Micronutrients for Soybean Production in the North Central Region

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This publication is intended to be a resource for farmers and crop advisors in the North Central Region of the United States regarding micronutrient use in soybean production. The purpose is to discuss issues and provide information on soybean micronutrients requirements, factors that influence their utilization, and the value of soil and plant tissue testing to make decisions about fertilization. This publication is not intended to provide specific fertilizer recommendations or to act as a substitute for information and recommendations provided in state extension publications, but rather to complement them by focusing on relevant issues across the region.

Introduction

Micronutrients are essential plant nutrients that are utilized by crops in very small amounts. A micronutrient deficiency can have a large impact on crop yield because it contributes to critical physiological processes. Elements considered micronutrients include boron (B), chlorine (Cl), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). The concentration of micronutrients in the soil is determined by the mineralogy of the soil's parent material and its organic matter content. Crop availability of micronutrients during the growing season also is affected by several interacting environmental factors including soil moisture, aeration, and temperature. These factors influence chemical reactions, the effectiveness of recycling with crop residues or animal manures, and processes mediated by soil microorganisms. Micronutrient deficiencies in soybean in the North Central Region are uncommon except for Fe and Mn. Most soils have naturally adequate levels of crop-available micronutrients and some fertilizers, manure, and other amendments contain micronutrients. For example, potassium (K) chloride fertilizer (KCl) has 47 percent Cl. The complex factors that affect the crop availability of most micronutrients and infrequent deficiencies in the region make it more difficult to calibrate and use soil and plant tissue tests to predict micronutrient fertilization requirements compared with nutrients such as phosphorus (P) and K.

Farmers and crop consultants are more concerned about micronutrient deficiencies now than in the past because soybean yield has increased. The removal of micronutrients in harvested grain is much less than for macronutrients or secondary nutrients. Table 1 shows micronutrient uptake by soybean aboveground plant parts at physiological maturity and removal in the harvested grain in Wisconsin (Gaspar et al., 2017).

Table 1. Soybean micronutrient uptake and removal in harvested grain for a crop yielding 65 bushels/acre crop in Wisconsin.

Uptake or removal with harvest	B	Cu	Fe	Mn	Zn
	------------ lb/acre ----------				
Total plant nutrient uptake	0.20	0.06	0.54	0.44	0.21
Nutrient removed with the grain	0.09	0.04	0.16	0.11	0.14

Although concentration of micronutrients in soybean grain varies and depends on many factors, yield level is the main determinant of the amounts removed with harvest. Figure 1 shows relationships between soybean yield and the concentrations or removal of several micronutrients from research conducted on fields in Iowa, Kansas, and Minnesota and representing a broad range of growing conditions. The concentration of B in grain was not related to the yield level and the concentrations of Cu, Mn, and Zn decreased only slightly as yield increased. On the other hand, the amount of micronutrients removed increased as the yield level increased. The amount of B, Cu, Mn, and Zn removed increased 0.18, 0.06, 0.15, and 0.20 lb per 100 bu/acre of soybean, respectively. The data show a particularly larger variation in the relationships of B and Mn with yield, which may be related to environmental factors affecting the crop availability of these nutrients.

While crop removal is used together with soil testing to determine P and K fertilization rates in many states, no university in the region suggests using removal as a criterion for fertilization with micronutrients. It is recognized that in the long term, however, continued removal may result in a decrease of crop-available micronutrient levels in the soil.

