MICRONUTRIENTS FERTILIZATION FOR CORN AND SOYBEAN: A RESEARCH UPDATE

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INTRODUCTION

Essential plant nutrients such as boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn), and others are absorbed by crops in very small amounts and are referred to as micronutrients. A deficiency can have a large impact on crop yield, however, because they perform important physiological functions. The soil parent material and soil formation processes over time along with effects of soil moisture, aeration, and temperature can significantly influence the amount of plant-available micronutrients. These factors make much more difficult the calibration and use of diagnostic tools such as soil and plant-tissue testing than for P or K. Micronutrients deficiencies in corn and soybean are not widespread in the north-central region with few exceptions. Table 1 summarizes conditions in which deficiencies would be most likely. Overall, deficiencies tend to occur in sandy and high-pH calcareous soils that are common only in some regions of some states. However, in recent years farmers and crop consultants have been asking many questions about possible yield loss due to deficiency of micronutrients because of increasing crop yields and word of deficiencies in other regions of the US. For this reason, several studies have been conducted in several states of the region in recent years. This article highlights results from recent or ongoing studies conducted in Indiana, Iowa, Kansas, Minnesota, and Wisconsin.

INDIANA STUDIES

Northwest Indiana soils high in organic matter with near neutral to basic pH have been known to be Mn deficient since the 1930's (Conner, 1932; 1933). The positive yield response of soybean to soil and foliar applications of Mn fertilizer was first reported in the 1940's (Steckel, 1947). Recent research has been evaluating response to Mn fertilization with higher yielding soybean varieties, different Mn fertilizers and application techniques, and the possible interaction of Mn nutrition with glyphosate use (Duke et al., 2012). Field research from 2007 to 2009 focused on wide-row (30 inches) soybean response to starter-banded and foliar Mn applications when varying glyphosate applications (none, pre alone, pre plus post, and pre plus two post) were made (Xia, 2009). In an experiment conducted at three locations with five replications in 2007 and 2008 (with mean soil-test Mn ranging from 2.8 to 13.7 ppm), we concluded that (a) glyphosate application treatments never reduced leaf Mn concentrations in soybean, (b) that starter-banded Mn applications at 0, 2.5, and 5.0 lb/acre had no influence on leaf Mn concentrations, but did increase seed Mn concentrations, (c) that foliar Mn application (0.50 lb/acre) substantially increased leaf Mn concentrations for a short time following application, (d) that neither foliar nor banded applications increased seed yield significantly, and (e) that trifoliate leaf Mn concentrations were often highly correlated with individual plot soil pH (negatively) and Mehlich-3 extractable soil Mn (positively).

In these detailed studies we confirmed that lack of soybean response to starter Mn when applied alone. However, responses to band or foliar applied Mn sometimes are observed when starter fertilizer containing N and P is used. Soybean yield was increased 6 bu/acre by Mn applied foliar, in a 2x2 band with 10-34-0, or both foliar and banded in a 2007 study conducted on a soil (pH-6.5, OM-5%, CEC, 22 meq/100g, Mehlich 3 Mn-12 ppm) known to show Mn deficiency. Banding 10-34-0 alone did not increase yield. Leaf tissue Mn at first flower was unaffected by fertilizer treatment, averaging 15 ppm which is considered deficient. In a second year on a similar soil there was no effect of Mn applied by any method.

In more recent Mn research, we have focused on evaluating older and experimental products for foliar applications. We are now focused on expanding the number of replications (eight or more) to help separate treatments statistically in the context of field variability and the sometimes small (5-15%) yield gains that sometimes occur. Weather conditions have a huge impact on plant uptake of soil Mn. As an example, the variability in soybean yield responses to foliar applications of Mn in Indiana is illustrated in Table 2. In one case (Wanatah) a 5-7 bushel yield response was noted for applying foliar Mn products twice. In the other case (LaCrosse), the same products/rates applied to the same soybean variety produced a significantly positive response only after the single application, and there was a yield reduction in some treatments for the second foliar application.

IOWA STUDIES

Iowa research with micronutrients from the 1960s until 1990s showed no corn and soybean response to fertilization with several micronutrients, except isolated corn responses to Zn only in some soils that tested less than 0.9 ppm DTPA Zn and soybean response to Mo in extremely acidic soils which should have been limed. More recent research by Bickel and Killorn (2007) at 12 Iowa fields showed some small yield increases and decreases from banded Zn application to corn that were not related to soil-test DTPA Zn levels.

Three projects were conducted from 2012 through 2014 that encompassed more than 30 Iowa soil series. Two projects evaluated foliar fertilization at fields managed with no-till or chisel-plow/disk tillage. Conventional-plot trials were conducted at 46 soybean fields and 11 corn fields in which treatments were a control; B, Cu, Mn, or Zn applied separately; and a mixture. Commercial fertilizers based on boric acid for B and EDTA for the other nutrients were sprayed at the V5-V6 growth stage of both crops and again at the soybean R2/R3 stage or corn V8-V10 stage. Total amounts applied were 0.16, 0.08, 0.33, and 0.50 lb/acre of B, Cu, Mn, and Zn. Replicated strip-trials were conducted at 17 soybean fields and nine cornfields. Treatments sprayed once at the V5-V7 stage were a control and a mixture that applied 0.11, 0.08, and 0.11 lb/acre of B, Mn, and Zn. A third project evaluated application of granulated B, Mn, and Zn fertilizers to the soil for corn-soybean rotations at eight sites managed with tillage that were evaluated for three years. Six annual replicated treatments were a control; a mixture of B, Mn, and Zn banded with the planter or broadcast and incorporated into the soil; and separate band applications of each micronutrient. All planter-band micronutrient fertilizers were mixed with MAP and the same starter MAP rate was used for the control and broadcast treatments. Boron was applied at 0.5 or 2.0 lb/acre for band and broadcast treatments, respectively, whereas the Mn and Zn rates (sulfates) were 5 lb/acre for the band and broadcast treatments.

