SOYBEAN FOLIAR MANGANESE RECOMMENDATIONS ON CHRONICALLY MN DEFICIENT SOILS

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Introduction

Soil Mn availability decreases with increasing pH and organic matter concentrations, leading to seasonal Mn deficiency symptoms in soybeans produced on these soils. In Michigan, high pH conditions are often found in alluvial calcareous lakebed soils where conditions lead to low Mn solubility. High organic matter concentrations in organic soils reduce Mn availability due to formation of unavailable chelated Mn^{2+} compounds and organic complexes in the soil. While Mn deficiencies on lakebed soils are common, their development is not consistent and corrective measures are not necessary every year. Manganese deficiencies are a yearly occurrence on muck soils and generally of much greater severity compared to lakebed soils. Soybeans suffering Mn deficiencies on lakebed soils will often grow through deficiency symptoms without treatment, though likely with some associated yield reduction. Untreated soybeans suffering Mn deficiencies on muck soils, however, might not be expected to develop to reproductive stages. Due to these soil conditions, soil applied Mn is not effective at preventing Mn deficiencies during the growing season. Producers utilize foliar fertilizer applications though the season to remedy Mn deficiencies as they develop. On lakebed soils, one Mn application is typically sufficient to correct deficiency symptoms. Organic soils, however, frequently require two to four foliar applications to correct deficiencies that reoccur through the season.

The specific nature of Mn deficiencies on these soils has resulted in few recommendations for Mn fertilizer products and application timings that are specifically tailored for these unique conditions. Producers often mix antiquated non-specific micronutrient recommendations with anecdotal evidence to formulate management plans, with little knowledge of the true efficiency of their micronutrient programs. The wide array of foliar fertilizer products available to treat these deficiencies creates substantial confusion among producers. The impacts of formulation and chelation of fertilizer products on these chronically deficiency conditions has not been well researched.

The addition of foliar Mn products with glyphosate herbicide has been a popular practice by producers to reduce total application costs. While research has shown that glyphosate efficacy is reduced when applied with various Mn forms (Bernards et al., 2005), many producers feel benefits of this practice offset any possible reduced weed control. Glyphosate was originally developed as a chelating agent, and like many other phosphoric acids, forms stable complexes with divalent and trivalent metal cations (Glass, 1984; Subramaniam and Hoggard, 1988). The presence of these cations, such as Ca^{2+}, Mg^{2+}, and Fe^{3+}, in spray solutions has shown to decrease glyphosate efficacy by complexing with glyphosate to form salts that are not readily absorbed by plants (Thelen et al., 1995). In addition to weed control issues, glyphosate have been shown to negatively affect Mn nutrition within the soybean plant. Hall et al. (2000) demonstrated that glyphosate efficacy can be decreased not only by cations on the plant, but also those found in the plant. Huber (2007) found that Mn uptake and translocation was reduced for up to eight days following applications of glyphosate.

Manganese deficiency has been a frequently cited nutrient issue associated with glyphosate resistant (GR) soybean production. Flashing, or yellowing of the leaves, has commonly been documented following glyphosate applications on soils not otherwise expected to be Mn limiting. This effect has been linked to the immobilization of Mn in the plant by glyphosate. Flashing tends to vary in intensity by variety and environmental conditions. Soybeans under stress, such as that induced by dry conditions, seem to be more susceptible. Flashing has not been consistently linked to yield reductions (Krausz and Young, 2001). These Mn nutrition problems have not been found to be solely a result of glyphosate applications. Huber et al. (2004) found GR genotypes to be less Mn efficient than non-GR genotypes, have decreased Mn uptake, and lead to greater Mn immobilization in tissues than non-GR soybeans. Similarly, Bott et al. (2008) found higher Mn uptake and/or root to shoot translocation in GR varieties when not exposed to glyphosate application. Gordon (2007) observed that while foliar applications of Mn to GR soybeans increased yields compared to treatments without Mn, conventional non-GR varieties without any Mn application out yielded all GR variety Mn treatments. These findings suggest a higher Mn requirement for GR soybeans compared to non-GR soybeans.

Numerous studies have investigated the effects of foliar Mn application on soybeans throughout the Midwest, but few have specifically focused on soils with chronic Mn deficiencies. Recommendations for Mn application on these sites are limited, particularly when planning multiple applications. Improved management of Mn nutrition, specifically with glyphosate resistant soybeans and the use of glyphosate herbicide, is essential to maximizing production on these unique landbases. This study seeks to improve recommendations for foliar fertilizer applications to correct Mn deficiencies on chronically Mn deficient soils. Main goals of this work include determining optimum fertilizer and herbicide application scenarios, evaluation of Mn fertilizer formulations within these management scenarios, and attempting to improve our understanding of Mn deficiencies on these soils.