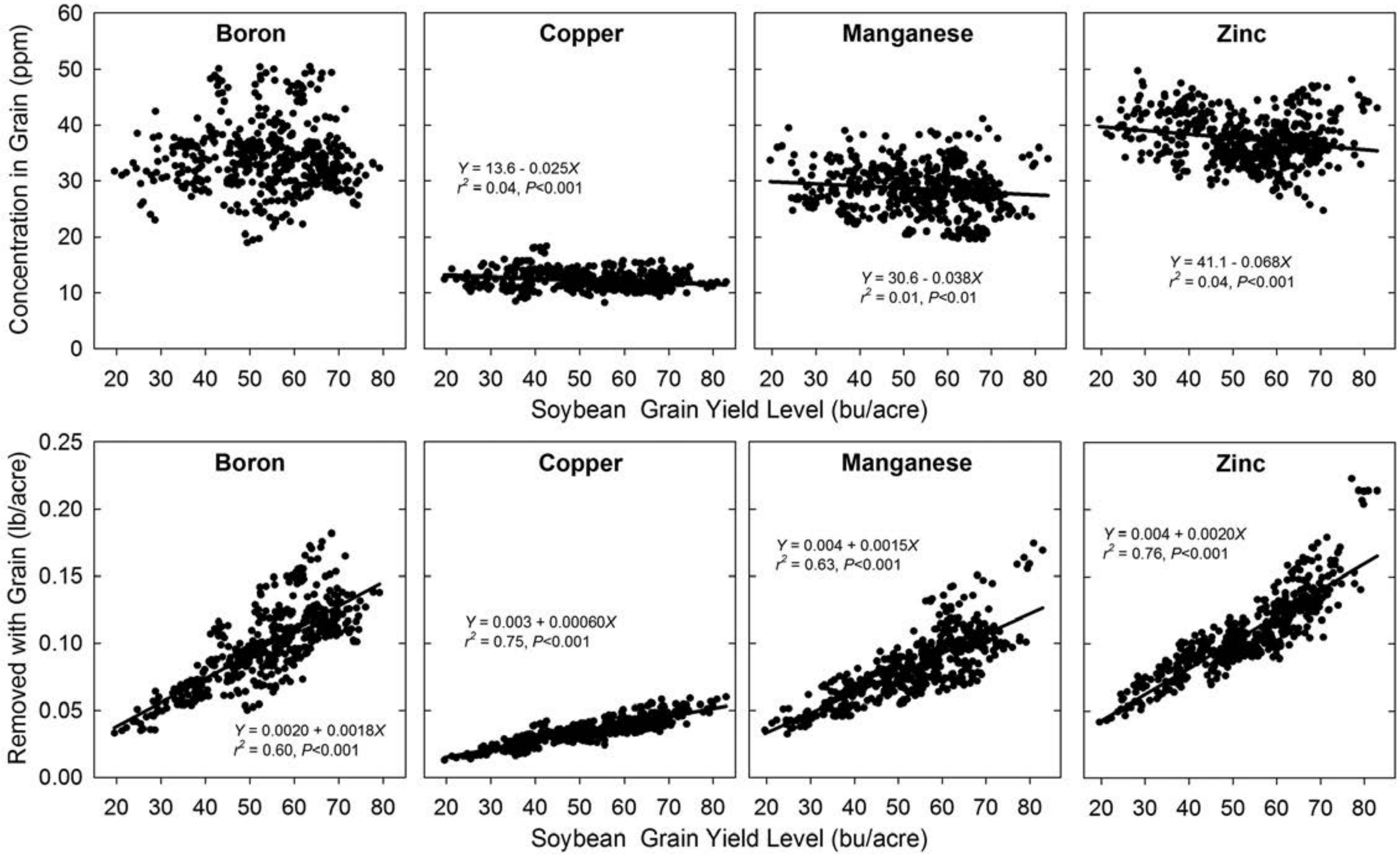

Figure 1. Relationships between micronutrient concentrations in soybean grain and amount removed with harvest with the soybean grain yield level for several micronutrients in Iowa and Kansas (Mallarino and Ruiz-Diaz, unpublished).

Plant Micronutrient Requirements and Management

Boron

Boron has a major role in cell wall biosynthesis and membrane functions and therefore, affects many processes in plants including root elongation, tissue differentiation, pollen germination, and growth. Boron also has roles in the synthesis and transport of carbohydrates and proteins, and in legumes such as soybean, nodulation and atmospheric N fixation. Boron deficiency symptoms in soybean include yellowing leaves, curling of leaf tips, interveinal chlorosis, and cessation of terminal bud growth followed by death of young leaves. With severe deficiency, soybean roots are stunted and flowering is inhibited.

Soil organic matter is the primary source of B and it becomes available for plants mainly through microbial activity. Plant available B in the soil solution is mainly the undissociated boric acid (H_3BO_3) and the anion $B(OH)^{4-}$. Because H_3BO_3 is a neutral molecule, it is not retained on soil particles and organic matter, and $B(OH)^{4-}$ is only weakly retained by soil aluminum and iron oxides and hydroxides. As a result, B can be easily leached from soils in humid areas, over-irrigated fields, and coarse-textured soils. Drought can decrease B availability in soils because organic matter decomposition is slowed and there is limited movement of B to the plant roots through mass flow.

There has been no widely documented evidence of soybean grain yield increases from fertilization with B in the North Central Region. Soybean is very sensitive to excess B, however. Results from Minnesota have shown that a B application often results in a yield decrease.

Boron toxicity is likely because of a narrow range in concentrations between deficiency and toxicity. Boron toxicity in soybean typically shows as a yellowing of leaves with scorching on the leaf edges (Figure 2). In-furrow and seed applications of B should be avoided.

Figure 2. Boron toxicity symptoms in soybean on a sandy soil near Rochester, Minnesota. Photo courtesy of Daniel Kaiser.

Most B fertilizers are inorganic compounds derived from boric acid that are soluble in water. The most common sources are sodium borate and boric acid solutions. Several states of the region do not have B fertilizer recommendations. A few base recommendations on soil or tissue testing while other states recommend fertilization only when B deficiency is observed.

Cobalt

Cobalt is essential for atmospheric nitrogen (N) fixation by bacteria hosted by leguminous plants. Nodulation and N fixation in soybean by *Rhizobia* are critical for profitable soybean production. Recent research suggests that Co also may be an essential component of enzymes that affect plant growth and metabolism. Cobalt is a component of several soil minerals and soil organic matter. The Co^{2+} ion is the form absorbed by plants and is found in the soil solution and in soil cation exchange sites. In legumes, Co deficiency symptoms show as a general plant yellowing and stunting. There have been no documented Co deficiencies for soybean or published information about Co fertilization of soybean in the North Central Region.

There is no published research from the region about Co fertilization and soil or tissue testing. Deficiencies in Co tend to occur in weathered, coarse-textured soils, which are not common in the region.

Copper

Copper is a component of several enzymes that play roles in photosynthesis, respiration, lignin synthesis, and metabolism of carbohydrates and N. Copper exits in various soil minerals and is complexed in organic matter. Plant roots take up Cu as the Cu^{2+} ion. Copper deficiency results in the stunting of plants and since Cu is required for lignin synthesis, a deficiency reduces cell wall strength. Soybean is considered among the least susceptible crops to Cu deficiency. Copper deficiency symptoms include reduced nodulation and N fixation in legumes, delayed flowering and maturity, pollen sterility, necrosis of leaf tips and stems, yellowing of leaves, and stunted growth. Copper has low mobility within plants, so deficiency symptoms appear first in new leaves. Copper deficiencies are more likely in organic, sandy, and calcareous soils. Cool and wet conditions favor Cu deficiency.