Soil pH, clay, organic matter, and CEC across all conventional-plot sites were 4.9-7.5, 15-33%, 3.1-8.0%, and 14-36 meq/100 g, respectively (6-inch depth). Soil B was measured by the hot-water method and was 0.2-1.7 ppm. Soil Cu, Mn, and Zn were 0.3-1.8, 2.1-42, and 0.5-15 ppm by the DTPA method, which are among methods recommended methods by the north-central region committee for soil and plant analysis (NCERA-13). Soil Cu, Mn, and Zn also was measured with the Mehlich-3 method and were 1.6-5.5, 7-128, and 1.1-32 ppm, respectively. This method is being used by some laboratories in the region but is not recommended by the NCERA-13 due to lack of field calibrations with yield response.

Crop yield levels varied greatly across the trials due to the variety of conditions across Iowa during three years. Soybean yield ranged from 25 to 73 bu/acre and corn yields ranged from 144 to 255 bu/acre. There were no statistically significant ($P \leq 0.05$) grain yield increases from application of any micronutrient at any conventional plot trial with fertilization to the foliage or the soil. Therefore, crop yields are not shown. Slight foliage burning was observed only for the mixture and at a very few sites. At one soybean foliar fertilization trial there were yield decreases from application of Cu alone and the mixture of B, Cu, Mn, and Zn. In contrast, fertilization sometimes increased the micronutrient concentrations in vegetative plant tissue and often in grain (not shown). At the foliar fertilization strip trials, there was a yield increase at one soybean field and a yield decrease at one corn field (not shown).

A lack of yield response did not allow for the identification of sufficiency values for soil- or tissue-test results. Published soil-test interpretations by some states of the region based on older research (Buchholz, 1983; Penas and Ferguson, 2000; Gerwing and Gelderman, 2005; Fernandez and Hoeft, 2009; Laboski and Peters, 2012; Mallarino et al., 2013; Vitosh et al., 1995) predicted a high frequency of responses for some micronutrients. Corn or soybean yield responses from B were expected at five sites using the lowest suggested value or at all sites using the highest suggested value; from Cu and Mn at no site; and from Zn at six sites using the lowest suggested value or at most sites using the highest suggested value. These studies could not be used to determine which of DTPA or Mehlich-3 soil-tests for Cu, Mn, and Zn was better because there were no grain yield increases. However, Fig. 1 shows a good correlation between DTPA and Mehlich-3 tests for Zn, but poor for Cu and nonexistent for Zn. These results indicate that both tests assess Zn availability similarly but one of them is better for Cu and Mn.

The aboveground portions of corn and soybean plants were sampled at the V6 growth stage, mature soybean leaves were sampled at the R2-R3 stage, and corn ear-leaf blades were sampled at the R1 stage (silking). As an example, Fig. 2 shows a poor correlation between soybean tissue test results at two growth stages and DTPA Mn but no correlation for DTPA Cu, DTPA Zn, and hot-water B. Results for corn and for the Mehlich-3 test for either crop were similar (not shown). There are no published sufficiency levels in the region for tissue tests at the V5-V6 growth stage. Use of published sufficiency ranges in some states or elsewhere (Bryson et al., 2014) for soybean leaves at midseason predicted no yield responses from B or Mn, at 39 sites from Cu, and at two sites for Zn. Interpretations for corn ear-leaf blades at silking predicted no yield responses from Cu and Mn, and responses from B at one site and from Zn at one site. Existing interpretations of tissues tests for B, Mn, and Fe (but not Cu) were better at predicting the lack of yield response in these studies than the interpretations for soil tests.

Therefore, the Iowa studies at many fields showed very unlikely corn and soybean response to fertilization with micronutrients, that use of most published soil or plant-tissue test interpretations often have called for unneeded micronutrient fertilization in many fields.

KANSAS STUDIES

Four projects were completed (three for soybean and one for corn) from 2009- 2014. One soybean study focused on iron (Fe) deficiency chlorosis (IDC), and targeted soil conditions that are prone to IDC (high pH and high calcium carbonate). Seven locations with a history of IDC in soybean were selected. The study consisted of a factorial design with three foliar treatments (two chelated Fe fertilizer forms and no foliar), two seed-applied Fe fertilizer treatments (with and without chelated ortho-ortho EDDHA fertilizer), and two different varieties (a nontolerant and tolerant commercial variety). Soil pH varied from 8.1-8.5, calcium carbonate equivalent from 5-14% and organic matter from 1.7-2.7%. Plant population, chlorophyll meter (CM) readings (V3 and V6 growth stage), plant height at maturity, and grain yield were measured. Foliar Fe application did not affect any plant parameter, however, the use of seed-applied chelated o-o-EDDHA Fe fertilizer significantly increased CM readings at the V3 and V6 growth stages, plant height at maturity, and grain yield across all locations (Fig. 3). Given soil conditions conducive to the development of severe IDC, seed-applied chelated o-o-EDDHA Fe fertilizer increased yields by approximately 55% for both varieties (Liesch et al., 2011). Results from this study suggest that if supplemental seed-applied Fe fertilizer will be used, producers should choose the best varieties primarily based on yield potential for the region. Furthermore, chelated o-o-EDDHA Fe fertilizer applied in contact with the soybean seed can contribute to significant yield increase, however foliar applications showed no yield response.

