SOYBEAN RESPONSE TO BROADCAST APPLICATION OF BORON, CHLORIDE, MANGANESE, AND ZINC

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ABSTRACT

Micronutrients are essential for plant growth but in low concentration. There has been increased pressure for farmers to apply micronutrients to soybean [*Glycine max* (Merr.) L.] due to a perception that deficiencies have increased. The objective of this study was to evaluate soybean yield and quality response to broadcast micronutrients. A study was conducted in Minnesota from 2013 to 2014. Treatments consisted of B (0 or 2 lb ac^{-1}), Cl (0 or 20 lb ac^{-1}), Mn (0 or 10 lb ac^{-1}), and Zn (0 or 10 lb ac^{-1}) applied using a factorial design replicated four times. Manganese concentration in trifoliate and grain tissue was not impacted by the application of fertilizers. Interaction between B and Zn occurred which resulted in increased B concentration in the trifoliate tissue with Zn when B was applied. Concentration of Zn and Cl was also increased by both the application of Zn and Cl fertilizer. Micronutrients did not increase soybean grain yield, protein, and oil concentration when averaged across locations and years. The effect of micronutrients on the concentration of grain was as similar as the concentration of nutrients in the trifoliate tissue. The data indicated that B, Cl, and Zn were being actively taken up by plants but were not needed to increase soybean grain yield. There does not appear to be likelihood that micronutrients are deficient at a level across the state that warrants wide-spread application of fertilizer.

INTRODUCTION

Early plant development and yield significantly affected by micronutrient deficiency. Soybean [*Glycine max* (Merr.) L.] is an important cash crop in Minnesota. Previous research conducted at several locations through the state indicated that micronutrient deficiency did no limit soybean grain yield. Therefore, application of micronutrients are not suggested in a fertilizer program for soybean production. However, in the recent years, there has been increased pressure for farmers to apply micronutrients to soybean due to a perception that deficiencies have increased.

Boron exists in the soil solution as borate anion ($H_2BO_3^-$). Because $H_2BO_3^-$ is negatively charged, it is not attracted to soil particles and organic matter. As a result, $H_2BO_3^-$ is subject to leaching. Borate anion leaching is greater in coarse textured soils with low organic matter content. Crop response to B can be expected on sandy loam, loamy sand, and sand textured soils. Organic matter contains a greater part of B. Boron becomes available for plant nutrition as organic matter decomposes. Lack of moisture in soil slow down organic matter decomposition rate and potentially affect B availability.

Boron deficiency has been reported on over 130 crops so far on a wide range of soil types (Shorrocks, 1997). The deficiency of B can be prevented and corrected by both soil and foliar fertilizer application. Many research results indicated that soybean responded to B application and improved agronomic productivity. In a study in northeast Arkansas on silt-loam soils, Ross et al. (2006) reported that soil applied B fertilizer increased soybean seed yields from 4 to 130% at three of four sites. Boron applied at V2 growth stage increased grain yield by 13% compared to B applied at R2 growth stage. Trifoliate and grain B concentration increased as B rate increased applied at R2 growth stage. Application of 0.31 to 1.25 lb B ac^{-1} was sufficient to produce near maximum yield.

Chloride plays an important role in gas exchange, photosynthesis, and disease control in plants. Chloride deficiency could negatively impact plant's normal growth and reduce yield if affected by disease. In Minnesota, Cl deficiency has not been reported for major field crops. Most crop fields in Minnesota routinely receive KCl in order to prevent K deficiency. Therefore, Cl deficiency is not expected in those fields where KCl was applied in the past.

