Manganese Management in Glyphosate-Resistant Soybean Cropping Systems

Tony J. Vyn, Yanbing Xia and Jim Camberato

Agronomy Department, Purdue University

Abstract:

How much are our current soybean yields limited by micronutrients like manganese (Mn)? Many soybean growers have noticed a yellowing (sometimes referred to as “yellow flash”) of glyphosate-tolerant soybean following post-emergent glyphosate applications. Glyphosate molecules are known to chelate with Mn, and prior research has suggested that leaf Mn deficiencies are more prevalent following glyphosate applications. Foliar Mn applications have been recommended when leaf Mn levels are low, and these are perhaps most effective when applied about 7-10 days after each glyphosate application. In this presentation, we will review what is known about foliar Mn applications versus banding of Mn at planting, and about the soil factors that limit Mn availability to soybean plants at various intensities of glyphosate application (from no glyphosate at all to 3 applications per year). The Indiana Soybean Alliance has been instrumental in funding this project in 2007 and 2008.

Introduction:

Recent soybean research in Indiana and a few other states have confirmed that one of the most limiting factors to the achievement of high yields in Roundup Ready® (RR) seeding systems is a suspected micronutrient deficiency resulting from applications of glyphosate (Roundup®) to soil, weeds, and directly to glyphosate-resistant soybean. Manganese (Mn) concentrations in soybean plants are frequently lower than optimum, particularly in the week or two following post-emergence glyphosate application, because glyphosate reduces the uptake and translocation of Mn via physiological immobilization of Mn in soybean plants, and because glyphosate is toxic to soil microbes that reduce soil Mn into a form that is available for plant uptake. 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.

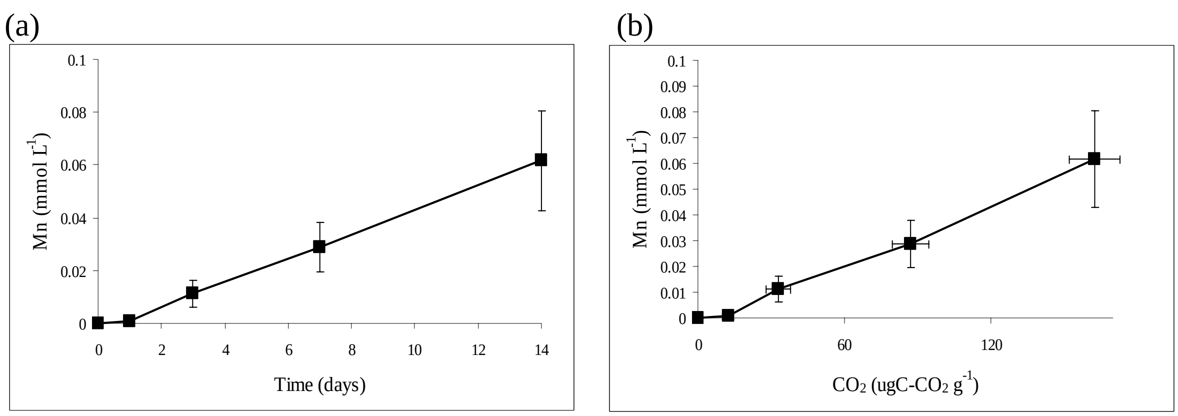
Concerns about suspected Mn deficiency following glyphosate application have often been expressed by Indiana farmers to Purdue Extension specialists over the last 10 years of RR soybean production. Some of the early concerns were in suspected low soil Mn soils (perhaps because of unusually high organic content, high pH, or sandy textures). But increasingly, Mn deficiency symptoms are being reported from some of the most productive soils in Indiana. These concerns have multiplied as glyphosate-resistant soybean have grown to more than 90% of the soybean acreage, and as overall glyphosate applications increase with the more recent adoption of RR corn (which may represent more than 50% of the corn acreage in 2008). At first, industry reactions or comments were that the yellow “flash” following glyphosate application was just a temporary phenomenon, and that the RR soybean plants would recover from this without experiencing any yield reduction. However, recent trials by Dr. Huber (Professor Emeritus at Purdue University) and others (e.g., Kansas) have shown large soybean yield increases (up to 18 bushels per 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). We also know that low plant Mn could be a factor in temporarily delaying soybean N fixation, and in enhancing the severity of certain soybean diseases.