There have been no documented soybean Cu deficiencies in the North Central Region. However, there have been reports of possible deficiency in highly organic and poorly drained soils. Recent studies at 42 locations in Iowa (Enderson et al., 2015) and 10 locations in Kansas (Ruiz-Diaz, unpublished) evaluated soybean response to foliar or soil applied Cu and found no yield increases. In Iowa, yield was decreased significantly by Cu application at one location. Copper sulfate is the most common Cu fertilizer source, but there are other commercially available inorganic sources and synthetic chelates. Animal manures often contain significant amounts of Cu due to its addition to animal feed and its occasional use for disease control.

Chlorine

Chorine is a gas in its pure elemental form, but it exists in nature as the monovalent chloride anion (Cl^-) in water solutions or combined in highly soluble salts (such as calcium, potassium, or sodium chloride). The Cl^- ion is retained weakly by soil constituents and in humid areas or irrigated fields can be leached, especially in coarse-textured soils. Chloride functions in plants primarily in osmotic regulation and cation charge neutralization, and its deficiency has been linked to increased incidence of root and leaf diseases.

Deficiencies of Cl in soybean are rare in the region because it is among the least sensitive crops to Cl deficiency, and deposition by rainfall and potash fertilizer supply large amounts of Cl^-. The amount of Cl^- deposited by rainfall varies greatly, with larger quantities deposited near the oceans. Crops grown in the central U.S. that are more sensitive to a Cl^- deficiency (such as small grains) may require Cl fertilization. Deficiency symptoms in soybean are not clearly defined but generally involve chlorosis and wilting of leaves. Sensitive crops, such as wheat, can show leaf chlorosis and necrotic lesions known as leaf spot syndrome. Chloride toxicity can be a problem in soils where high quantities of Cl^- are present. Toxicity symptoms show as premature yellowing of leaves, necrosis of leaf tips, or bronzing and abscission of leaves.

Chloride fertilization has not increased soybean grain yield in the North Central Region. In an Iowa study in fields where no potash fertilizer had been applied for at least 30 years, the application of 50 lb Cl/acre/year as calcium chloride increased corn yield but did not affect soybean yield (Mallarino, unpublished). In a Minnesota study at 12 locations, the application of 20 lb Cl/acre as calcium chloride increased soybean leaf tissue concentrations but not grain yield (Sutradhar et al., 2017). Research in Kansas at two locations with 5-20 lb Cl/acre as liquid magnesium chloride showed no soybean yield increases (Ruiz Diaz, unpublished). Soil-test Cl^- (DTPA method, 6-inch sampling depth) measured in the Kansas and Minnesota studies ranged from 3 to 48 ppm.

Iron

Iron is the fourth most common element in the earth's crust and is abundant in soils of the North Central Region. Most Fe in soil is not in the soluble form needed for plant uptake. Iron deficiencies in soybean occur in many productive soils of the western North Central Region. Soybean, together with dry beans, are among the most sensitive crops to Fe deficiency. Iron is a component of several molecules in the plant that are essential in oxidation-reduction reactions in respiration and in chlorophyll required for photosynthesis. Iron is immobile within the plant and therefore the yellowing often occurs in the new growth at the top of the plant, and is characterized by yellow leaves with dark green veins (Figure 3). The symptoms are referred to as iron deficiency chlorosis (IDC). With severe deficiency, the entire plant is stunted, yellow, and growth does not recover. With a light deficiency, plants can recover later in the growing season, but a significant yield reduction still may occur.

Iron minerals become less soluble with high soil pH, especially when the soil has large amounts of bicarbonate or calcium carbonate. The most soluble form of Fe in oxidized (aerated) soils is $Fe(OH)_3$, where Fe is in the Fe^{3+} form. Soybean requires Fe to be in the reduced Fe^{2+} form for uptake. Complex chemistry in the soil, including pH, carbonates, aeration, moisture, and nitrate levels interacting with root exudates and microbial activity influence the relative concentrations of reduced Fe forms and their crop availability. The interactions between these factors help explain why the severity of IDC symptoms for the same field vary greatly during a season and over the years.

Figure 3. Typical Fe deficiency symptoms in soybean showing interveinal plant yellowing. Photo courtesy of Dorivar Ruiz-Diaz.

Several interacting complex factors complicate the assessment of available Fe by soil and plant tissue testing, which have been of little value in the North Central Region.

Conventional analyses measure extractable Fe from the soil and total Fe in plant tissue, although the evaluation of available Fe^{+2} is considered a better indicator of soybean IDC. Furthermore, in plant analyses, contamination with Fe from soil particles in the foliage and Fe from equipment during sample handling often is a problem.

Past knowledge of IDC symptoms and measurements such as pH and calcium carbonate or soluble calcium salts are typically used to identify field areas prone to IDC in soybean.

Areas of northwest Minnesota, North Dakota, and South Dakota are affected by elevated levels of soluble salts. Although soluble salts alone will not cause IDC, high soluble salt concentrations result in soybean stress and increase the severity of IDC if free carbonates are present in the soil. Because of this reason, soybean IDC ratings for this region are different than those for other states in the North Central Region (Franzen, 2013).

Research in Minnesota, South Dakota, and North Dakota has shown that seeding oats in spring prior to planting soybean can reduce the severity of IDC probably by reducing soil nitrate levels or soil moisture (Kaiser et al. 2014). Also, it is a common occurrence in some fields and years with severe IDC that soybean is greener in wheel tracks (Figure 4), and yield is greater in the tracked areas. Soil compaction is higher in wheel tracks, but the degree of compaction has not fully explained this effect. Work in Iowa and Minnesota in calcareous soils showed lower soil nitrate levels in the wheel tracked area compared with adjacent nontracked areas (Bloom et al., 2011; A.M. Blackmer and A.P. Mallarino, unpublished). Other soil or tissue tests, including commonly used tests for Fe, have not differed consistently between tracked and nontracked areas.