Materials and Methods

Field experiments were established at four locations in 2009; two sites with high-pH lakebed soils in Michigan's Thumb region and two sites with high organic matter muck soils in central Michigan (Table 1). All sites were prepared and planted by cooperating producers utilizing conventional tillage methods and grain drills in 25 cm row configurations. All sites have a history of Mn deficiency.

Table 1. Soil characteristics of research sites

	Soil Series	pH	OM %	P ppm	K ppm	Mg ppm	Mn ppm
Stockbridge	Adrian muck	6.4	59.3	40	122	910	9.9
Owosso	Linwood muck	7.2	23.3	139	238	913	21.4
Sandusky	Parkhill loam	7.8	3.3	131	217	309	22.0
Marlette	Parkhill loam	6.8	2.3	47	137	193	16.6

Manganese foliar fertilizer products included dry $MnSO_4$ (32% Mn, Techmangam, Tetra Micronutrients), Mn-SA (5.0% Mn as sugar alcohol derived from manganese sulfate, Manni-Plex S-Mn, Brandt Consolidated), and Mn-EDTA (6.0% Mn derived from Ethylenediaminetetraacetate, Nachurs Apline Solutions). All products were applied at 1.12 kg Mn ha^{-1}. A potassium salt formulation of glyphosate (RoundUp WeatherMax®) was applied as needed at 1.61 L ha^{-1} with AMS at 20.4 g L^{-1}. When tank-mixed, glyphosate was first added to the tank, followed by AMS, and finally by Mn fertilizers. All herbicide and fertilizer applications were made with a backpack sprayer at 140 L ha^{-1}.

Plots measured 3 m by 15 m and were arraigned in a randomized complete block design with four replications. Normalized difference vegetation index values were recorded lengthwise through each plot at a height of 1 m from the canopy surface four to seven days following fertilizer application. A total of around 90 readings were averaged for each plot. Plant tissue samples were obtained from the uppermost fully expanded trifoliate leaves four to seven days following fertilizer application. If significant rainfall events has not occurred between fertilization and sampling, leaves were washed to remove residual surface fertilizer. Visual ratings were recorded at Owosso and Stockbridge to quantify visual Mn deficiency and time application events. A zero to ten scale was used, with zero indicating no Mn deficiency and ten corresponding to severe Mn deficiency. Fertilizer applications were made if ratings exceeding a five rating. Yield was determined from a 1.5 by 13.7 m area within each plot. Grain weights are adjusted to 15.5% moisture.

Three fertilizer application scenarios were evaluated. These management scenarios were compared to a control treatment where no Mn fertilizer was applied, and a non-limiting Mn treatment where Mn was applied in an attempt to prevent limiting conditions.

<u>Efficiency</u>: Efficiency treatments combined fertilizer with herbicide applications when possible, compromising application timings if necessary. Foliar fertilizer, alone or in combination with herbicide, was applied in response to visual Mn deficiency symptoms.

<u>Intervention</u>: Intervention treatments isolated fertilizer applications at least three days prior and seven days following herbicide applications. Foliar fertilizer applications were made in response to visible Mn deficiency symptoms.

<u>Prevention</u>: Prevention treatments separated fertilizer and herbicide treatments identically to Intervention treatments, but foliar fertilizer treatments were made prior to visual Mn deficiency symptoms.

Frequent applications of Mn-EDTA at Stockbridge and Owosso resulted in leaf chlorosis and noticeable plant stunting for the non-limiting treatment, negating the usefulness of this treatment for comparison purposes. This treatment was not included in analysis at Stockbridge and Owosso.

Results

Prevention and Non-limiting treatments at lakebed site were applied on June 25 at the V2 growth stage. Non-limiting treatments were applied again on June 30 at the V3 growth stage. Soybeans did not demonstrate Mn deficiency symptoms at application, nor did they develop deficiency symptoms later in the season.

Initial Mn fertilizer and glyphosate herbicide applications followed similar patterns at both Owosso (Figure 1) and Stockbridge (Figure 2). Soybeans were at the V2 growth stage and weeds around three inches tall at this time. Manganese was applied at least four days prior to glyphosate in Prevention treatments and three days prior to glyphosate in Intervention treatments. At both sites, moderate Mn deficiency symptoms were evident when glyphosate was applied to all treatments and combined with Mn fertilizer in Efficiency treatments. Application timing was consistent between all fertilizer products.