We began research in 2007 with the goal of improving the management of micronutrients such as Mn to help achieve the highest soybean yields possible in cropping systems that are ever more reliant on glyphosate for weed control. The research was funded by the Indiana Soybean Alliance in 2007 and 2008.

Soil, Environmental, and Glyphosate Factors Affecting Mn Uptake by Soybean Plants:

Characterizing the soil environment on which RR soybeans are growing is important. Soil Mn availability, pH, and concentration of other cations can vary tremendously. Even soil moisture following glyphosate application may be an important factor in whether or not leaf Mn deficiencies occur. We know from recent laboratory studies by Alfredo Campos (2006, Ph.D. student of Dr. Cliff Johnston) that soluble Mn availability in cultivated soils is improved with time following flooding, probably because of the increase in microbial mediated reduction of Mn (Figures 1a and 1b). Recording of precipitation events and monitoring volumetric soil moisture concentrations in the two-week period following glyphosate application will be important for understanding the fluctuations in apparent reduced Mn availability to soybean plants.

Figure 1. Effects of (a) time from soil flooding, and (b) consequential CO_2 release by micro-organisms, on reduction of plant-available Mn in cultivated soil. Source: Dr. Alfredo Campos, Purdue University, 2006.



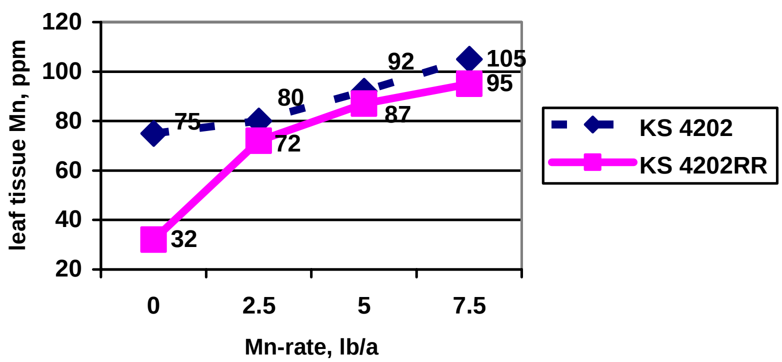
Soil pH is probably the strongest factor affecting plant-available Mn in the soil. Soil Mn concentrations have been observed to be higher in corn production than in soybean production

(Smith, 2006), but even the possible crop rotation influence needs to be interpreted in the context of differential soil pH levels. Most often, visible Mn deficiencies are going to show up first in field areas with high pH. In our recent field studies, we have observed a strong dependency of leaf Mn concentrations on soil pH. The soil pH was measured in each individual plot (about 20 feet wide by 70 feet long), so these results characterize the range in soil pH within the experiment itself.

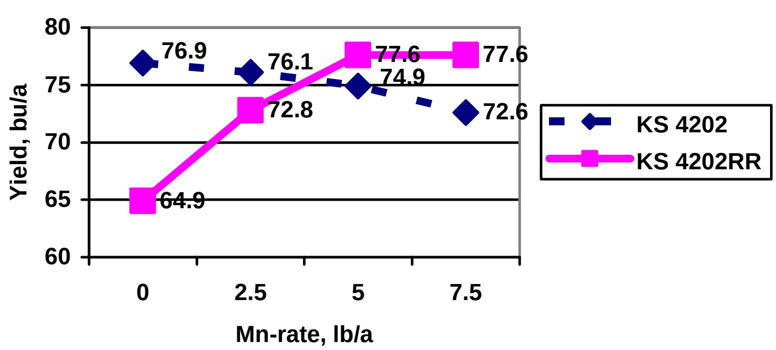
Previous studies on the optimum mode for Mn supplementation in RR soybean:

Preliminary research by Dr. B. Gordon in Kansas in 2005 and 2006 has shown that the application of $MnSO_4$ holds considerable promise for RR soybean. In his research, $MnSO_4$ application at planting more than doubled leaf tissue Mn concentration and increased RR soybean yields by about 13 bushels per acre (Figure 2). In this case, the conventional soybean variety appeared to be much more Mn efficient than the RR variety, and higher rates of Mn application to the conventional variety may have been toxic for this environment.

Figure 2. Effect of Mn rates on (a) leaf tissue, and (b) yield response of an RR soybean variety and its isoline on a silt loam soil with sprinkler irrigation in 2005. Source: Dr. Barney Gordon.
(a)



(b)



Other previous work by Dr. Huber (now a Professor Emeritus at Purdue University) has provided a lot of evidence concerning the degree to which RR soybean will respond to supplemental Mn after post-emergent application of glyphosate (Huber, 2007). In 2006, at the Pinney-Purdue Agricultural Center, Dr. Huber measured up to 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 RR soybeans for years. His most recent publication summarizes the current strategies to ameliorate glyphosate-induced Mn deficiency (Huber, 2007). He emphasizes in that report that tank mixes of Mn with glyphosate will not work because it reduces herbicide efficacy and does not result in improved Mn uptake by soybean plants. He also encouraged the use of the K-salt of glyphosate formulations (WeatherMax®) because they immobilize less Mn than the isopropylamine formuation (UltraMax®).

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	% weed control
No herbicide*	None	46 a**	0 a
Glyphosate***	24 oz/a	57 b	100 e
Glyphosate + MnCO3	0.5 # Mn/a	75 d	91 de
Glyphosate + MnSO4	0.5 # Mn/a	70 cd	93 e
Glyphosate + Mn EDTA chelate	0.25 # Mn/a	72 cd	100 e
Glyphosate + Mn AA chelate	0.15 # Mn/a	67 c	85 d

* Heavy weed pressure

**Similar letters behind the means indicate non-significant differences

*** Applied as the WeatherMax® formulation at 24 oz/a + ammonium sulfate

Liming?: Among the strategies Dr. Huber has investigated is the whole concept of in-row application of pelleted lime or gypsum ($CaSO_4$) for the potential direct immobilization of either residual glyphosate in soil or that exuded into the soybean root zone after glyphosate application via complexing with Ca. The assumption is that if some glyphosate is immobilized, it will not be as toxic to the organisms that reduce Mn. To our knowledge there has been no further work on the in-row application of gypsum in the Eastern Corn Belt. Other obstacles to that approach were the high product rates required (possibly 75 to 250 pounds per acre), the higher potential cost to farmers versus $MnSO_4$, greater challenges in delivery of gypsum with soybean planters, and the fact that too much Ca in soil may lower plant-available Mn availability (e.g., in high pH situations). Nevertheless, the latter strategy of gypsum banding should receive more research attention in both RR corn and RR soybean situations. Gypsum may have more of a place in RR corn since this crop has less buffering capacity for recovery from micronutrient deficiency than soybean.

Applying Mn in a Starter Band: We investigated the banded application of manganese sulfate ($MnSO_4$) while planting soybean on the premise that Indiana soybean farmers would find it more convenient and economically efficient to band micronutrients while planting than to foliar apply chelated forms of Mn approximately 8 days after each post-emergence glyphosate application. In 2007 and 2008, we tested multiple rates of $MnSO_4$ at 3 locations involving RR soybean in 30-inch rows after corn in north central and northwest Indiana. Weed pressure was maintained at the near zero level in all plots by the common application of residual herbicides to the entire experiment before planting. While we acknowledge that this is not a general farm management practice except for the no glyphosate treatment, we wanted to ensure that all treatment effects on soybean are the result of nutrient factors, and not differential weed competition. Plant tissue sampling focused on the uppermost fully expanded trifoliate leaves. Tri-foliate leaf samples were removed from all treatments four times each year (generally at weekly or bi-weekly intervals after the first and second post glyphosate applications). This research has, to our knowledge, never been conducted before in the Eastern Corn Belt.