A second study (including both corn and soybean) included micronutrient fertilizer blends applied at planting to fields without a history of deficiencies, in combination with N-P-K starter fertilizers as well as foliar applications on corn and soybean. Eight site years (four sites for each crop) were established to evaluate combinations (factorial arrangement) of liquid starter and foliar fertilizers that contain N-P-K with and without a blend of micronutrients (Fe, Mn, Zn, Cu, and B) under high yielding irrigated conditions. Starter fertilizer treatments included: control; N-P-K only; and N-P-K plus 0.5 lb/acre of each micronutrient. Foliar fertilizer treatments included: control; N-P-K fertilizer at 2, 1, and 2 lb/acre of N, P, and K; and N-P-K plus 0.2 lb/acre of each micronutrient. Foliar applications were made at the R2 and V6–V8 growth stages in soybean and corn, respectively. No early growth or yield increases were attributed to the micronutrient blend in corn or soybean. Foliar fertilization did not increase yield in corn or soybean. Starter fertilizers showed more tendencies to increase yield than did foliar fertilization in corn and soybean, however with no statistically different values (Table 3).

A third soybean study was completed at ten locations using a randomized complete-block design with four replications. This study focused on a range of soybean yield potential, but with no history of visual micronutrient deficiency. Treatments consisted of an unfertilized control, micronutrient fertilizer as individual nutrient for B, Cu, Mn, S and Zn applied broadcast pre-plant, in addition to a combination of these nutrients using two different placements (broadcast and band). All fertilizer sources were dry and sulfate-based, except for liquid fertilizer applied as band placement. Sulfur and micronutrient fertilization showed no significant effect on soybean yield; except for one location (Sandy, 80% sand) with approximately 6 bu/acre increase of the broadcast mix compared to the control. Zinc fertilization had significant effects on tissue and grain zinc concentration. Copper in tissue was below sufficiency ranges in almost all sites, therefore this nutrient sufficiency ranges must be revised for further studies.

MINNESOTA STUDIES

The most commonly studied micronutrient in soybean in Minnesota has been Fe due to the prevalence of iron deficiency chlorosis (IDC) in areas of central and western Minnesota. Past research has demonstrated responses to Fe when applied as o-o-EDDHA (ortho-ortho-EDDHA) chelate isomer. Randall (1977) outlined foliar application of o-o-EDDHA at early vegetative stages for the correction of IDC in soybean. However, o-o-EDDHA fertilizers were traditionally cost prohibitive for use in soybean production. Recent advances have lowered the cost of production making o-o-EDDHA more cost effective to use for correction of IDC. Many soybean producers are currently applying o-o-EDDHA directly on the seed in IDC prone areas.

Figure 4 summarizes data collected from five field locations in west-central Minnesota prone to IDC. Rates of 0, 1, 2, and 3 lb of Soygreen (West Central Inc., Willmar, MN) were applied directly on the soybean seed in 0, 2, 4, or 6 gallons of a water and Soygreen mixture at the time of planting. Soygreen is a 6% Fe fertilizer source where 80-83% of the Fe is chelated as o-o-EDDHA. Average response across locations indicated that Soygreen increased soybean grain yield by 3-4 bu/acre. Statistically, the 3 lb rate increased yield over the control and the 2 lb rate was no different than the control or the 3 lb rate. Of the five sites, two exhibited the greatest response and there was very little to no difference at the remaining three sites (not shown). While products like Soygreen have shown promise for reducing IDC, targeting areas with the greatest severity of IDC are suggested due to the cost of the product and the lack of impact on soils not prone to IDC (Kaiser et al., 2014).

Recent studies with other micronutrients have shown very little benefit for application to soybean. Twelve locations were established across Minnesota between 2011 and 2012 to study the impact of MicroEssentials-SZ [MEZ (Mosaic, Plymouth, MN)] on soybean. The product MEZ was broadcast applied at a rate of 200 lb. or product per acre which supplied 24 lb. N, 80 lb. P_2O_5, 20 lb. S, and 2 lb. Zn per acre. In addition to the control and 200 lb. MEZ rate, three treatments were included which omitted one or more nutrients (N only, N plus P, and N, P, plus S) but supplied the same amount of nutrient as was applied with the MEZ. Across the twelve locations there was no effect of Zn on soybean grain yield (Fig. 5). When a response did occur within a location is was either due to the N or P applied in the MEZ and never S or Zn (data not shown). In all cases soil test Zn was above the threshold (0.75 ppm DTPA extractable Zn) considered sufficient for crops such as corn which are more susceptible to Zn deficiency). In a more recent study, soybean yield was increased by the use of 10 lb of Zn broadcast in the spring at one of twelve locations which had a Zn soil test less than 0.5 ppm (DTPA).

Additional work has been conducted applying 10 lb of Zn, 10 lb of Mn, 0.5 lb of Mo, and 2lb of B broadcast in the spring prior to planting. Twelve locations were studied from 2011 to 2013 comparing a non-fertilized control to a treatment where all nutrients were applied and individual treatments where one of the nutrients was omitted. Data were combined across the 12 locations and is summarized in Fig.6. There was no positive impact of any of the treatments individually among locations or across all locations. The only significant difference occurred at a few locations where the 2 lb B treatment reduced yield. This reduction was not reflected in the yield mean across the locations. The data provided indicated that micronutrients other than Fe will not increase the yield of soybean for nearly all fields across Minnesota.