At Owosso, when Mn was tank-mixed with glyphosate, Mn deficiency symptoms reemerged sooner than when Mn had been applied before glyphosate (Table 2). Secondary Mn applications were required 10 days later to address deficiency symptoms. Secondary Mn applications were not required in Intervention treatments for 39 days following initial application. In addition, glyphosate weed control was not adequate when tank-mixed with Mn; a secondary application was required in early August to control weed escapes. More frequent Mn fertilizer applications in Prevention treatments minimized deficiency symptom severity.

At Stockbridge, reemergence of Mn deficiency symptoms did not occur as quickly as at Owosso, but when they did in late July, Intervention and Prevention treatments demonstrated the most severe deficiency symptoms (Table 2). Deficiency symptom severity did not require fertilizer applications for another 10 days. Anticipation of Mn deficiencies in Prevention treatments proved more difficult than at Owosso, with fertilizer applications frequently made in response to deficiency symptoms.

Table 2. Visual Mn deficiency ratings by treatment, Owosso and Stockbridge locations

	Owosso				Stockbridge					
Treatment	July 3		August 4		July 24		August 5		August 18	
Control	8.5	a	5.3	a	10.0	a	9.8	a	8.3	a
Efficiency- $MnSO_4$	5.5	bc	0.0	c	3.5	c	5.5	b	0.0	d
Efficiency- SA	6.8	ab	0.5	c	3.0	c	5.8	b	0.3	cd
Efficiency- EDTA	5.5	bc	0.8	c	3.3	c	6.8	b	0.3	cd
Intervention- $MnSO_4$	3.3	de	2.5	b	5.5	b	0.0	c	1.8	bc
Intervention- SA	3.8	cde	4.3	a	6.3	b	1.3	c	3.3	b
Intervention- EDTA	4.8	cd	5.0	a	6.3	b	1.0	c	3.3	b
Prevention- $MnSO_4$	2.5	e	0.0	c	3.5	c	0.0	c	1.8	bc
Prevention- EDTA	3.0	de	0.0	c	6.0	b	1.0	c	2.0	b
P value	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
Scenario	***		***		***		***		***	
Product	*NS*		*		**		**		*NS*	
Scenario x Product	*NS*		*NS*		**		*NS*		*NS*	

** = 10%, ** = 5%, *** = 1%, NS= non-significant*

Means within a column followed by the same letter are not significantly different at the 5% level

NDVI measurements at Owosso taken through early July following initial applications of Mn and glyphosate were able to discern differences between treatments (Table 3). Within Intervention and Prevention scenarios, applications of $MnSO_4$ tended to result in greater NDVI readings than treatments with EDTA. NDVI readings through August did not indicate differences between treatments, though visual ratings identified Mn deficiency symptoms in Intervention treatments.

Table 3. NDVI measurements by treatment, Owosso location

	Owosso					
	June 28	July 3	July 9	July 13	August 4	August 18
Control	0.7290	0.6614 ab	0.5779 c	0.5691 bc	0.8218	0.8429
Efficiency- $MnSO_4$	0.6901	0.6620 ab	0.5928 bc	0.5822 bc	0.8328	0.8434
Efficiency- SA	0.7087	0.6560 bc	0.5826 bc	0.5838 b	0.8292	0.8433
Efficiency- EDTA	0.7085	0.6828 ab	0.6125 ab	0.5941 bc	0.8338	0.8365
Intervention- $MnSO_4$	0.7223	0.6668 ab	0.6030 ab	0.6001 b	0.8390	0.8483
Intervention- SA	0.7312	0.6395 bc	0.5869 bc	0.5940 b	0.8318	0.8471
Intervention- EDTA	0.6741	0.6129 c	0.5535 c	0.5421 c	0.8227	0.8489
Prevention- $MnSO_4$	0.7365	0.7033 a	0.6472 a	0.6542 a	0.8384	0.8487
Prevention- EDTA	0.7279	0.6678 ab	0.5779 bc	0.5738 bc	0.8354	0.8468
P value	0.6753	0.0367	0.0273	0.0083	0.1552	0.2096
Senario	*NS*	**	*NS*	**	*NS*	*
Product	*NS*	*NS*	*	*	*NS*	*NS*
Senario x Product	*NS*	*NS*	**	*	*NS*	*NS*

** = 10%, ** = 5%, *** = 1%, NS= nonsignificant*

Means within a column followed by the same letter are not significantly different at the 5% level

Stockbridge NDVI readings were not able to differentiate between fertilizer treatments, only identify control treatments (Table 4). The effects of no Mn fertilizer were much more drastic at Stockbridge than Owosso. While at Owosso control treatments eventually grew through deficiency symptoms and were indistinguishable from fertilizer treatments late in the season, control treatments are Stockbridge were severally stunted and chlorotic throughout the season with many never developing to reproductive stages.