Effect of Cl on soybean growth and yield were not available in the literature. But effect of Cl has been documented on grain yield for other crops such as wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) (Diaz-Zorita et al., 2004; Engel et al., 1997; Mohr et al., 1995). Chloride deficiency has been documented in Montana and its neighboring states. A study was conducted by Engel el al. (1997) to determine the response of Cl on winter wheat grain yield and the origin of leaf spots. Leaf spot damage increased exponentially as whole-plant Cl concentration at emergence dropped below 1000 ppm. At six of seven sites, application of 12.3-13.4 lb Cl ac^{-1} greatly suppressed leaf spotting and increased grain yield. Diaz-Zorita et al. (2004) reported wheat grain yield increased at five of 10 sandy sites in Pampas region of Argentina when treated with KCl and NH_4Cl as sources of Cl. The region is characterized by high extractable soil test K. Additionally, no significantly difference was found between KCl and NH_4Cl on grain yield. Increased grain yield with the application of KCl and NH_4Cl have been attributed to direct application Cl rather than the effect of K. Mohr et al. (1995) reported increased of barley grain yield with the application of Cl containing fertilizers, however, the results were not consistent.

Manganese deficiency is the most common micronutrient deficiency of soybean in the United States. Manganese deficiency has been reported in a wide range of soil types (Adams et al., 2000; Gettier et al., 1985a). Deficiency is likely to occur on soils with high soil pH (Mueller and Diaz, 2011). In the areas where soil pH is low, application of lime in order to raise soil pH could potentially increase the incidence of Mn deficiency. These conditions exist in the eastern part of Minnesota where lime application is suggested to raise soil pH for soybean production (Kaiser et al., 2011). Ebelhar et al. (2007) reported plant uptake of Mn was reduced due to liming of acid soil in a study in Illinois. Lack of soil moisture affects plant available Mn. In a dry soil, Mn is readily oxidized to form Mn^{4+} which is unavailable for plant to uptake (Hong et al., 2010). Further, high yielding crops and multiple cropping systems could accelerate depletion of Mn from soil reserve (Gettier et al., 1985b).

Soybean seed yield responded to Mn fertilizer either foliar or soil application. In a study in the coastal region of Virginia, foliar application of $MnSO_4$ at the rate of 1.25 lb Mn ac^{-1} at early and late growth stages increased soybean yield up to 2822 lb ac^{-1} over the control (Gettier et al., 1985). Soybean yield increase was due to increase in seed weight and seed number. Manganese deficiency not only reduce growth and yield of soybean but also affect seed quality factors. A study was conducted by Wilson et al. (1982) in the Southern Coastal Plain using soybean to evaluate the effect of Mn on seed quality. Results indicated that severe Mn deficiency increased seed protein percentage and decreased seed oil percentage. Seeds from plants with below sufficiency level of Mn contained higher percentage of linoleic, palmitic, linolenic, and stearic acids and lower percentage of oleic acid.

Zinc fertilization is not included in a fertilizer program for soybean production in Minnesota because previous studies did not indicate any soybean yield response to Zn application. Zinc deficiency is more prominent on calcareous, high pH, and heavily irrigated sandy soils which is common in many areas in Minnesota. Research trials with corn conducted throughout Minnesota showed grain yield responded to Zn application (Lamb et al., 2015).

Research on the effect of micronutrients application on soybean in the Midwest is limited. Micronutrient deficiency can cause significant effect on soybean by reducing productivity. The objectives of this study were a) to determine if there is any need for a direct application of boron, manganese, chloride or zinc to soybean, and b) to better understand how the application of micronutrients may affect tissue concentration of these nutrients and whether grain protein concentration may be limited by micronutrient deficiencies.

MATERIALS AND METHODS

Studies were established at six locations across Minnesota in each of 2013 and 2014 (Table 1). Prior to treatment application, soil samples were collected from each replication. Each sample was collected at the 0-6″ depth and was a composite of 10 cores. Soils were analyzed using standard procedures recommended for the North Central region.

Treatments consisted of boron (0 or 2 lb ac^{-1}), chloride (0 or 20 lb ac^{-1}), manganese (0 or 10 lb ac^{-1}), and zinc (0 or 10 lb ac^{-1}) applied using a factorial design replicated four times. The factorial design allowed for combinations of no, one, two, three, or four micronutrients applied together. Micronutrient sources were NuBor10 [B (Agrium Advanced Technologies)], BroadMan 20 [Mn (Agrium Advanced Technologies)], EZ20 [Zn (Agrium Advanced Technologies)], and calcium chloride (Cl). All sources except for the Cl treatment contained a small amount of sulfur. Additional ammonium sulfate and ammonium nitrate was added to balance the amount of sulfur and nitrogen on all treatments. Additional calcium was not applied to treatments not receiving $CaCl_2$ since soils used contain adequate levels of Ca and soybean has not been shown to respond to this nutrient. No additional P or K was applied the fall or spring prior to soybean planting. All fertilizer sources were broadcast applied and incorporated prior to planting.