WISCONSIN STUDIES

A three-year research study was conducted with the following objectives: i) to quantify the effect of glyphosate on Mn availability in glyphosate resistant soybean systems; and ii) to evaluate soybean response to starter and/or foliar Mn applications (Laboski et al., 2012). Field research studies were established at four on-farm locations in Walworth County near East Troy in 2008, Dodge County near Hubbleton and Jefferson County near Watertown in 2009, and in Outagamie County north of New London in 2010 (Table 4). Treatments consisted of: i) three soybean variety/herbicide combinations including a non-glyphosate resistant (Non-GR) soybean variety (Dairyland DSR2118) with conventional herbicide, a glyphosate resistant (GR) variety

(Asgro AG2204) with conventional herbicide, and a GR variety with glyphosate herbicide; ii) two rates of Mn (as $MnSO_4$) in a 2 x 2 starter fertilizer band including 0 and 5 lb Mn/a; and iii) four levels of foliar Mn (as $MnSO_4$) rate and timing including none, 1.25 lb Mn/a at the R1 growth stage, 1.25 lb Mn/a at the R3 growth stage, and 1.25 lb Mn/a at the R1 and R3 growth stages. Treatments were replicated four times. Soybean leaf samples were collected from select treatments at several times throughout the season including: i) at the R1 growth stage just prior to R1 foliar application; ii) about 10-days post R1 foliar application; iii) at the R3 growth stage just prior to R3 foliar application; and iv) about 10-days post R3 foliar application. Samples consisted of collecting 10 leaves (uppermost fully-developed trifoliate and petiole) from the center two rows within the plot. Leaf samples were analyzed for Mn concentration.

At all locations tissue Mn concentrations at the R1 growth stage were less than current UW sufficiency range (54 to 300 ppm) (Schulte et al. 2000); thus a yield response to Mn application would be expected. Ten days after 1.25 lb Mn/acre was applied foliarly at R1, tissue Mn concentrations were greater compared to R1 at all locations. There was a significant effect of variety/herbicide on tissue Mn concentrations 10 days post R1 application at all locations except Walworth. Tissue Mn concentrations at the R3 growth stage were generally less than at R1 for plots that had not received any foliar Mn application at R1 at all locations except at Outagamie. Tissue Mn concentrations at Outagamie were about double the concentrations at the other locations at the R3 sampling time. At the R3 sampling time there were some significant differences between variety/herbicide at Jefferson and Outagamie where GR/Conv and Non-GR/Conv had significantly greater tissue Mn, respectively.

At all locations, tissue Mn concentrations 10 days post R3 were significantly affected by foliar Mn application. No foliar application and application of Mn at R1 had significantly lower tissue Mn concentrations compared to foliar applications at R3, and R1 + R3. Application of foliar Mn at R1 resulted in tissue Mn concentrations initially increasing through 10 days post R1 and then decreasing at Walworth and Dodge. At Jefferson, foliar application of Mn at R1 resulted in tissue Mn initially increasing to 10 days post R1, then decreasing to R3 and then remaining steady or slightly increasing through 10 days post R3. Outagamie often showed trends in tissue Mn data that was not consistent with other locations. This may be the result of soil test Mn being optimum and the soil being somewhat poorly drained compared to other sites which were poorly or very poorly drained.

Soybean yields ranged from 27 to 59 bu/acre across the locations. Manganese application and variety/weed management had minimal effects on soybean yield over all locations. At Jefferson, there was an interaction between foliar Mn applications and variety/herbicide management. Foliar applications of Mn at R1 significantly increased yield compared to foliar applications at R3 and no foliar application for the GR/Conv only; there were no differences between foliar Mn treatments in Non-GR/Conv and GR/glyphosate variety/herbicide treatments. At Dodge and Jefferson there was a significant three-way interaction between variety/herbicide, starter, and foliar treatments. When starter Mn was applied to the GR/glyphosate, yields were greater than when foliar Mn was applied at R1 + R3 (51 and 52 bu/a) compared to no foliar application (45 and 48 bu/a). However, when no starter Mn was applied to this variety/herbicide treatment, the trend was reversed; yields were lower where Mn was applied at R1 + R3 (46 and 43 bu/a) compared to no foliar application (52 and 51 bu/a). These trends for the GR/glyphosate treatment were not observed for the other variety/herbicide treatments. There was no correlation between yields achieved and tissue Mn concentrations 10 days post R3 at any locations. This is not surprising because there were generally no significant yield differences.

In conclusion, the Wisconsin studies showed that application of Mn in starter or as foliar at R1, R3, or R1 + R3 did not increase soybean yield at locations where Mn was expected to be a problem based on low or optimum soil test levels. At all of these locations, R1 tissue Mn concentrations were considered low based on current UW plant analysis interpretation guidelines; however, there were no visual Mn deficiency symptoms. Also, the results did not suggest that glyphosate resistant soybean varieties are more sensitive to Mn, or benefit from foliar applications after glyphosate application. These data suggest that a tissue Mn sufficiency concentration range of 54 to 300 ppm may be too high because all sites had R1 tissue Mn concentrations below this range but did not respond to Mn applications. These data also 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%), if no visual deficiency symptoms are apparent, then application of Mn is likely not economical.