Treatment and prevention of IDC is difficult because it is caused by a combination of several factors. Use of soybean varieties tolerant to IDC is a good option. The most tolerant varieties available still show reduced yield, although this is an active area of research by plant breeders. Once IDC symptoms appear, potential corrective actions such as foliar fertilizer application may improve leaf greenness but seldom contribute to a significant yield increase.

Several research trials were conducted with soil or foliar applied Fe in the western Corn Belt. The data has shown no benefit of Fe products such as broadcast iron sulfate. Iron chelates with DTPA and EDTA applied to the soil or foliage partially alleviated IDC symptoms but did not consistently increase yield. Chelated Fe fertilizer sources applied to the seed or in-furrow have shown the most consistent benefit.

Figure 4. Effect of wheel tracks compaction on iron chlorisis deficiency in soybean. Photo courtesy of Antonio Mallarino.

Iron chelates vary in their stability under high pH conditions, and ortho-ortho-EDDHA (o-o EDDHA) chelated Fe is one of the most stable chelates. The o-o-EDDHA chelate has been available for over 30 years, but not until recently have advances in manufacturing made it cost-effective for widespread use in production agriculture.

Recent research with o-o-EDDHA chelate in Kansas and Minnesota has shown significant alleviation of IDC symptoms (Figure 5) and increased grain yield (Figure 6).

The placement method is crucial, however and application of o-o-EDDHA directly to the seed furrow with the planter or as a seed coating have been the most effective strategies for reducing the severity of IDC. It is important to note the percentage of o-o-EDDHA when purchasing chelated Fe because approximately similar products, such as ortho-para EDDHA, have not been able to keep Fe in available forms long enough for sufficient plant uptake.

Figure 5. Effect of ortho-ortho-EDDHA chelate fertilizer applied to the seed furrow on soybean IDC. Photo courtesy of Dorivar Ruiz-Diaz.

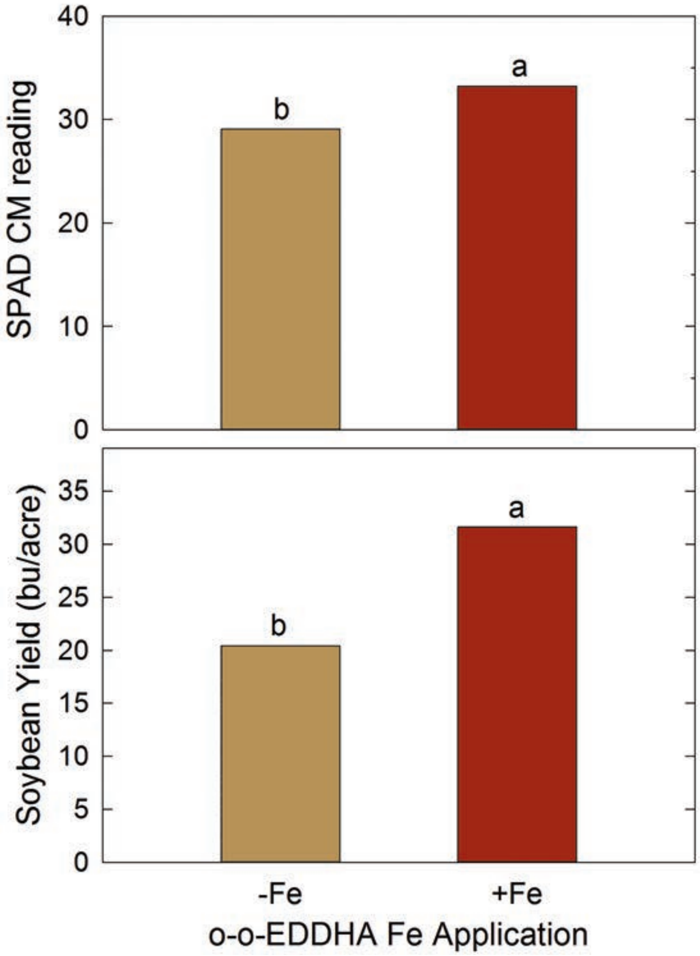

Figure 6. Soybean yield leaf greenness as indicated by the SPAD chlorophyll meter readings at the V6 growth stage, and yield as affected by seed-applied ortho-ortho-EDDHA chelated Fe fertilizer. Bars with different letters at the top indicate statistically significant differences. Modified from Liesch et al., 2012.

Manganese

Manganese is absorbed by plants as Mn^{2+} as well as complexed Mn. Manganese is a component of plant enzymes involved in photosynthesis and protection from free radicals. Manganese is an activator for many other enzymes including those involved in symbiotic N fixation by legumes. Symptoms of Mn deficiency in soybeans is distinctive, interveinal yellowing of the leaf while the veins remain dark green (Figure 7), which may look similar to Fe or Zn deficiency symptoms. Therefore, soil and tissue testing should be used to help differentiate among these nutrient deficiencies.

Figure 7. Interveinal chlorosis of soybean leaves typical of Mn deficiency. Photo courtesy of James Camberato.

Manganese deficiency is typically restricted to certain landscapes and soils such as calcareous mineral soils, calcareous muck, and organic soils. Manganese deficient soils are common in some areas of Indiana, Michigan, Ohio, and Wisconsin. Complex interactions between chemical reactions, biological activity, and environmental factors influence the crop availability of Mn in soils and its evaluation by soil or tissue testing.

Crop availability of Mn is typically low at pH higher than 7.0, but it can become highly available and toxic to plants at low pH levels. Soils that are flooded or have high and fluctuating water tables may experience Mn deficiency caused by changes in its oxidation-reduction status and leaching.

