EFFECT OF SOYBEAN VARIETY, GLYPHOSATE USE, AND MANGANESE APPLICATION ON SOYBEAN YIELD

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Introduction

Manganese (Mn) deficiency in crops has occasionally been noted in Wisconsin and is most common on soils with high pH (>7.0) and/or high organic matter (>6.0 %). Soils that meet these criteria are typically, but not exclusively, found in Eastern Wisconsin. Soybean has a relatively high requirement for Mn. 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 was 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.

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/a 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/a 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).

Soybean acreage in Wisconsin has increased from 216,000 acres in 1975 to 1,670,000 acres in 2011with significantly higher yields due to improved management and varieties with higher yield potential. The percentage of total soybean acreage planted to herbicide tolerant soybean varieties (primarily glyphosate resistant) in the United States has increased from 7% in 1996 to 94% in 2011 (USDA-ERS, 2011). Likewise, nearly 90% of soybean planted in Wisconsin in 2010 was herbicide tolerant varieties (USDA-NASS, 2010).

Recent soybean research in Indiana and Kansas have suggested 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

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directly to glyphosate resistant soybean. Manganese concentration in soybean plants is frequently lower than optimum, particularly in the week or two following post-emergence glyphosate application. It has been hypothesized 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.

Huber et al. (2007) reported that glyphosate resistant (GR) soybean varieties were less efficient at manganese (Mn) uptake compared with non-GR varieties. In 2006, results from a one-year study in Indiana by Huber (2007) showed that where glyphosate was applied to a GR soybean variety, yields increased from 57 bu/a without Mn to an average of 72 bu/a where Mn was applied. Research in Kansas by Gordon (2006) showed that a $MnSO_4$ application to a GR soybean variety at planting more than doubled leaf tissue Mn concentration and increased yield by about 13 bu/acre. These results also showed that a non-GR soybean variety had greater Mn uptake efficiency compared with the GR variety, and that yields declined as Mn rate increased suggesting Mn toxicity.

The most extensive study evaluating the relationship between GR soybean response to Mn following glyphosate application was conducted at five Kansas locations in 2006 to 2008 and was recently published (Loecker et al., 2010). A significant yield increase occurred where Mn was added at three of the locations; however, it was not consistent whether the soybean variety was GR or non-GR. The authors concluded that soybean genetics likely influenced Mn uptake and yield response to Mn, but that these responses were not conclusively related to GR in soybean. Due to the limited research on this topic and the potential economic impact this may have on soybean growers in Wisconsin, a three-year research study was conducted with the following objectives: i) to quantify the effect of glyphosate on Mn availability in GR soybean systems; and ii) to evaluate soybean response to starter and/or foliar Mn applications.

Materials and Methods

Field research studies were established at six on-farm locations in the spring of the 2008 to 2010 growing seasons. Two of the locations (Jefferson County near Hubbleton in 2008 and Outagamie County east of New London in 2010) were not completed due to excessive rainfall resulting in flooded conditions. The four locations which were completed included Walworth County near East Troy in 2008, Dodge County near Hubbleton and Jefferson County near Watertown in 2009, and a second site in Outagamie County north of New London in 2010 (Table 1).

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. The experiment was a split-split-plot in a randomized complete block design with four replications. Soybean variety/herbicide was the main plot, starter Mn rate was the sub-plot, and foliar Mn rate and timing was the sub-sub-plot.

Soybean was planted at a 1-inch soil depth on 30-inch row spacing at a rate of 155,500 seeds/acre on 19 or 20 May at each location. For the treatments receiving 5 lb Mn/acre as starter fertilizer, $MnSO_4$ (ManGro DF; 31% Mn and 15% S) was dissolved in water and the solution was applied at a rate of 8.6 gal/acre using a 4-nozzle CO_2 sprayer connected with polyethylene tubing to each of the four granular starter fertilizer applicator tubes on the planter and placed in a band 2-in. below and 2-in. laterally from the seed at planting. The initial plot size was four-rows wide (10 ft.) and 30-ft long and was trimmed to 25-ft long at the V1-V2 stage of growth.