OVERALL CONCLUSIONS

The results of recent research with micronutrients in five states of the north-central region confirmed that many of our soils have sufficient amounts of micronutrients for corn and soybean production and that there is a great deal of uncertainty concerning the value of current interpretations of soil and tissue testing. Data from the studies discussed here showed that high yielding crops can remove higher amounts of micronutrients with the harvested grain. However, yield potential alone cannot be used as indicator for micronutrient fertilizer requirement, and ultimately specific soil conditions will determine the potential yield response. Furthermore, scarce yield responses to some nutrients were observed in small areas of some states with specific soil conditions. Therefore, decisions about micronutrient fertilization could be better made by targeting fields in regions with soils which traditionally have been identified with more likelihood of yield response such as sandy, calcareous, organic, or severely eroded soils.

REFERENCES CITED

Bickel, A. and Killorn, R. 2007. Response of corn to banded zinc sulfate fertilizer in fields with variable soil pH. Commun. Soil Sci. Plant Anal. 38:1317-1329.

Bryson, G.M., Mills, H.A., D.N. Sasseville, J.B. Jones Jr., and A.V. Barker. 2014. Plant analysis handbook III: A guide to sampling, preparation, analysis, and interpretation and use of agronomic and horticultural crop plant tissue. Micro-Macro Publishing, Inc. Athens, GA.

Buchholz, D.D. 1983. Soil test interpretations and recommendations handbook. Dept. Agron. University of Missouri, Columbia. Accessed 2 July 2014 at http://aes.missouri.edu/pfcs/soiltest.pdf.

Conner, S.D. 1932. Factors affecting manganese availability in soils. Jour. Amer. Soc. Agron. 28:726-733.

Conner, S.D. 1933. Treatment of muck and dark sandy soils. Ind. Agr. Ext. Ser. Leaflet 179.

Duke, S.O., J. Lydon, W.C. Koskinen, T.B. Moorman, R.L. Chaney, and R. Hammerschmidt. Glyphosate effects on plant mineral nutrition, crop rhizosphere microbiota, and plant disease in glyphosate-resistant crops. J. Agric. Food Chem. 60:10375-10397.

Fernandez, F.G. and R.G. Hoeft. 2009. Managing soil pH and crop nutrients. In: Illinois Agronomy Handbook.

Gelderman, R.H., and A.P. Mallarino. 2012. Soil sample preparation. In: Recommended chemical soil test procedures for the North Central Region. North Central Regional Publ. No. 221 (Rev.). Missouri Agric. Exp. Stn. Columbia, MO. p. 5-7.

Gerwing, J., and R. Gelderman. 2005. Fertilizer recommendations guide. South Dakota State University Extension. EC750. Accessed 2 July 2014 at http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC750.pdf.

Kaiser, D.E., J.A. Lamb, P.R. Bloom, and J.A. Hernandez. 2014. Management strategies for iron deficiency chlorosis assessed using replicated strip trials. Agron J. 106:1963-1974.

Laboski, C.A.M., T. Andraski, S. Conley, J. Gaska. 2012. Effect of soybean variety, glyphosate use, and manganese application on soybean yield. Proc. Wisconsin Crop Management Conf. 51:49-64.

Laboski, C.AM. and J.B. Peters. 2012. Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. University of Wisconsin Extension. A2809. Accessed 2 July at http://learningstore.uwex.edu/Assets/pdfs/A2809.pdf.

Liesch, A. M., D. A. Ruiz Diaz, K. L. Martin, B. L. Olson, D. B. Mengel, and K. L. Roozeboom. 2011. Management Strategies for Increasing Soybean Yield on Soils Susceptible to Iron Deficiency. Agron. J. 103:1870-1877.

Mallarino, A.P., J.E. Sawyer, and S.K. Barnhart. 2013. A general guide for crop nutrient and limestone recommendations in Iowa. Iowa State Univ. Extension and Outreach. PM1688. Accessed 2 July 2014 at http://www.agronext.iastate.edu/soilfertility/nutrienttopics/limesoilph.html.

Randall, G.W. 1977. Correcting iron chlorosis in soybeans. Soils Fact Sheet No. 27. Univ. of MN Ext., Saint Paul.

Schulte, E.E., K.A. Kelling, J.B. Peters, and S.M. Combs. 2000. Plant analysis interpretations used in the revised Wisconsin Program. New Horizons in Soil Science No. 7-2000. Dept. of Soil Science, Univ. of Wisconsin-Madison.

Steckel, J.E. 1947. Manganese fertilization of soybeans in Indiana. Soil Sci. Soc. Am. J. 11:345-348.

Vitosh, M.L., J.W. Johnson, and D.B. Mengel. 1995. Tri-state fertilizer recommendations for corn, soybeans, wheat, and alfalfa. Extension Bulletin E-2567. Accessed 2 July 2014 at https://www.extension.purdue.edu/extmedia/AY/AY-9-32.pdf.

Xia, Yanbing. 2009. Soybean plant responses to glyphosate and manganese in glyphosate-resistant production systems. MS Thesis, Purdue University. Major Advisor: T.J. Vyn.

TABLES

Table 1. Traditional views concerning likelihood of crop micronutrients deficiency in the north-central region.

Micronutrient	Soil Conditions	Most Sensitive Crop
Boron (B)	Sandy or highly weathered soils low in organic matter, drought	Alfalfa, clovers
Copper (Cu)	Acid organic or very sandy soils	Wheat, oats, corn
Iron (Fe)	Calcareous soils (pH>7.0)	Soybean
Manganese (Mn)	Organic soils with pH>5.8 and calcareous soils (pH>7.0)	Soybean, wheat, oats, sugar beets
Zinc (Zn)	Sandy or very low organic matter or calcareous soils (pH >7.0)	Corn
Molybdenum (Mo)	Sandy or very acid soils (pH< 5.5)	Soybean, legumes

Table 2. Soybean yield response in Indiana to commercial foliar Mn products applied in a separate pass 5-20 days after post-emergent glyphosate application(s) in 2011.