Table 4. NDVI measurements by treatment, Stockbridge location

	Stockbridge					
	July 9	July 13	July 24	August 5	August 17	August 25
Control	0.4148	0.4702	0.4867 b	0.4972	0.5100 b	0.4800 b
Efficiency- $MnSO_4$	0.4229	0.4998	0.5938 a	0.6195	0.8547 a	0.8024 a
Efficiency- SA	0.4093	0.4968	0.6187 a	0.6297	0.8560 a	0.8010 a
Efficiency- EDTA	0.4056	0.4891	0.5822 a	0.6914	0.8380 a	0.7805 a
Intervention- $MnSO_4$	0.4124	0.4883	0.6136 a	0.6494	0.8426 a	0.7969 a
Intervention- SA	0.4015	0.4697	0.5735 a	0.6532	0.8343 a	0.7851 a
Intervention- EDTA	0.4509	0.5030	0.5931 a	0.6931	0.8315 a	0.7796 a
Prevention- $MnSO_4$	0.4193	0.4877	0.6231 a	0.6367	0.8525 a	0.7983 a
Prevention- EDTA	0.4270	0.4976	0.6278 a	0.7139	0.8493 a	0.7953 a
P value	0.2828	0.6530	0.0153	0.0959	<0.0001	<0.0001
Senario	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Product	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Senario x Product	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

** = 10%, ** = 5%, *** = 1%, NS= nonsignificant*

Means within a column followed by the same letter are not significantly different at the 5% level

Tri-foliate tissue samples and yield results were not available at the time of these proceedings.

Summary

Manganese deficiency reemergence at Owosso indicated applications of Mn prior to glyphosate application resulted in longer control of Mn deficiency compared to treatments combining Mn and glyphosate. In addition, treatments with tank-mixes of Mn and glyphosate reduced herbicide efficacy and necessitated a second herbicide application. NDVI readings were higher for treatments utilizing $MnSO_4$ fertilizer compared to EDTA. At Stockbridge, the reemergence of Mn deficiency symptoms after initial fertilizer and herbicide applications followed a contrary pattern to that at Owosso. Deficiency symptoms reemerged more rapidly and more frequently in Intervention and Prevention treatments compared to Efficiency treatments. Herbicide control was not compromised when fertilizer was tank-mixed with herbicide. Tissue sample and yield data are pending at time of this publication.

References

Adams, M.L., W.A. Norvell, W.D. Philpot, and J.H. Peverly. 2000. Spectral detection of micronutrient deficiency in ‘Bragg’ soybean. Agron. J. 92:261-268.

Bernards, M.L., K.D. Thelen, and D. Penner. 2005. Glyphosate efficacy is antagonized by manganese. Weed Tech. 19:27-34.

Bott, S., T. Tesfamariam, H. Candan, I. Cakmak, V. Römheld, and G. Nuemann. 2008. Glyphosate-induced impairment of plant growth and micronutrient status in glyphosate-resistant soybean (*Glycine max* L.). Plant Soil. 312:185-194.

Glass, R.L. 1984. Metal complex formation by glyphosate. J. Agric. Food. Chem. 32:1249-1253.

Gordon, B. 2007. Manganese nutrition of glyphosate-resistant and conventional soybeans. Better Crops. 91:12-13.

Hall, G.J., C.A. Hart, and C.A. Jones. 2000. Plants as sources of cations antagonistic to glyphosate activity. Pest Manag. Sci. 56:351-358.

Huber, D.M., J.D. Leuck, W.C. Smith, and E.P. Christmas. 2004. Induced manganese deficiency in GM soybeans. In R.G. Hoeft (ed.) Proc. Thirty-fourth North Central Ext.-Ind. Soil Fert. Conf. Vol. 20:80-83.

Huber, D.M. 2007. What about glyphosate-induced manganese deficiency? Fluid Journal. Fall 2007: 20-22.

Krausz, R.F., and B.Y. Young. 2001. Response of Glyphosate-resistant soybean (*Glycine max*) to Trimethylsulfonium and Isopropylamine salts of Glyphosate. Weed Tech. 15:745-749.

Subramaniam, V., and P.E. Hoggard. 1988. Metal complexes of glyphosate. J. Agric. Food. Chem. 36:1326-1329.

