DOES GLYPHOSATE INTERACT WITH Mn IN SOYBEAN?

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Manganese deficiency in soybean can be expected on Wisconsin soils with high pH (>7.0) and/or higher soil organic matter (OM) contents (>6.0). Soils that meet these criteria are typically, but not exclusively, found in Eastern Wisconsin. In the 2005 and 2006 growing season, Dr. Laboski did not receive any calls/emails regarding suspected Mn deficiency in soybean. However, in the 2007 growing season, Dr. Laboski received many inquiries. Manganese was confirmed to be deficient in many fields over an area from Eastern Waupaca Co. south to Jefferson Co., and mostly east of Lake Winnebago. In every case that was confirmed with soil and tissue analysis, the soil had high pH and/or higher OM content. In most cases, glyphosate resistant (GR) soybean varieties were planted in the field.

Recent soybean research in Indiana and Kansas have confirmed that one of the most limiting factors to high yield in glyphosate resistant soybean systems is a suspected micronutrient deficiency resulting from applications of glyphosate to soil, weeds, and directly to glyphosate resistant soybean. Manganese concentrations in soybean plants are frequently lower than optimum, particularly in the week or two following post-emergence glyphosate application. It has been identified that glyphosate reduces the uptake and translocation of Mn via physiological immobilization of Mn in soybean plants, and that glyphosate is toxic to soil microbes that reduce soil Mn into a form that is available for plant uptake (Huber, 2007). Glyphosate exuded by roots of resistant soybean plants, as well as by weeds surrounding the soybean plants, is particularly likely to immobilize available Mn in the rhizosphere of soybean roots. Both root Mn uptake, and translocation of Mn to the shoot, are lower when glyphosate residues are present in soil.

Concerns about a yield plateau and suspected Mn deficiency following glyphosate application have been expressed by growers and agricultural professionals since the introduction of GR soybean. Some of the early concerns were in suspected low Mn soils (perhaps because of high organic matter content, high pH, or sandy textures). But increasingly outside of Wisconsin, Mn deficiency symptoms are being reported on soils where Mn should not be limiting. These concerns have multiplied as glyphosate-resistant soybean have grown to over 90% of the soybean acreage, and as overall glyphosate applications increase with the more recent adoption of GR corn (which may represent over 45% of the corn acreage in 2007). At first, industry reactions or comments were that the yellow "flash" following glyphosate application was just a temporary phenomenon, and that the GR soybean plants would recover from this without experiencing any yield reduction. However, recent trials by Dr. Huber and others (e.g., Kansas) have shown large soybean yield increases (up to 18 bu/acre) by applying foliar Mn at least 8 days following glyphosate application, by applying manganese sulfate at planting, or by adding gypsum at planting (the latter in an attempt to immobilize glyphosate exuded into the root area after glyphosate application).

Current University of Wisconsin nutrient application guidelines (Laboski et al., 2006) for Mn are based on research conducted in the early 1970s (Randall et al., 1975) when soybean

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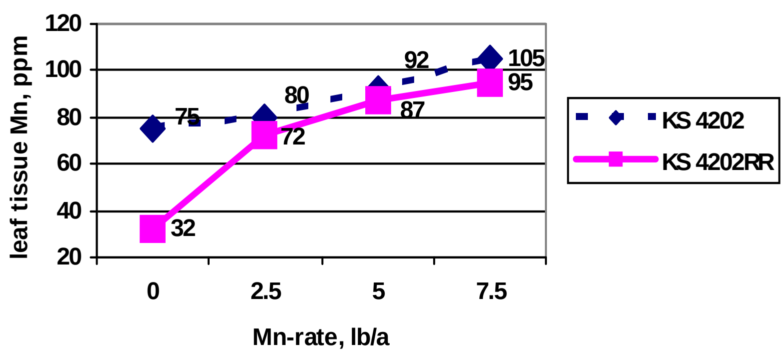
were gaining popularity as a crop in Wisconsin. These guidelines indicate that for soils with OM ≤ 6.0% a soil test for Mn coupled with the relative crop need for Mn should be considered to determine fertilizer Mn needs. For crops with a high relative need for Mn, like soybean, grown on soils with OM > 6.0%, starter fertilizer containing Mn or foliar Mn application is recommended. Thus, it is not surprising that Mn deficiency is occurring on many of these soils.

Randall et al. (1975) assessed the effectiveness of various rates of broadcast, row (starter), and foliar applications of $MnSO_4$ along with row and foliar applications of MnEDTA on improving soybean yield on soils with OM >6.0% and average soil pH of 6.3. They found that soil applied MnEDTA decreased yield slightly. All methods of $MnSO_4$ application and foliar application of MnEDTA were effective in supplying Mn to the plant. Starter fertilizer applications containing 4.5 to 19.5 lb Mn/acre as $MnSO_4$ were the most effective in increasing yield. Foliar applications of Mn were most effective when applied at early blossom (R1) or early pod set (R3), or at multiple application timings during these growth stages. On soils with moderate to severe Mn deficiency, 4.5 to 10 lb Mn/acre as $MnSO_4$ in starter fertilizer was suggested. If Mn deficiency appeared after the canopy was large enough, then a foliar Mn application could be made (Randall et al., 1975).