		Soybean Yield †	
Application(s)	Foliar Treatment	Wanatah	LaCrosse
		-------- bu/acre ------	
	Control	40.3 c	38.5 bc
July 21	EDTA Mn @32 oz/acre	42.8 bc	43.3 a
	Pro Mn @ 38 oz/acre	44.6 abc	43.2 a
	ProMn @ 76 oz/acre	44.6 ab	43.3 a
	ManniPlex for Beans @ 60 oz/acre	44.8 abc	40.9 ab
July 21 + August.5	EDTA Mn @32 oz/acre	45.7 a	41.8 ab
	Pro Mn @ 38 oz/acre	46.4 a	39.3 b
	ProMn @ 76 oz/acre	47.0 a	40.1 ab
	ManniPlex for Beans @ 60 oz/acre	45.7 a	35.1 c
	LSD (0.05)	2.6	3.6

† Yields are averages over two glyphosate treatments (at V4 stage alone or at V4 plus R1 stages). Soils were sandy loam to loam.

Table 3. Mean yield response of corn and soybean to starter and foliar fertilization in Kansas.†

		Starter			Foliar		
Crop	Site	Control	N-P-K‡	N-P-K-M‡	Control	N-P-K	N-P-K-M
		------------	------------	------------ bu/acre	------------	------------	------------
Corn	1	228	236	226	230	231	229
	2	212	212	209	213	212	208
	3	224	229	230	226	228	229
	4	229	244	237	237	239	234
Soybean	1	55	58	57	59	56	55
	2	63	63	64	64	62	64
	3	42	41	39	42	41	40
	4	64	70	71	68	69	68

† Mean values are not statistically different at the 0.10 probability level
‡ Fertilizer containing N, P, and K; M, micronutrient blend of Fe, Mn, Zn, Cu, and B.

Table 4. Experimental conditions at four Wisconsin locations.

Information	County and Year			
	Walworth 2008	Dodge 2009	Jefferson 2009	Outagamie 2010
Soil and texture	Sebewa silt loam	Granby fine sandy loam	Wacousta silty clay loam	Shiocton silt loam
Parent material	Loamy outwash over calcareous sandy and gravelly outwash.	Sandy outwash or glaciolacustrine deposits on outwash or lake plains.	Silty stratified lacustrine deposits.	Silty lacustrine deposits over stratified sandy and silty lacustrine deposits.
Soil drainage	Poorly drained	Poorly drained	Very poorly drained	Somewhat poorly drained
Soil group	B	E	B	D
pH	7.2	8.1	7.8	7.2
Org. matter, %	3.1	5.2	6.1	2.6
Bray 1 P, ppm	123 (EH)†	2 (13 ppm Olsen)‡	12 (H)	19 (H)
Bray 1 K, ppm	189 (EH)	68 (O)	109 (O)	73 (L)
Mn, ppm	16 (O)	2 (L)	4 (L: organic matter > 6% and pH > 6.9)	14 (O)
Previous crop	Corn grain	Corn grain	Corn grain	Corn grain
N-P_2O_5-K_2O	0-0-0 lb/a	5-64-60 lb/a	0-0-60 lb/a	0-0-90 lb/a
Tillage	No-till	No-till	Spring chisel plow	Spring chisel plow

† Soil test category: L, low; O, optimum; H, high; and EH, excessively high.
‡ The soil test P level using the Bray 1 P extract was very low (2 ppm) due to the high soil calcium carbonate content. The Olsen soil P extract (commonly used in regions with alkaline or highly calcareous soils) was 13 ppm would be considered to be in the optimum to high category in Iowa.

FIGURES

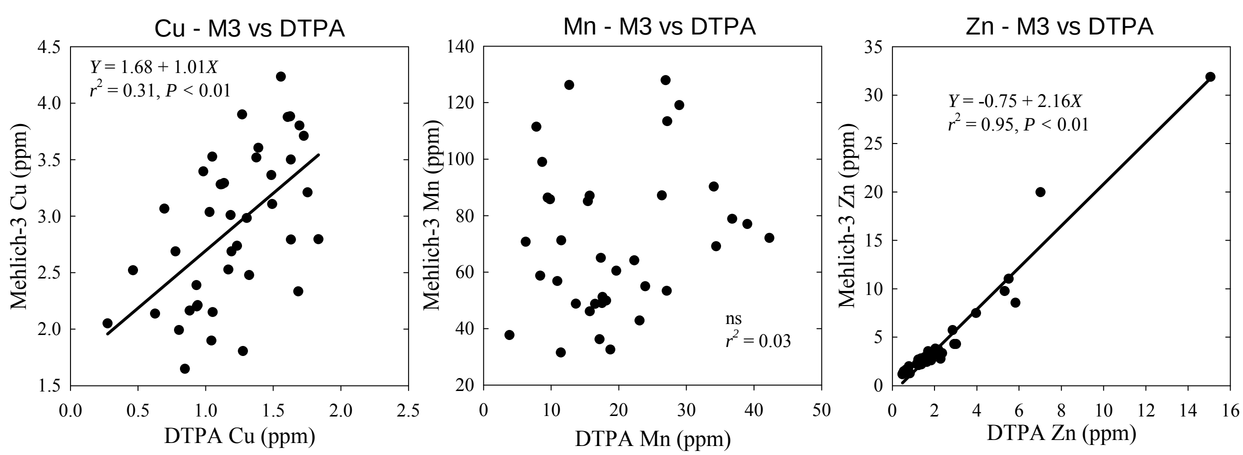


Fig. 1. Relationships across Iowa conventional plot trials soil Cu, Mn, and Zn measured with DTPA and Mehlich-3 test methods.