On soils with over 6.0 percent organic matter, tests for Mn may not correlate very well with crop response and pH is a better predictor of crop response. In soils with less organic matter, both soil pH and organic matter levels affect the Mn level needed for soil test sufficiency. When liming is needed on mineral soils prone to Mn deficiency, maintaining a soil pH below 6.3 is recommended. On organic soils a pH below 5.8 is recommended.

Foliar-applied or planter-banded Mn in most instances is the most effective method for overcoming a deficiency, because Mn broadcast to the soil rapidly becomes unavailable.

For maximum effectiveness, apply foliar Mn as soon as deficiency symptoms appear. Foliar applications of 0.2

to 0.5 lb Mn/acre as a chelate or 1 to 1.25 lb Mn/acre as a sulfate are sufficient for maximum yield in most cases. Sometimes multiple applications are required because Mn is poorly translocated within the plant. Early research in the region (Randall et al., 1975) on soils with a history of moderate to severe soybean Mn deficiency showed that a combination of Mn banded with an acid-forming fertilizer at planting and foliar applications later in the season maximizes the soybean response compared to either application method alone (Figure 8). Soybean yield increased significantly with banded starter applications up to 10 lb Mn/acre. The yield with foliar applications was significantly greater than without foliar application.

Recent research examining soybean response to Mn fertilization shows that the response is quite variable, however, depending on soil conditions, soybean cultivar and the Mn source, placement, and timing (Diedrick and Mullen, 2008; Laboski et al., 2012; Loecker et al., 2010; Xia et al., 2009). A recent study in Wisconsin (Laboski et al., 2012) evaluated the Mn placement method (starter or foliar), glyphosate resistance of soybean varieties, and use of glyphosate herbicide for their effect on soybean yield when grown on soils where Mn was expected to be a problem. Application of Mn in starter or as a foliar application at R1, R3, or R1 plus R3 growth stages did not increase soybean yield. These and other research results suggest that even on soils where Mn deficiency has the potential to be a problem (low Mn soil test or pH over 6.9 on soils with organic matter greater than 6.0 percent), fertilization with Mn is unlikely to be economical if no visual deficiency symptoms are apparent. Furthermore, application of Mn can reduce yield when levels are sufficient.

Growers should be aware that foliar Mn fertilizers can interact with glyphosate in tank mixtures, resulting in reduced herbicide efficacy due to binding with Mn^{2+}. Manganese-glyphosate antagonism also occurs when Mn fertilizer and glyphosate are applied separately. Thus, a strongly chelated Mn fertilizer, such as Mn-EDTA, will reduce potential antagonism when Mn is applied with glyphosate.

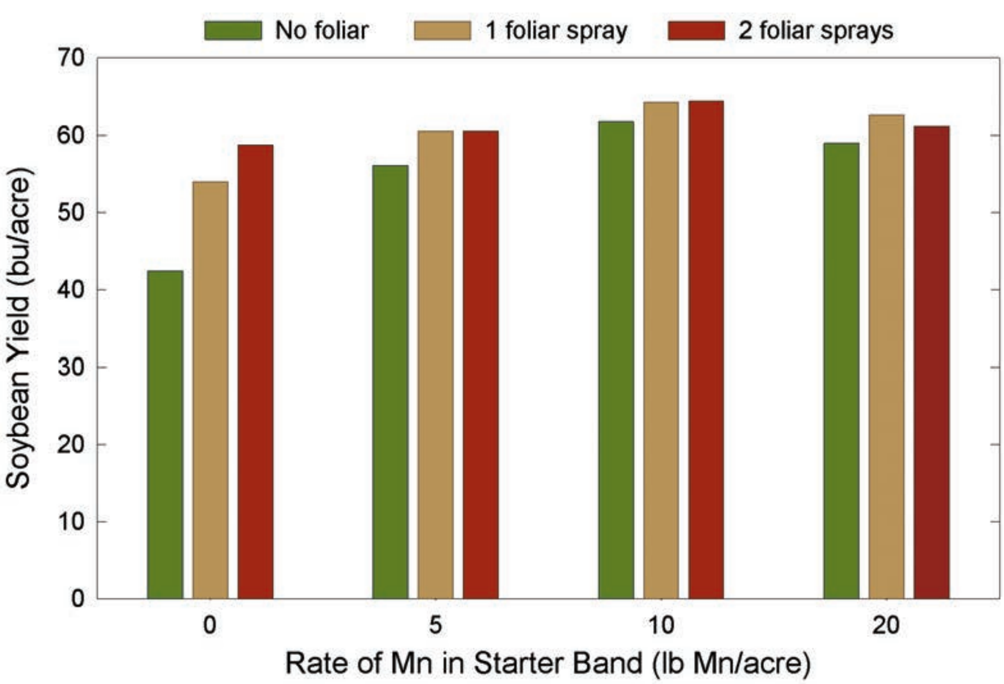

Figure 8. Effect of banded and foliar applications of Mn on soybean yield on a Sebewa loam in Wisconsin. $MnSO_4$ was applied in a starter band containing 7-13-25 lb/acre N-P_2O_5-K_2O. Each foliar application was 0.15 lb Mn/acre as MnEDTA (from Randall et al., 1975).

Molybdenum

Molybdenum is an essential component of the plant enzyme nitrate reductase and of the nitrogenase enzyme required by *Rhizobia* bacteria for the fixation of atmospheric N in root nodules. Therefore, Mo is important for soybean to utilize absorbed nitrate from the soil as well as for N fixation. For this reason, Mo deficiency can show as an induced N deficiency. Molybdenum also plays a role in the absorption and translocation of Fe within plants. Plants absorb Mo as the molybdate ion (MoO_4^{2-}), but most of Mo in soils is found in soil minerals or as the molybdate ion adsorbed on organic matter, Fe and aluminum (Al) oxides and hydroxides, and carbonates.