All treatments received either a preplant incorporated or preemergence herbicide application to control weeds prior to the postemergence herbicide treatment (conventional or glyphosate) application. Glyphosate herbicide was applied at a 0.75 lb ae/acre around 1 July (29 June to 2 July) to the GR/Glyphosate treatment. Non-glyphosate containing herbicides were applied, if needed, at this time to the Non-GR/Conventional and GR/Conventional variety/herbicide treatments. Postemergence herbicides included First Rate (0.6 oz/a) at Walworth County in 2008, and a tank mix of Assure II (10 fl oz/a) and Harmony GT (1/24 oz/a) at Dodge and Jefferson counties in 2009. No postemergence herbicides were applied to the Non-GR/Conventional and GR/Conventional variety/herbicide treatments at Outagamie County in 2010 due to negligible weed pressure.

Foliar Mn treatment applications were made about 10 and 25 days following postemergence herbicide treatment applications, specifically at the R1 (10-13 July) and R3 (25-29 July) growth stages, respectively. The foliar Mn treatments were applied using dissolved $MnSO_4$ (in water) with a non-ionic surfactant (0.32 oz/gal) at a rate of 20 gal/acre using a CO_2 sprayer using flat fan spray tips.

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 dried at 160^oF, ground to pass a 1-mm mesh screen, digested, and analyzed for Mn using an inductively coupled plasma (ICP) emission spectrophotometer. Soybean grain yield was determined by harvesting the middle two rows from each plot using a plot combine in early- to mid-October. Soybean grain yields are reported at 13% moisture.

Soybean leaf Mn concentration and grain yield data were analyzed using the PROC MIXED procedure for a balanced split-split-plot design with the whole plots arranged in a randomized complete-block design (SAS Institute, 2002). The variety/herbicide, starter Mn, and foliar Mn treatments were fixed effects and replication and replication x variety/herbicide x starter Mn were random effects. Significant mean treatment differences were evaluated using Fisher's protected LSD test at the 0.10 probability level. The relationship between soybean leaf Mn concentration 10-days post R3 foliar Mn application and grain yield was determined using linear regression analysis (PROC REG).

Results and Discussion

Site Background

Soil characteristics and site background information are provided in Table 1. The Mn soil test was optimum at Walworth and Outagamie, and low at Dodge. At Jefferson the soil organic matter (OM) content was greater than 6.0% and thus out of the interpretative range for the Mn soil test (Laboski et al., 2006). The pH at Jefferson was 7.8 and in combination with an OM of 6.1%, suggests that soil Mn may be low for soybean production.

Growing season rainfall and temperature at each location are provided in Table 2. Of particular note are the relatively dry and cool conditions at both locations in 2009 (Dodge and Jefferson) and wet conditions at Outagamie in 2010. At Walworth, brown stem rot set in late in the growing season and limited yields.

No visual Mn deficiency symptoms were observed throughout the growing season at any location.

Tissue Manganese Concentrations

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) (Tables 3 though 6); thus a response to Mn application would be expected. There was no significant effect of starter Mn application or soybean variety/herbicide on R1 tissue Mn concentrations.

Ten days after 1.25 lb Mn/a 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. At Dodge and Jefferson, the non-glyphosate resistant variety with conventional weed management (Non-GR/Conv) had significantly lower tissue Mn concentrations compared to the glyphosate resistant variety with either conventional (GR/Conv) or glyphosate (GR/glyphosate) weed management. The opposite trend occurred at Outagamie where the Non-GR/Conv had significantly greater tissue Mn compared to GR/Conv or GR/glyphosate.