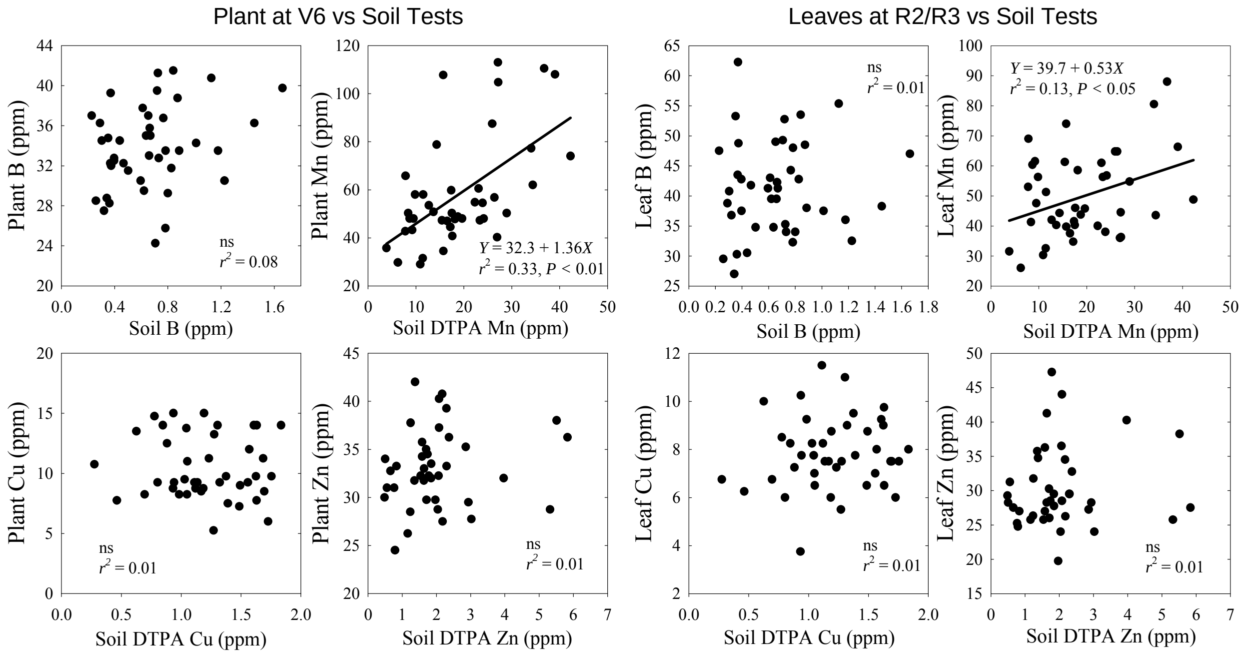


Fig. 2. Relationships across Iowa foliar fertilization trials between soybean tissue test results at two growth stages and soil-test results for B (hot-water test), Cu, Mn, and Zn(DTPA test).