Crop availability of Mo in soils is greatly affected by soil pH where availability decreases as soils acidify. Decreased soil moisture content can reduce Mo uptake by reducing mass flow of Mo to the plant root. A high concentration of sulfate in the soil solution may also reduce the crop availability of Mo, so the application of very high rates of sulfate-containing fertilizer may induce a Mo deficiency in soils that are marginally deficient in Mo. Due to the importance of Mo with N nutrition, a deficiency of Mo will resemble an N deficiency in plants.

In the North Central Region there has been evidence of Mo deficiency in soybean with yield increases when Mo is applied. Iowa research conducted at several locations in the 1960s found a yield increase from Mo only in some very acidic soils and yield decreases in some fields with high pH, calcareous soils. Since then no Mo deficiencies have been reported in Iowa, but have been observed on certain acidic soils of Indiana. Molybdenum deficiencies can be corrected by liming soils to the proper soil pH level.

Liming of acidic soils is the best and most common practice to avoid Mo deficiency.

Testing soil or plant tissue for Mo is not common in the North Central Region and test methods are not calibrated for soybeans. If soil pH is adequate but Mo deficiency is observed, fertilization is an option. The most common fertilization procedure is to treat soybean seed or apply 0.01 to 0.07 lb Mo/acre as a foliar spray. Most commonly used Mo fertilizers are sodium or ammonium molybdate, which are highly soluble in water.

Nickel

Nickel is one of the most recent elements added to the list of essential plant nutrients. Nickel is important for plants such as soybean, in which ureides (urea-like compounds) are necessary for N metabolism and can benefit growth and the nodulation by *Rhizobia*. Nickel is a component of several soil minerals and the Ni ion is present in the soil solution as well as soil cation exchange sites. Nickel is taken up by plants as the Ni^{2+} ion, and its crop availability decreases as soil pH increases. The uptake of Ni can be impacted by excessive concentrations of Cu and Zn in the soil solution.

Nickel deficiency symptoms in soybean or other crops have not been observed in the North Central Region. In other plants, symptoms include necrosis of the leaf tips because toxic levels of ureides accumulate in the leaves. A deficiency of Ni can also lead to a reduction in the expansion of leaf tissues. Toxicity symptoms will typically mimic symptoms of IDC. There is no published research from the region about Ni fertilization and soil or tissue testing.

Zinc

Soybean has low to medium susceptibility to Zn deficiency, and is much less sensitive than corn, sorghum, or wheat. Zinc is an important component of various enzymes that are responsible for mediating many metabolic reactions in crops. Carbohydrate, protein, and chlorophyll formation is significantly reduced in Zn-deficient plants. Symptoms of Zn deficiency in soybeans include interveinal mottling or chlorosis (Figure 9). Symptoms show in the upper plant canopy due to the limited mobility of Zn in the plant. Zinc is absorbed primarily as a divalent cation Zn^{2+}, which is present in the soil solution and on soil exchange sites. Zinc mobility is limited in soils and movement of Zn to the plant primarily occurs via diffusion through soil water. Zinc reacts easily with organic chelating agents present in most soils, which can increase crop-available Zn in the soil solution mainly when Zn retention by minerals is strong.

Figure 9. Zinc deficiency creates interveinal chlorosis on soybean plants. Photo courtesy of International Plant Nutrition Institute.

The crop-availability of Zn in the soil depends primarily on the Zn minerals' solubility, the amount of Zn adsorbed on clay and organic matter, soil pH, and the organic matter content. As for most micronutrients except Mo, Zn availability decreases as soil pH increases. The presence of chelating agents and complexation of Zn by organic matter can increase the availability of Zn in the soil solution. When soil temperature is low, mineralization of soil organic matter and diffusion to the roots slows down, resulting in less Zn availability and uptake. The probability of a response to Zn fertilization is higher on sandy soils and in eroded soils. When soils in the western North Central Region are eroded, pH and free calcium carbonate at the soil surface increases. A P-induced Zn deficiency may occur with very high application rates of P fertilizer when soil Zn is marginal. Long-term Iowa research on soils adequate in Zn showed that excessive P fertilizer applications did not induce a Zn deficiency even in corn, which is more sensitive to Zn deficiency than soybean.

Very few states of the North Central Region have specific Zn fertilization guidelines for soybean because deficiencies are not common, even in fields where sensitive crops (such as corn) respond to Zn additions.

Field research seldom has reported soybean yield increases from Zn application. Results of many recent trials conducted in Iowa, Kansas, Minnesota, and Missouri showed no soybean yield increase from Zn application, even though several soils had soil-test Zn levels in a range where corn yield increases are expected. A wide variety of Zn fertilizers are available, which include inorganic fertilizer, synthetic chelates, or other organic compounds. Water solubility is the primary factor affecting the performance of inorganic Zn fertilizers. Commonly available inorganic sources include zinc sulfate, zinc oxides, and oxisulfates, with the zinc oxides having a lower solubility in water.

Soil and Plant Tissue Testing for Micronutrients

It has been known for more than a century that soil test methods must be evaluated and correlated with yield response to fertilization for specific crops, sampling depths, and across soils with various chemical and mineralogical properties. Plant tissue testing is another diagnostic tool that should also be calibrated with crop yield response for specific crops, plant parts, growth stage, cultivars, and climate regions.

A lack of widespread and consistent micronutrient deficiencies in the North Central Region has made the development of appropriate soil and tissue test interpretations difficult. In spite of considerable research on micronutrient management, significant field calibration research has not been successful at establishing reliable test interpretations for specific micronutrients due to infrequent responses (Oplinger et al., 1993; Enderson et al., 2015; Mallarino et al., 2015; Sutradhar et al., 2017).