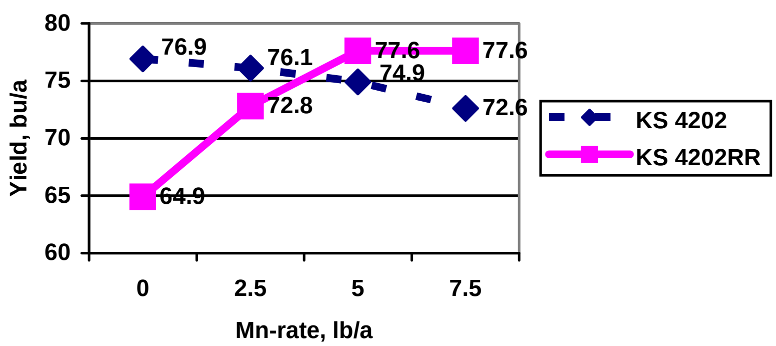
More recently, research by Dr. Gordon in Kansas in 2005 and 2006 has shown that the application of $MnSO_4$ holds considerable promise for GR soybean. In his research, a $MnSO_4$ application at planting more than doubled leaf tissue Mn concentration and increased GR soybean yields by about 13 bushels per acre (Fig. 1a,b). In this environment, the conventional soybean variety appeared to be much more Mn efficient than the RR variety, and higher rates of Mn applied to the conventional variety may have been toxic.

Figure 1. Effect of $MnSO_4$ rates on (a) leaf tissue, and (b) yield response of a RR soybean variety and its isoline on a silt loam soil with sprinkler irrigation in 2005. Source: Dr. Gordon.

(a)



(b)



Other previous work by Dr. Huber (Indiana) has provided a lot of evidence concerning the degree to which GR soybean will respond to supplemental Mn after post-emergent application of glyphosate (Huber, 2007). In 2006, at the Pinney-PAC farm in Indiana, Dr. Huber quantified an 18-bushel yield response to foliar application of supplemental Mn (Table 1). Dr. Huber has been involved in intensive investigations on glyphosate and its potential negative effects on Mn immobilization in GR soybeans for years. His most recent publication summarizes the current strategies to ameliorate glyphosate-induced Mn deficiency (Huber, 2007). He emphasizes that tank mixtures of Mn with glyphosate do not work due to reduced herbicide efficacy and reduced Mn uptake by soybean plants. He encouraged the use of the K-salt of glyphosate (WeatherMax®) formulations because it immobilized less Mn than the isopropylamine (UltraMax®) formulation.

Table 1. Effect of Mn sources on herbicidal efficacy of glyphosate on RR soybeans. Source: Dr. D. Huber, Purdue University, 2007.

Treatment/Nutrient source	Rate	Yield
No herbicide*	None	46 a**
Glyphosate***	24 oz/acre	57 b
Glyphosate + MnCO3	0.5 # Mn/acre	75 d
Glyphosate + MnSO4	0.5 # Mn/acre	70 cd
Glyphosate + Mn EDTA chelate	0.25 # Mn/acre	72 cd
Glyphosate + Mn AA chelate	0.15 # Mn/acre	67 c

* Heavy weed pressure
**Similar letters behind the means indicate non-significant differences
*** Applied as the WeatherMax® formulation at 24 oz/a + ammonium sulfate

In 2007, J. Camberato (Purdue University) examined the effect of source and timing of Mn on RR soybean yield (Table 2). Soybean yield in the starter + DDP and the starter + DDP + foliar Mn treatments was greater than in the starter alone or untreated check (Table 3). These preliminary results further suggest that Mn applied in-row may prove beneficial in alleviating Mn deficiency in environments or cropping systems when Mn availability is limited.

Table 2. Starter fertilizer and Mn timing treatments at the PPAC farm (Wanatah, IN) in 2007.

Treatment #	Starter	Starter Mn	Foliar
1	None	None	None
2	10-34-0 at 10 gal/acre	None	None
3	10-34-0 at 10 gal/acre	DDP[1] at 8 oz/acre	None
4	10-34-0 at 10 gal/acre	DDP at 8 oz/acre	DDP at 3 oz/acre with Roundup[2]
5	**None**	**None**	DDP at 3 oz/acre 10 d after Roundup

[1] DDP is mixture of $MnSO_4$ and $MnCl_2$, about 30% Mn.
[2]Roundup was applied at V4 soybean.

Table 3. Affect of source and timing of Mn on soybean yield at the PPAC farm (Wanatah, IN) in 2007.

Treatment	-------Grain yield (bu a^{-1}) ------	-----Harvest moisture (%)------
1 no starter or Mn	52.2 c	14.9 a
2 starter only	52.7 c	15.2 a
3 starter Mn	58.0 ab	15.0 a
4 starter Mn +foliar Mn	61.5 a	17.0 a
5 foliar Mn	56.4 bc	17.0 a
Source of variation	-----------------------Level of significance	----------------------
Treatment	0.003	0.92
Trt. 1 vs 2	0.85	0.91
Trt. 2 vs 3	0.03	0.93
Trt. 3 vs 4	0.14	0.51
Trt. 1 vs 5	0.08	0.50
Coefficient of variation	7.1	25

References

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