increased soybean yields in Indiana, Ohio, and Wisconsin. Addition of Mn has not increased crop yields in Minnesota. Of all major crops grown, Mn deficiency is usually found with soybeans.

The chemistry and metabolism of Mn^{++} is similar to that of Fe^{++}. Deficiency symptoms for the nutrients are nearly the same and it is difficult to differentiate one from the other in field situations. Minnesota soils apparently have adequate amounts of Mn to support crop production. This micronutrient is present as Mn^{++} and is held by soil and organic matter particles thereby preventing leaching.

Like other micronutrients, Mn is involved in the enzymes that govern many biological reactions in plant tissue. However, a specific role has not been defined. This micronutrient is not a concern for crop production in Minnesota.

1d. Copper

In many ways, copper (Cu) is like Mn. It has a role in enzyme reactions. However, the specific function in growth and development of plants has not been identified.

Copper exists in soils as the Cu^{++} cation. Therefore, it is closely associated with clay size particles and soil organic matter. Similar to Zn, Fe, and Mn, this micronutrient is not mobile in plant tissue and any deficiency symptoms would be expected on new growth.

Documentation of crop responses to Cu fertilization in Minnesota is limited to small grains grown on organic (peat) soils.

Trials with spring wheat grown on mineral soils have been conducted in northwestern Minnesota. The yields from that trial are summarized in Table 7. Canadian researchers had reported a response to Cu fertilization on sandy soils having low organic matter content. Thus, the majority of sites selected for study in 2000 and 2001 were sandy with an organic matter content of 2.0% or less.

Table 7. Effect of Cu fertilizer application on yield of hard red spring wheat grown on mineral soils.

		County					
Cu Applied	**Source**	**Norman 2000**	**East Polk 2000**	**Marshall 2000**	**Norman 2001**	**East Polk 2001**	**West Polk 2001**
lb./acre		- - - - - - - - - - - - - - - - bu./acre - - - - - - - - - - - - - - - -					
0	---------	50.4	55.2	47.4	45.2	57.0	59.5
6	copper sulfate	55.7	65.8	50.0	47.9	57.0	58.3
12	copper sulfate	55.1	67.0	47.9	40.8	55.5	59.6
6	copper chelate	57.4	64.6	47.6	43.0	58.5	58.7
12	copper chelate	57.2	67.9	51.1	47.3	55.9	60.7
Texture:		loamy fine sand	silty clay loam	loamy fine sand	loamy fine sand	silty clay loam	loamy fine sand

Copper fertilization produced an increase in yield of hard red spring wheat at one site (Norman County 2000). Otherwise, there was no significant effect on yield. Based on the results of this study, additions of Cu to a fertilizer program are not suggested for small grain production on the mineral soils of Minnesota.

Use of Cu is still recommended for situations where small grains might be grown on organic soils (6). Those recommendations are summarized in Table 8. Because of the reduced cost when compared to chelated sources, copper sulfate is the preferred source. Broadcast application followed by incorporation is preferred.

Table 8. Suggestions for use of copper for small grain production on organic soils.

	Method of Application			
	Broadcast		Foliar	
Copper Soil Test *	Actual Copper	Copper Sulfate	Actual Copper	Copper Sulfate
ppm	- - - - - - - - - - rate to apply (lb.acre) - - - - - - - - - -			
0 to 2.5 (low)	6 to 12	24 to 48	0.3	1.2
2.6 to 5.0 (marginal)	trial only		0.3	1.2
More than 4.0 (adequate)	0	0	0	0

*Copper is extracted by the DTPA procedure (1).

1e. Boron

The requirement for boron (B) in Minnesota is minimal. Even though testing and evaluation has been extensive over the years, response of agronomic crops was only measured for alfalfa production in northeastern Minnesota (4). Research with corn, soybeans, and small grains has shown no response. We think B is involved with cell elongation, development, and nutrient transport from roots to shoots.

Relatively little is known about the chemistry of boron (B) in soils. It exists in the soil solution as an anion rather than a cation (thought to be $H_2B0_3^-$). Because of the negative charge, this anion is not attracted to particles of soil or organic matter and, theoretically, is subject to leaching. Leaching, however, has not been documented by research. The borate anion ($H_2\ B0_3^-$) may be held much more strongly to soil particles than are nitrate (NO_3^-) or chloride (Cl^-).

The soil minerals that supply B are only slightly soluble. Therefore, availability is related to soil moisture content: Deficiency symptoms occur when soils are dry and disappear when rainfall increases water content.

The risk of over application is much greater for B than for other essential nutrients. Minnesota research has shown that soybean yields can decrease as the rate of applied B increases (Table 9).

Table 9. Soybean yield as affected by the rate of applied boron (broadcast).

B Applied*	Yield
lb./acre	bu./acre
0	35
1	34
2	32
4	27

*Soil test B = 0.2 ppm

There is a soil test for predicting the amount of B to apply in a fertilizer program (Table 10). However, we lack confidence in the ability of this test to accurately predict need and the test should only be used for alfalfa production. Sodium borates are used to supply B where needed.

Table 10. Boron fertilizer recommendations for alfalfa in Minnesota.

Soil test for Boron	Boron to Apply
ppm	lb./acre
less than 1.0	2 to 4
1.1 to 5.0	0
more than 5.0	0

See (1) for soil test

1f. Molybdenum

Molybdenum (Mo) is the least abundant of all micronutrients in Minnesota soils. Most or the Mo in the soil solution is in the form of the molybdate anion ($MoO_4^{=}$). Although molybdate is an anion; there are no studies documenting downward movement (leaching) in soils. Research indicates that molybdate is held strongly by certain components of soil organic matter.

Molybdenum is involved in nodule formation and N fixation in legumes. It is associated with activity of a specific enzyme, nitrate reductase. Otherwise, not much is known about the importance of molybdenum in plant nutrition.

There have been no research trials to document the need for Mo in a fertilizer program. Apparently Minnesota soils are well supplied with this essential micronutrient.

1g. Chloride

The necessity of chloride (Cl^-) for plant growth and development was first documented in the 1970's. Application of this micronutrient increased small grain yields when seedling diseases such as root rot were a problem. The application of Cl reduced disease severity, thereby increasing yields.

Faculty at South Dakota State University developed a soil test for Cl appropriate only for small grain production. Collection of soil samples to 24 inches is required and the number of pounds of Cl per acre is measured. This number is subtracted from 60 to determine the number of pounds of Cl to apply per acre. Potassium chloride (0-0-60) is the least expensive source of Cl.

Need for Cl fertilization is not expected in fields where potassium chloride (0-0-60) has been applied in the past. Most fields in Minnesota routinely receive applications of 0-0-60 so Cl should not be needed in a fertilizer program.

References

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