As a result, there are limited interpretations for micronutrients in the North Central Region.

Soil test methods for micronutrients vary across the North Central Region. Many laboratories use methods recommended by the North Central Region Extension and Research Committee for Soil Testing and Plant Analysis (NCERA-13, 2015). Most laboratories analyze soils for B, Fe, Cu, Mn, and Zn. In most states, the hot water method for B and the DTPA method for Cu, Fe, Mn, and Zn is suggested. However, Wisconsin recommends the phosphoric acid test for Mn (Laboski and Peters, 2012) and Indiana, Michigan, Ohio, and Wisconsin recommend the hydrochloric acid test for Cu, Fe, Mn, and Zn (Laboski and Peters, 2012; Vitosh et al., 1995). Some private laboratories use methods not recommended by the NCERA-13 committee or land-grant universities. For example, a few laboratories use the Mehlich-3 for some micronutrients. The NCERA-13 committee has not sufficiently evaluated the Mehlich-3 method for any micronutrient because its use is relatively recent in the region and the scarce calibration research available has not included sufficient numbers of responsive sites.

Field calibration research of soil and plant tissue test methods for micronutrients with modern soybean varieties including many trials in different soils and environmental conditions were conducted from 2012-2016 in Iowa, Kansas, and Minnesota. The micronutrients evaluated in at least two of the three states were B, Cu, Mn, and Zn. Soybean yield did not increase with micronutrient application except for a response to Mn at one location with a sandy soil (80 percent sand). At a few locations application of B or Cu did reduce yield.

The lack of a yield response in the recent large field calibration research did not allow for the identification of soil test sufficiency values. However, the research results were used to evaluate how existing interpretations would have predicted the lack of yield response to B, Cu, Mn, and Zn. Table 2 shows a summary of the evaluations. Based on current soil test interpretations, a B deficiency was predicted at two sites and zinc deficiency at 24 sites. There was no response to B or Zn at any of these sites, which suggests that the low end of the sufficient range may be too high. The higher end of the current interpretation range for B was higher than any measured value, which may suggest the range is too high for the region. The sufficiency level for Cu appears to be correct because no response was expected or occurred. The low end of the sufficiency range for Mn may need to be raised since a yield increase occurred at one site, but was not predicted.

Table 2. Expectation of soybean yield increase from fertilization with B, Cu, Mn, and Zn according to current combined soil test interpretations from states of the North Central Region.†

Nutrient	Number of Field Trials	Number of Trials with a Yield Response	Measured Soil Test Range (ppm)	Soil Test Interpretation Range (ppm)	Number of Trials with Expected Yield Increase
Boron	88	0	0.2 to 1.8	0.25 to 2.0	2
Copper	56	0	0.2 to 2.7	≥ 0.2	0
Manganese	88	1	2.3 to 59.0	1.0 to 2.0	0
Zinc	99	0	0.33 to 15.1	0.75 to 3.0	24

† Soil test methods for all trials were hot water for B and DTPA for other nutrients. For B, the range encompasses hot water values by Buchholz (1983), Penas and Ferguson (2000), Gerwing and Gelderman (2005), Fernandez and Hoeft (2009), and Laboski and Peters (2012). For the other nutrients, single values or ranges are for the DTPA method and were obtained from Buchholz (1983) and Gerwing and Gelderman (2005) for Cu; from Penas and Ferguson (2000), Buchholz (1983), Fernandez and Hoeft (2009) for Mn; and from Buchholz (1983), Penas and Ferguson (2000), Gerwing and Gelderman (2005), Fernandez and Hoeft (2009), Leikam et al. (2003), and Mallarino et al. (2013). There are no interpretations for the other micronutrients in the region.

The field calibration trials, conducted in 2012-2016, with soybean in Iowa and Kansas used both the DTPA and Mehlich-3 tests for Cu, Mn, and Zn. It was not possible to determine which method was better at predicting responses because there were no yield increases. Figure 10 shows a good correlation between DTPA and Mehlich-3 soil tests for Zn but very poor for Cu and Mn. These results indicate that both tests assess Zn availability similarly, although the amounts extracted differed greatly. The high correlation between methods for Zn was increased slightly when soil pH was considered. Other measured soil properties, such as cation exchange capacity, organic matter, or texture, did not improve the relationships between the Mehlich-3 and DTPA tests for these micronutrients.