Trifoliate samples (trifoliate leaflets plus petiole) were sampled when soybean plants were at approximately the R2 growth stage. Twenty of the uppermost fully developed leaves were sampled per plot, dried, ground, and analyzed by ICP for B, Mn, and Zn concentration. The middle two rows of each research plot were harvested and grain yields were adjusted to 13.0% moisture content.

RESULTS AND DISCUSSION

Average concentration of B, Mn, Zn, and Cl in the soybean trifoliate samples summarized across the 12 locations is given in Table 2. Manganese concentration was the only measured element that was not impacted by application of fertilizer. Boron concentration was affected by both the application of B and Zn. There was an interaction between B and Zn where the concentration of B in the tissue was higher with Zn but only when B was applied. The concentration of Zn was only increased when Zn fertilizer was applied. The same effect was seen for Cl but only when Cl fertilizer was applied. The data suggests that the plants were actively taking up B, Cl, and Zn.

Micronutrients did not increase soybean grain yield considering the six location average

(Table 3). Considering the numerical values, yields trended lower when micro-nutrients were applied. Application of each individual micronutrient did tend to increase the corresponding concentration in the trifoliate samples except for Mn. The effect of micronutrients on the concentration in grain at the end of the season was similarly affected as the respective concentration of nutrients in the trifoliate tissue further supporting that the fertilizer supplied available nutrients that were being actively taken up but were not needed for increasing soybean grain yield.

Grain protein concentration was fairly unaffected due to the application of micronutrients except for Cl. Grain protein concentration decreased when Cl was applied likely due to the effect of Cl toxicity. Grain oil concentration was also decreased significantly by both the application of B and Zn. Trifoliate and grain tissue concentration of these two nutrients significantly increased by the application of B and Zn suggesting the previous explanation that these two nutrients were taken up by plant but was not utilize for increasing grain oil concentration.

There is some disagreement as to the benefits of micronutrients to the crop they are applied to. It has been stated that the best benefit occurs the second year after application. However, the data from this study indicates that the plants are utilizing the micronutrients applied as indicated by the increased trifoliate nutrient concentration. If any of these micronutrients were deficient the resulting increase should result in greater soybean grain yield. For instance, at Ada in 2013 where soybean grain yield was the lowest if Zn was limiting yield application of Zn fertilizer should have increased yield and Zn concentration in trifoliate samples. Since neither Zn concentration nor grain yield was increased it can be quested whether a third factor was limiting both Zn concentration and soybean grain yield. This type of situation important since more emphasis is being placed on utilizing tissue concentrations to detect where yield responses from micronutrients are more likely. If tissue nutrient concentration is correlated with yield but either is still independent of each other than the use of tissue analysis will result in poor decision making. More data needs to be collected to provide a clearer picture of potential for response. If soil supply of micronutrients is sufficient it is likely that additional fertilizer will not increase yield nor is it likely that the following crop will receive additional benefit if the crop is not highly sensitive to a deficiency of a particular micronutrient that is applied.

CONCLUSIONS

The data suggests that soybean production is not being limited by deficiencies of micronutrients across Minnesota. We cannot discount that there may be soils that test low in nutrients such as zinc or manganese. However, there does not appear to be likelihood that micronutrients (discounting fields affected by iron deficiency chlorosis) are deficient at a level across the state that warrants wide-spread application of fertilizer. Tissue and grain concentration data indicates that the soybean plants are taking up boron, chloride, and zinc when fertilizer was applied. Increased uptake did not increase soybean grain yield. For boron, a handful of field locations exhibited a reduction in yield due to toxicity of boron from excessive uptake. If soybean producers wish to test whether micronutrients would benefit their crop it is suggested to utilize on-farm comparisons with and without a product assuring adequate controls are in place.