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 Outagamie (Tables 3 through 6). At Outagamie, tissue Mn increased from R1 to R3. Where Mn was applied foliarly at R1, tissue Mn was lower at R3 compared to 10 days post R1 application at all locations except Outagamie where R3 tissue Mn was greater. Tissue Mn concentrations at Outagamie were about double the concentrations at the other locations at the R3 sampling time. Plots that received foliar Mn at R1 had significantly greater tissue Mn at R3 compared to plot that had not received foliar Mn at all locations except Walworth. 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 only had significantly lower tissue Mn concentrations compared to foliar applications at R3, and R1 + R3. Non-GR/Conv had significantly greater tissue Mn at 10 days post R3 compared to GR/Conv or GR/glyphosate at Walworth and Outagamie only.

Where no foliar Mn was applied tissue Mn concentrations decreased slightly or remained steady from R1 until 10 days post R3 at all locations except Outagamie where tissue Mn generally increased through the growing season. 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.

Effect of Manganese Application on Yield

Soybean yields were the greatest at Outagamie and ranged from 53 to 59 bu/a (Table 10). Yields at the other locations were 43 to 52 bu/a at Jefferson; 45 to 52 bu/a at Dodge; and 27 to 43 bu/a at Walworth (Tables 7 through 9). Manganese application and variety/weed management had minimal effects on soybean yield over all locations. At Walworth, which had the largest range in yields, there were no significant differences between any treatments. This was caused by the large variability between plots within the same treatment and was likely a result of brown stem rot that set in late in the growing season.

The glyphosate resistant variety had significantly greater yield compared to the non-glyphosate resistant variety regardless of whether or not glyphosate was applied (Table 10). 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. Interactions like this are difficult to understand. At both of these locations, when starter Mn was applied to the GR/glyphosate, yields were greater than 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.

Summary and Conclusions

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 soil test levels or at locations with 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. It should be noted that some Mn treatments at some locations may have increased yield by a couple bushels, yield reductions with Mn application were also observed.

At some tissue sampling times in Outagamie and Walworth, the non-glyphosate resistant variety had greater tissue Mn concentrations compared to the glyphosate resistant variety with either conventional herbicides or glyphosate. The opposite of this was true at Dodge and Jefferson. Overall, these data do 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 OM greater than 6.0%), if no visual deficiency symptoms are apparent, then application of Mn is likely not economical.

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Table 1. Experimental conditions at four locations.

Information	County and year			
	Walworth 2008	Dodge 2009	Jefferson 2009	Outagamie 2010
Soil name and texture	Sebewa silt loam	Granby fine sandy loam	Wacousta silty clay loam	Shiocton silt loam
Soil 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
Soil test:				
pH	7.2	8.1	7.8	7.2
Organic 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
Fertilizer (non-treatment)	0-0-0 lb/a N-P_2O_5-K_2O	5-64-60 lb/a N-P_2O_5-K_2O	0-0-60 lb/a N-P_2O_5-K_2O	0-0-90 lb/a N-P_2O_5-K_2O
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.

Table 2. Monthly precipitation and average air temperature departure from the 30-yr average at four locations†, 2008 to 2010. Source NOAA.

Month	Walworth 2008		Dodge 2009		Jefferson 2009		Outagamie 2010	
	Precip.	Average air temp.	Precip.	Average air temp.	Precip.	Average air temp.	Precip.	Average air temp.
	in.	°F	in.	°F	in.	°F	in.	°F
May	-0.65	-5.4	0.56	0.9	0.18	-0.1	1.11	1.4
June	2.59	0.3	0.01	0.1	1.55	-0.8	2.82	-0.4
July	1.28	-1.6	-2.27	-6.1	-2.99	-6.2	8.44	1.4
Aug	-2.98	-1.1	-1.62	-0.6	-2.46	-3.3	0.96	3.7
Sept	1.05	1.8	-0.61	3.6	-2.35	1.4	1.60	-1.3
Oct	0.20	-0.6	1.64	-1.2	1.27	-4.6	0.64	2.7

† NOAA sites include Burlington (Walworth County), Waterloo, departures from Watertown (Dodge County), Watertown (Jefferson County), and New London (Outagamie County).