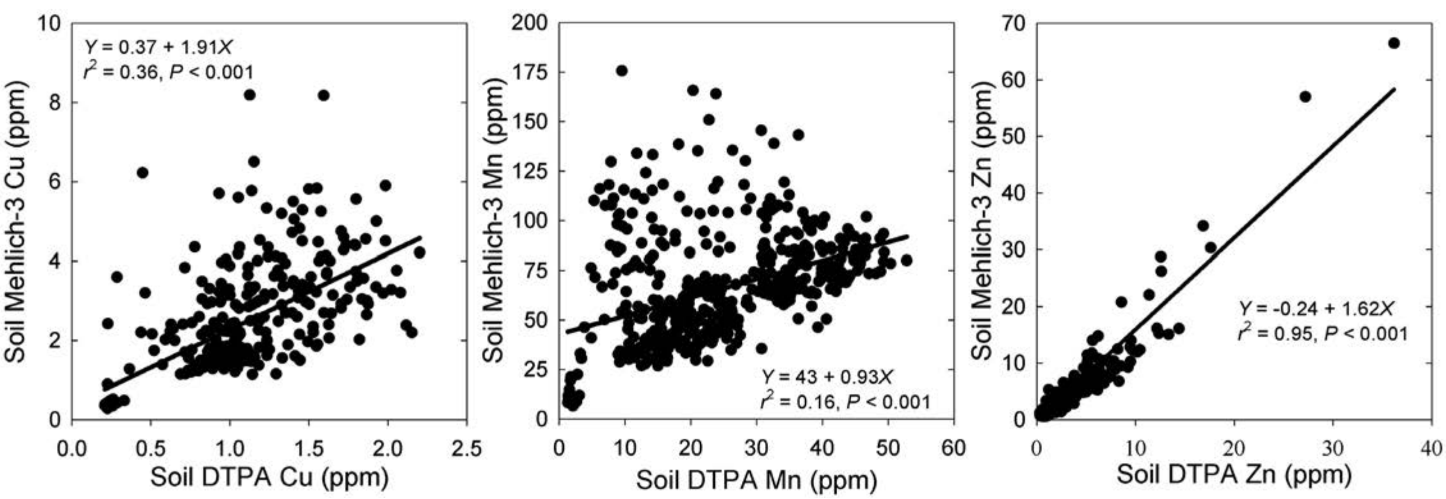

Figure. 10. Relationships between soil Cu, Mn, and Zn measured with DTPA or Mehlich-3 test methods for samples collected in field trials conducted in Iowa and Kansas (Mallarino and Ruiz-Diaz, unpublished).

Existing interpretations in the North Central Region for soybean tissue tests are even fewer than for soil tests, and often the specific sampling growth stage is not described using precise or widely accepted staging systems (such as by Pedersen and Licht, 2014). For this publication, the sufficiency ranges for the plant part and growth stage used in all the trials, which was the uppermost, fully opened trifoliate leaves including the petiole at the R1 to R3 growth stages, was evaluated on how well they predicted a yield increase. Table 3 summarizes estimates of how these tissue test interpretations predicted the general lack of soybean response to fertilization with micronutrients.

Table 3. Expectation of soybean yield increase from fertilization with B, Cu, Mn, and Zn.†

Nutrient	Number of Field Trials	Number of Trials with a Yield Increase	Measured Tissue Test Range (ppm)	Tissue Test Interpretation Range (ppm)	Number of Trials with Expected Yield Increase
Boron	78	0	22 to 62	20 to 55	0
Copper	56	0	3.8 to 13.2	5 to 30	1
Manganese	88	1	20 to 115	20 to 100	0
Zinc	99	0	16 to 52	15 to 50	0

† According to combined tissue test interpretations for early reproductive growth stages (R1 to R3) from several states of the North Central Region and a published plant analysis handbook. Ranges encompass values suggested for some states of the region by Vitosh et al. (1995) and Fernandez and Hoeft (2009), and general suggestions not specific to any region by Bryson et al. (2014).

At one location, the observed Cu tissue test level was less than the sufficient range and a yield response was expected but not observed, which suggests that the lower end of the sufficiency range could be lowered. However, the higher end of the range was more than twice than any observed value, which may suggest it is too high. For B and Zn, a yield increase was not predicted nor observed at any location, which suggests that current tissue sufficiency ranges may be correct. The lower end of the tissue sufficiency range for Mn is perhaps too high as evidenced by a yield response that was not predicted but occurred at one site.

General Recommendations

Many soils of the North Central Region have sufficient amounts of crop-available micronutrients for high-yielding soybean production. Thus, yield increase from fertilization is unlikely except for areas with specific soil and environmental conditions that favor deficiency of a specific micronutrient.

The acreage with likely yield increases from fertilization for the different micronutrients in each state varies from very small to large. Table 4 summarizes the soils and environmental conditions where a given micronutrient might be deficient for soybean, and its relative sensitivity to a deficiency.

Table 4. Soil properties and environmental conditions in which a deficiency is more likely for several micronutrients in the North Central Region.†

Micronutrient	Soil Conditions	Soybean Sensitivity
Boron	Sandy or highly weathered soils low in organic matter, drought	Moderate
Copper	Acid organic or very sandy soils	Low
Chlorine	Sandy soils, infrequent potash fertilizer use	Low
Iron	Calcareous soils (pH>7.0)	High
Manganese	Organic soils with pH>5.8 and calcareous soils (pH>7.0)	High
Zinc	Sandy or very low organic matter or calcareous soils (pH >7.0)	Low
Molybdenum	Sandy or very acid soils (pH< 5.5)	High

† There is insufficient information for Co and Ni to indicate sensitivity.

There is a great deal of uncertainty concerning the adequacy of current interpretations of soil and plant tissue testing for most micronutrients. High yielding soybean can remove larger amounts of micronutrients with the harvested grain, but there is no evidence of an increased probability of a yield response to micronutrient fertilizers at high yield levels compared to average levels. Yield potential alone cannot be used as an indicator for potential response to micronutrient fertilizer application and ultimately specific soil and environmental conditions will determine the potential yield response to fertilization.

The value of soil or tissue testing for micronutrients cannot be accurately evaluated in the North Central Region because of a lack of frequent deficiencies that would allow for field calibration research. Evidence from numerous field trials suggests that current sufficiency ranges may be appropriate but others are too high and their use would encourage unneeded fertilization and reduce profitability. The suggestions about test interpretations in this publication should be considered as general guidelines that include a great deal of uncertainty.

Soil and plant tissue testing together may aid in the diagnosis of deficiencies by comparing areas in a field with good or poor growth. However, use of plant tissue testing alone without soil testing can be misleading because of known effects of other growth factors on dry matter accumulation that often concentrate or dilute nutrients in foliage.

Decisions about micronutrient fertilization for soybean should consider soil or tissue test results, but should place more emphasis on the soils or environmental conditions that traditionally have been identified with a higher likelihood of deficiencies and an economic yield response to fertilization.

Research on the value of current diagnostic tools or new tools should continue with major emphasis for areas where micronutrient deficiencies are more likely.

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