Our preliminary research results will be discussed in the oral presentation at the conference. The available data must still be analyzed statistically, and the data are somewhat inconclusive. A few trends are interesting to note. At some locations, leaf Mn concentrations were highly dependent on soil Mn when no supplemental Mn was applied (Figure 3a). At other locations, leaf Mn concentrations were less dependent on soil Mn, but leaf concentrations were above 30 ppm even with soil Mn concentrations as low as 4 to 10 ppm (Figure 3b). Other variables that are known to be important to leaf Mn concentrations are soil pH and soil moisture content.

Figure 3a. Regression relationships between tri-foliate leaf Mn concentrations and soil Mn concentrations 8 days after the second post-emergent glyphosate application at White County (Mike Lehe farm, July 25, 2008).

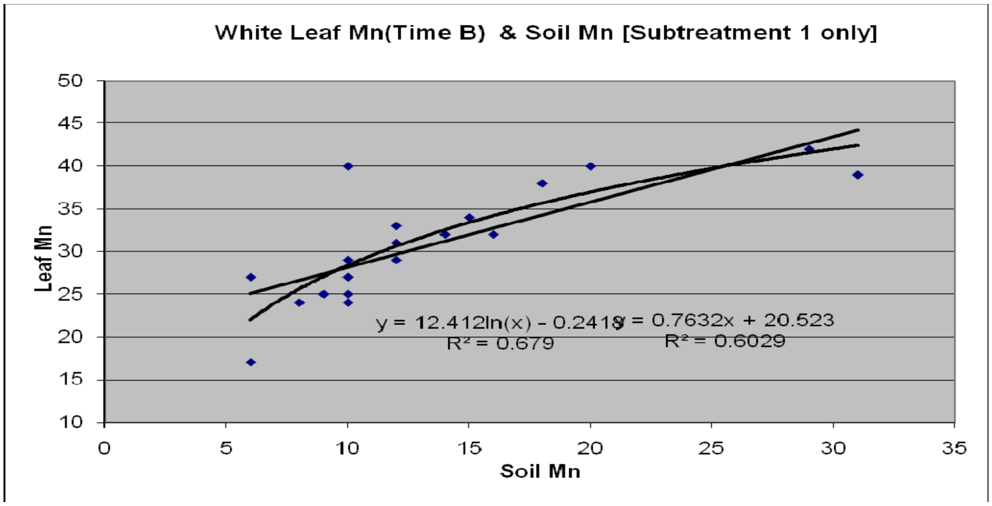
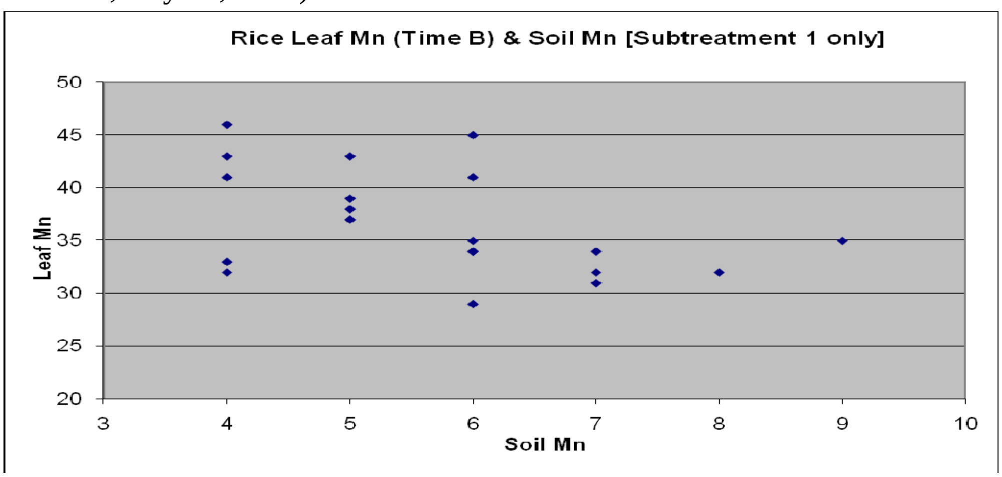