Table 3. Effect of soybean variety/herbicide, starter Mn, and foliar Mn on soybean leaf Mn concentration at four sampling times at Walworth County, 2008.

Variety/ herbicide	Starter Mn	Foliar Mn rate and time of application	R1	10-d post R1	R3	10-d post R3
			Time of sampling †			
	------------- lb/a	-------------	--------- leaf Mn concentration, ppm --------			
Non-GR/ Conventional	0	0				29
		1.25 @ R1	33	38		30
		1.25 @ R3			31	54
		1.25 @ R1+R3			34	63
	5	0				28
		1.25 @ R1	35	43		34
		1.25 @ R3			31	56
		1.25 @ R1+R3			35	57
GR/ Conventional	0	0				25
		1.25 @ R1	27	36		26
		1.25 @ R3			28	34
		1.25 @ R1+R3			34	47
	5	0				28
		1.25 @ R1	29	37		29
		1.25 @ R3			32	46
		1.25 @ R1+R3			32	47
GR/ Glyphosate	0	0				26
		1.25 @ R1	36	38		31
		1.25 @ R3			30	38
		1.25 @ R1+R3			33	37
	5	0				32
		1.25 @ R1	34	41		33
		1.25 @ R3			32	36
		1.25 @ R1+R3			29	36
				ANOVA		
		Source of variation:	------------------------ *p* ------------------------			
		Variety/herbicide(V)	0.19	0.29	0.62	<0.01
		Starter Mn (S)	0.74	0.06	0.93	0.51
		V x S	0.82	0.73	0.87	0.74
		Foliar Mn (F)			0.11	<0.01
		V x F			0.51	0.13
		S x F			0.13	0.86
		V x S x F			0.45	0.99

† R1, 10 July; 10-day post R1, 21 July; R3, 25 July; 10-d post R3, 4 August. Samples obtained prior to foliar Mn application at the R1 and R3 stage of growth.

Table 4. Effect of soybean variety/herbicide, starter Mn, and foliar Mn on soybean leaf Mn concentration at four sampling times at Dodge County, 2009.

Variety/ herbicide	Starter Mn	Foliar Mn rate and time of application	Time of sampling † R1	10-d post R1	R3	10-d post R3
	------------- lb/a -------------		--------- leaf Mn concentration, ppm --------			
Non-GR/ Conventional	0	0				36
		1.25 @ R1	40	62		38
		1.25 @ R3			32	63
		1.25 @ R1+R3			39	69
	5	0				37
		1.25 @ R1	35	55		36
		1.25 @ R3			35	73
		1.25 @ R1+R3			37	77
GR/ Conventional	0	0				37
		1.25 @ R1	37	63		32
		1.25 @ R3			36	74
		1.25 @ R1+R3			40	68
	5	0				39
		1.25 @ R1	51	77		38
		1.25 @ R3			38	69
		1.25 @ R1+R3			39	63
GR/ Glyphosate	0	0				32
		1.25 @ R1	58	68		41
		1.25 @ R3			35	60
		1.25 @ R1+R3			45	62
	5	0				38
		1.25 @ R1	46	81		41
		1.25 @ R3			41	75
		1.25 @ R1+R3			38	61

ANOVA

Source of variation:	R1	10-d post R1	R3	10-d post R3
	------------------------ *p* ------------------------			
Variety/herbicide(V)	0.15	0.02	0.44	0.79
Starter Mn (S)	0.86	0.15	0.96	0.12
V x S	0.13	0.11	0.89	0.44
Foliar Mn (F)			0.02	<0.01
V x F			0.87	0.23
S x F			0.02	0.67
V x S x F			0.42	0.36

† R1, 13 July; 10-day post R1, 23 July; R3, 29 July; 10-d post R3, 6 August. Samples obtained prior to foliar Mn application at the R1 and R3 stage of growth.

Table 5. Effect of soybean variety/herbicide, starter Mn, and foliar Mn on soybean leaf Mn concentration at four sampling times at Jefferson County, 2009.