Thelen, K.D., E.P. Jackson, and D. Penner. 1995. The basis for the hard-water antagonism of glyphosate activity. Weed Sci. 43:541-548.

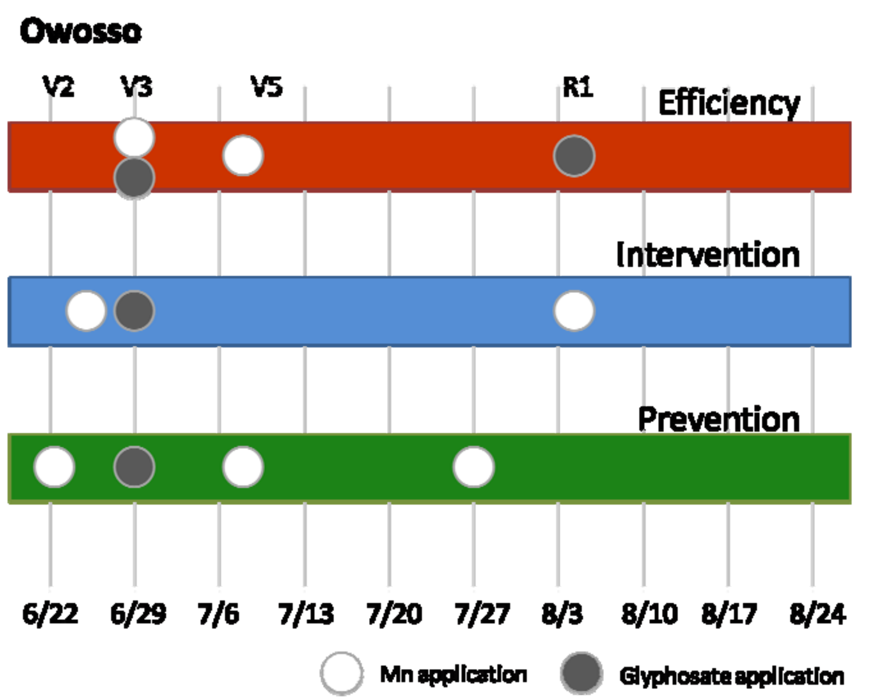

Figure 1. Timeline of fertilizer and herbicide applications- Owosso location

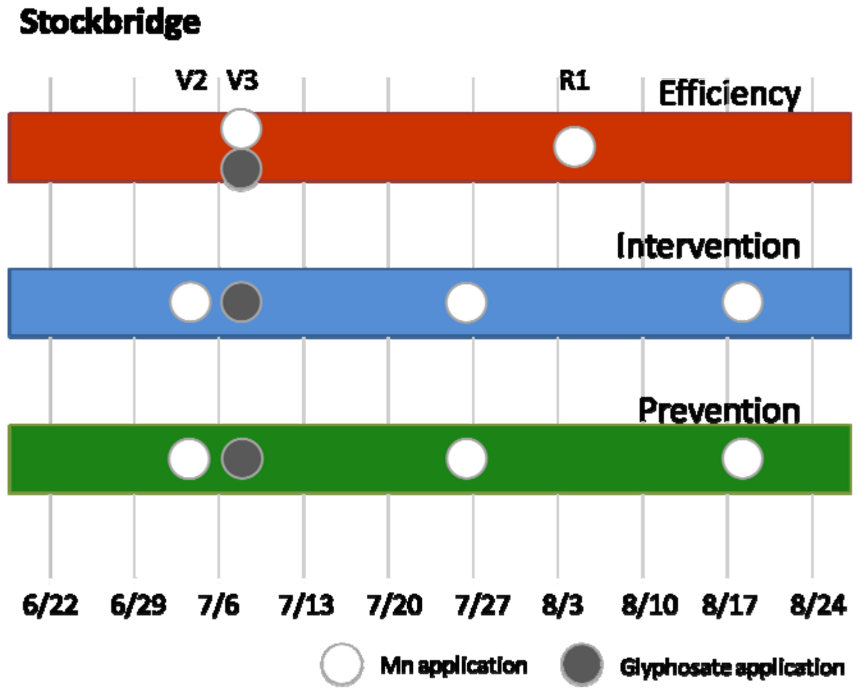

Figure 2. Timeline of fertilizer and herbicide applications- Stockbridge location

PROCEEDINGS OF THE

THIRTY-NINTH
NORTH CENTRAL
EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

Volume 25

November 18-19, 2009
Holiday Inn Airport
Des Moines, IA

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Published by:

International Plant Nutrition Institute
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Web page: www.IPNI.net