Figure 3b. Relationships between tri-foliate leaf Mn concentrations and soil Mn concentrations 8 days after the second post-emergent glyphosate application at LaCrosse, IN (Rice Farm, Jerry Danford, July 22, 2008).



The overall relationship of individual plot yields to leaf Mn concentrations during mid-season (July 29 to August 1, 2008) are also highly variable from location to location (Figures 4a, 4b, 4c) despite the use of the same cultivar (Pioneer 93M11) at all experimental sites. However, the overall data set at each location includes treatments with up to 3 Roundup Weather Max® applications, and 4 supplemental Mn treatments (3 banded and one foliar Mn application per glyhosate treatment) so one would expect yield variability. The overall effects of starter banded Mn on soybean yield were inconsistent in both years (data not shown).

Figure 4a. Regression relationship of 2008 soybean yields (bushels per acre) to leaf Mn concentrations (ppm) resulting from various glyphosate and Mn banding treatments on July 29 at Wanatah, IN on a Sebawa loam soil (Pinney Purdue Agricultural Center).

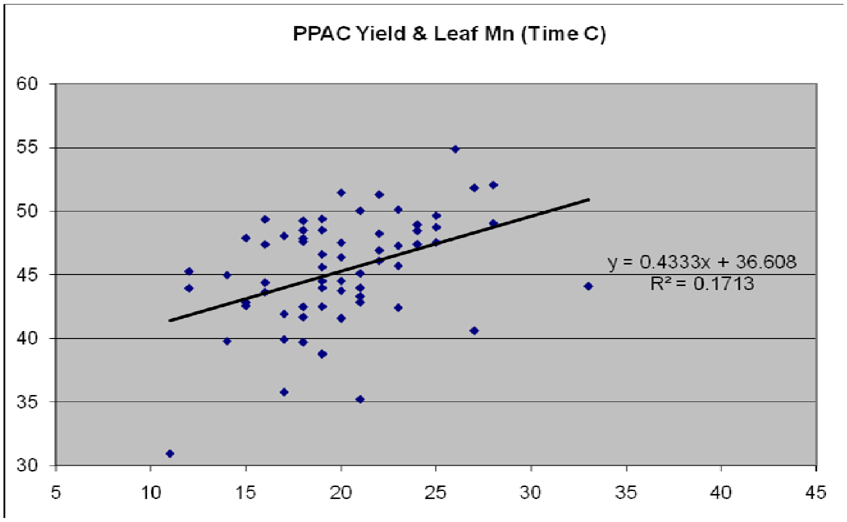


Figure 4b. Regression relationship of 2008 soybean yields to leaf Mn concentration on July 29 at La Crosse, IN (Farmer Jerry Danford, Rice Farm).