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TABLES

Table 1. Initial soil test data for 0-6" samples collected before treatment application for 2013-2014 soybean micronutrient studies.

			Soil Test							
Year	Location	County	P	K	Zn	Mn	B	Cl	OM	pH
			------------------------ppm----------------------						-%-	
2013	Ada	Norman	14*	177	0.4	11.0	0.57	10.7	3.7	8.1
	Lamberton	Redwood	13	150	0.9	47.2	0.65	6.3	4.5	5.8
	Rochester	Olmsted	47	143	2.1	34.8	0.27	6.3	2.1	5.8
	St. Charles	Winona	14	105	0.8	48.8	0.27	6.8	3.0	6.7
	Stewart 1	Sibley	13*	173	1.5	26.5	0.79	6.0	7.3	7.4
	Stewart 2	Sibley	26	134	1.6	46.6	0.80	6.0	5.2	6.8
2014	Ada	Norman	17	368	1.5	7.3	0.99	14.4	6.1	7.4
	Lamberton	Redwood	34	145	1.9	57.0	0.88	3.4	4.4	5.4
	Rochester 1	Olmsted	25	256	2.8	28.7	0.80	124.5	4.6	6.5
	Rochester 2	Olmsted	17	161	2.5	33.2	0.43	13.2	2.2	5.9
	Stewart 1	Sibley	25	179	1.5	14.1	1.09	3.2	6.5	7.7
	Stewart 2	Sibley	37	172	1.9	31.5	0.91	4.1	4.8	7.0

P, Bray-P1 phosphorus; K, ammonium acetate potassium; Zn, DTPA zinc; Mn, DTPA manganese; B, hot water extracted boron; Mg, ammonium acetate extractable magnesium; OM, organic matter loss on ignition; pH, 1:1 soil:water ;na, data not available.

*Olsen-P test was used instead of the Bray-P1

Table 2. Summary of R2 trifoliate micro-nutrient concentration summarized across twelve locations from 2013 to 2014.

		R2 Trifoliate			
Nutrient	Rate	B	Mn	Zn	Cl
	lb ac^{-1}	---------------------------------------ppm------------------------------------			
Boron	0	40.3b	76.5a	33.7a	546a
	2	50.3a	76.3a	33.2a	556a
Chloride	0	45.1a	76.3a	33.5a	431b
	20	45.4a	76.4a	33.4a	670a
Manganese	0	45.4a	75.9a	33.6a	554a
	10	45.1a	76.8a	33.4a	548a
Zinc	0	44.6b	75.7a	32.5b	543a
	10	45.9a	77.1a	34.4a	558a

Table 3. Summary of soybean grain yield, protein, and oil concentration (13% moisture) and micro-nutrient concentration summarized across twelve locations from 2013 to 2014.

		Grain			Grain Concentration			
Nutrient	Rate	Yield	Protein	Oil	Boron	Manganese	Zinc	Chloride
	lb ac^{-1}	bu ac^{-1}	----------%----------		----------------------ppm---------------------			
Boron	0	42.8a	40.0a	20.5a	30.0b	29.7a	38.1a	295a
	2	42.8a	40.0a	20.4b	31.8a	29.7a	37.9a	293a
Chloride	0	43.0a	39.8b	20.5a	30.2b	29.7a	37.9a	290b
	20	42.7a	40.1a	20.4a	30.5a	29.8a	38.1a	298a
Manganese	0	42.8a	40.0a	20.4a	30.4a	29.7a	38.0a	295a
	10	42.8a	40.0a	20.4a	30.4a	29.7a	38.0a	292a
Zinc	0	42.9a	40.0a	20.5a	30.3b	29.6a	37.1b	295a
	10	42.7a	40.0a	20.4b	30.6a	29.8a	38.9a	293a

† Indicates a significant interaction between applied zinc and boron

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