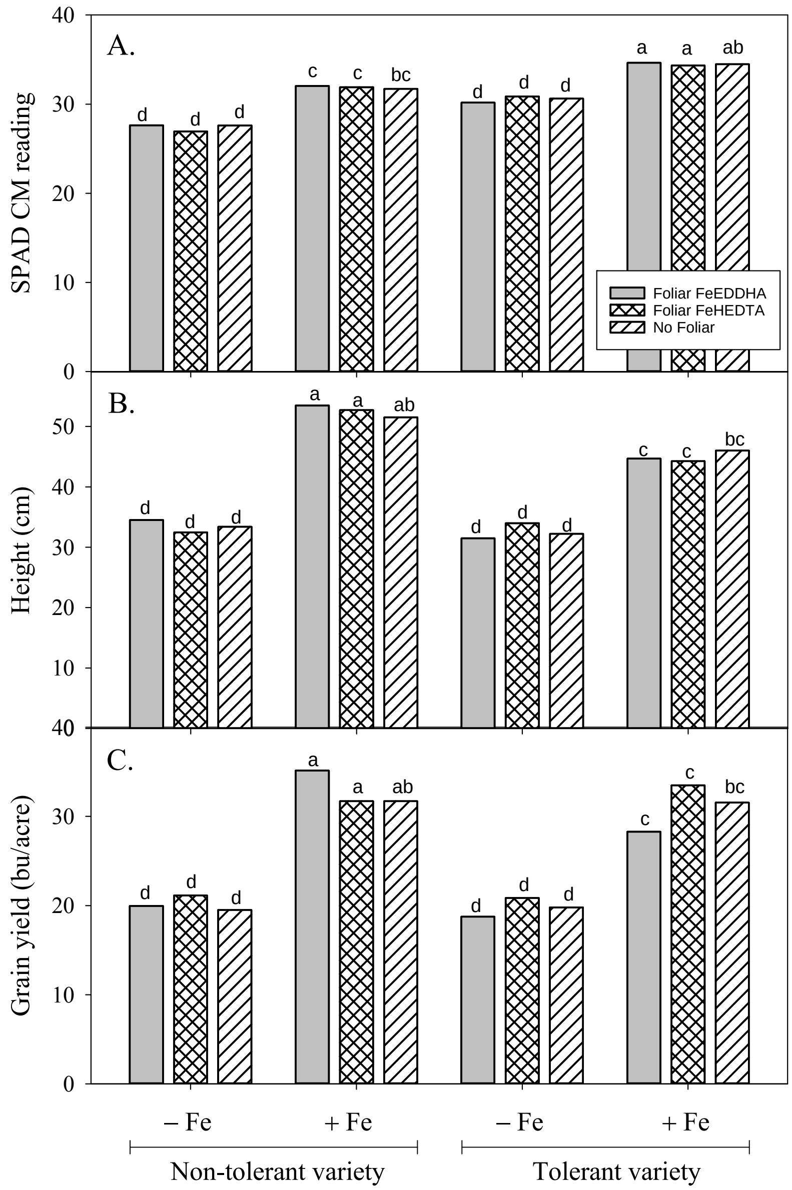


Fig. 3. Chlorophyll meter reading values, plant height and grain yield as affected by soybean variety selection seed-applied Fe-EDDHA – ortho- ortho fertilizer, and foliar applied chelated Fe (EDDHA and HEDTA). Average across seven site-years.

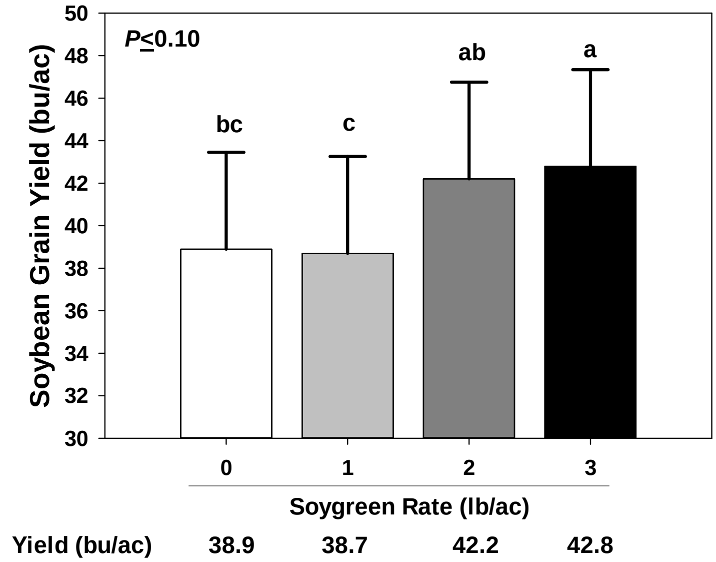


Fig. 4. Soybean grain yield response to 0, 1, 2 and 3 lb of Soygreen per acre applied directly on the soybean seed averaged across five locations in west-central Minnesota.

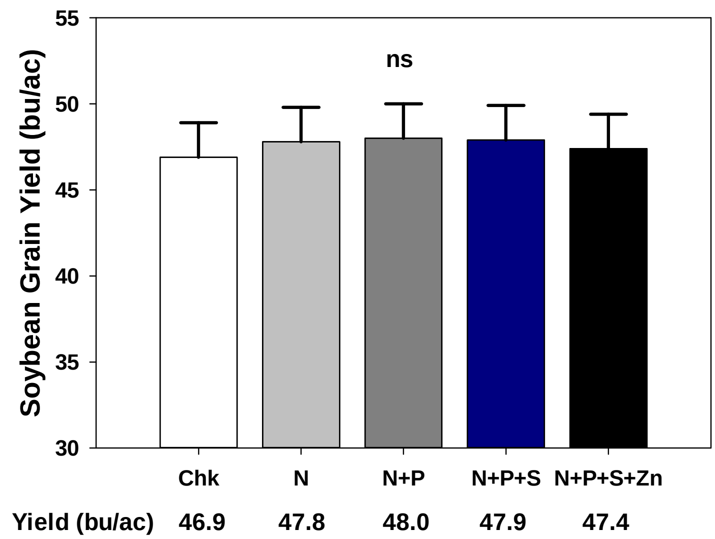
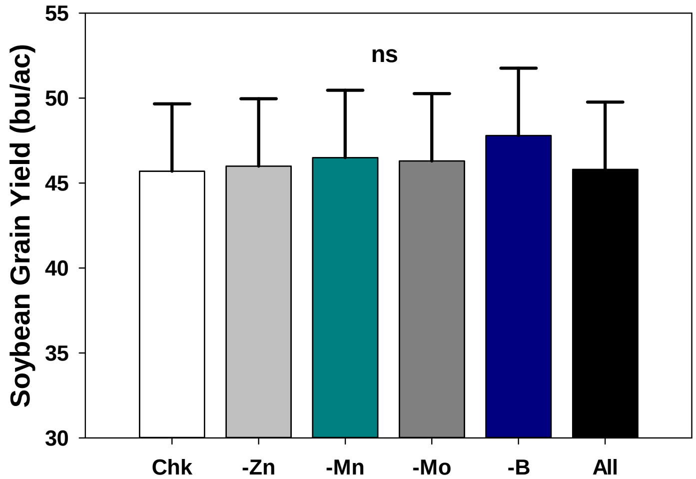


Fig. 5. Soybean grain yield response to 200 lb per acre of MicroEssentials-SZ broadcast before planting compared to a non-fertilized control and treatments that omitted one or more nutrients.



Yield (bu/ac) 45.7 46.0 46.5 46.3 47.8 45.8

Fig. 6. Soybean grain yield of a non-fertilized control compared to the application of 10 lb of Zn, 10 lb. of Mn, 0.5 lb of Mo, and 2 lb of B broadcast and incorporated before planting and treatments where one of the micronutrients (-Zn, -Mn, -Mo, or -B) were omitted.

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