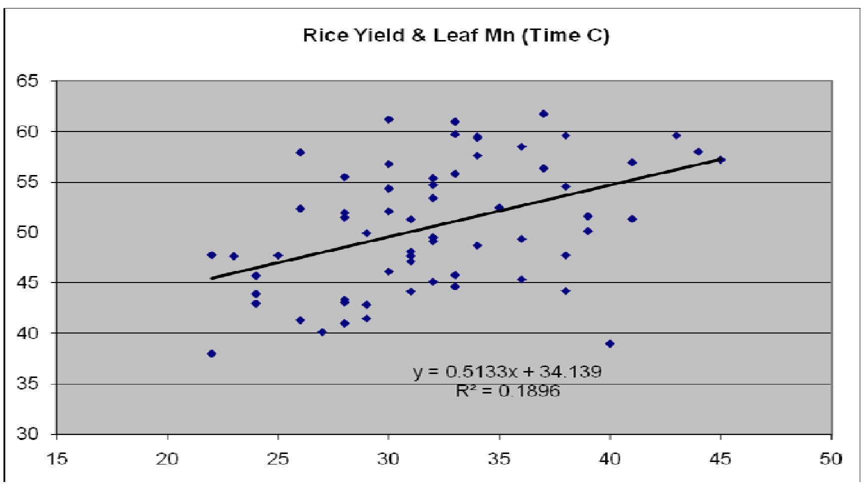
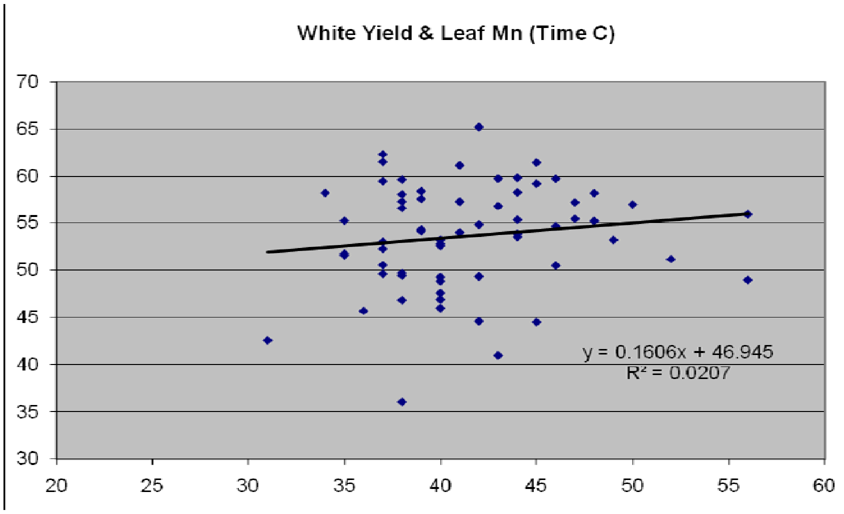


Figure 4c. Regression relationship of 2008 soybean yields to leaf Mn concentration on August 1 at White County (farm of Mike Lehe).



Our current recommendations (Tri-State Fertilizer Recommendations) suggest that the "sufficiency range" for tri-foliate leaf Mn prior to R1 stage is 21-100 ppm. Even if we accept that the minimum level needs to be at least 20 ppm we are far from certain as to the critical Mn concentrations during later reproductive stages of soybean. It appears that soybean yields can respond positively to soybean leaf Mn concentrations well above 30 ppm, but that the responses are dependent on soil and environmental factors. It is also possible that soybean cultivars will also vary in their requirement for leaf Mn.

We are thankful for the financial support of the Indiana Soybean Alliance, and we hope to continue work on manganese and other micronutrients to provide valid recommendations to crop consultants and farmers in Indiana.

Tentative Conclusions:

Based on our analysis of farmer and crop consultant inquiries concerning this issue, plus some preliminary results by earlier researchers, we believe the whole area of effective micronutrient management is a most important area to pursue in attempts to increase soybean yield. We regard Mn management as a particularly important area to pursue as the total "glyphosate load" to Indiana fields seems destined to increase (though we recognize that reliance on a solely glyphosate weed control approach may also be constrained by the development of resistant weeds). The body of literature building up concerning the deleterious effects of glyphosate on micronutrient availability is astounding (see PIs for details), but the management practices to ensure adequate Mn availability during vegetative and reproductive growth for soybean are still in the early stages. Banding of supplemental Mn fertilizer at planting of soybean may not be superior to one or more foliar Mn applications following post-emergent glyphosate application.

More research is needed to help guide critical sampling times and the most effective methods (products, rates, timing and placement) of supplementing leaf Mn concentrations in soybean.

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