			Time of sampling †			
Variety/ herbicide	Starter Mn	Foliar Mn rate and time of application	R1	10-d post R1	R3	10-d post R3
	------------- lb/a -------------		--------- leaf Mn concentration, ppm --------			
Non-GR/ Conventional	0	0				31
		1.25 @ R1	34	61		35
		1.25 @ R3			27	110
		1.25 @ R1+R3			30	118
	5	0				31
		1.25 @ R1	30	51		35
		1.25 @ R3			26	125
		1.25 @ R1+R3			32	115
GR/ Conventional	0	0				33
		1.25 @ R1	33	57		36
		1.25 @ R3			28	83
		1.25 @ R1+R3			36	98
	5	0				34
		1.25 @ R1	33	67		36
		1.25 @ R3			32	103
		1.25 @ R1+R3			30	93
GR/ Glyphosate	0	0				33
		1.25 @ R1	34	70		38
		1.25 @ R3			27	101
		1.25 @ R1+R3			32	100
	5	0				36
		1.25 @ R1	33	67		38
		1.25 @ R3			25	110
		1.25 @ R1+R3			32	109
			ANOVA			
		Source of variation:	------------------------ *p* ------------------------			
		Variety/herbicide (V)	0.65	0.04	0.01	0.20
		Starter Mn (S)	0.20	0.75	0.47	0.23
		V x S	0.40	0.12	0.66	0.96
		Foliar Mn (F)			<0.01	<0.01
		V x F			0.44	0.18
		S x F			0.22	0.37
		V x S x F			0.01	0.98

† R1, 13 July; 10-day post R1, 23 July; R3, 29 July; 10-d post R3, 6 August. Samples obtained prior to foliar Mn application at the R1 and R3 stage of growth.

Table 6. Effect of soybean variety/herbicide, starter Mn, and foliar Mn on soybean leaf Mn concentration at four sampling times at Outagamie County, 2010.

Variety/ herbicide	Starter Mn	Foliar Mn rate and time of application	Time of sampling † R1	10-d post R1	R3	10-d post R3
	------------- lb/a	-------------	--------- leaf Mn concentration, ppm --------			
Non-GR/ Conventional	0	0				83
		1.25 @ R1	44	71		76
		1.25 @ R3			79	311
		1.25 @ R1+R3			96	286
	5	0				79
		1.25 @ R1	49	75		81
		1.25 @ R3			72	222
		1.25 @ R1+R3			85	361
GR/ Conventional	0	0				60
		1.25 @ R1	49	71		66
		1.25 @ R3			63	132
		1.25 @ R1+R3			77	171
	5	0				70
		1.25 @ R1	42	63		67
		1.25 @ R3			64	166
		1.25 @ R1+R3			64	149
GR/ Glyphosate	0	0				64
		1.25 @ R1	49	63		77
		1.25 @ R3			66	141
		1.25 @ R1+R3			67	139
	5	0				72
		1.25 @ R1	45	68		64
		1.25 @ R3			60	155
		1.25 @ R1+R3			68	182

ANOVA

Source of variation:	R1	10-d post R1	R3	10-d post R3
	------------------------ *p*			------------------------
Variety/herbicide (V)	0.87	0.05	<0.01	<0.01
Starter Mn (S)	0.44	0.81	0.24	0.51
V x S	0.15	0.09	0.87	0.71
Foliar Mn (F)			0.06	<0.01
V x F			0.65	<0.01
S x F			0.65	0.23
V x S x F			0.66	0.02

† R1, 12 July; 10-day post R1, 21 July; R3, 27 July; 10-d post R3, 5 August. Samples obtained prior to foliar Mn application at the R1 and R3 stage of growth.

Table 7. Effect of soybean variety/herbicide, starter Mn, and foliar Mn on soybean grain yield at Walworth County, 2008.

Variety/herbicide	Starter Mn	Foliar Mn rate (lb/a) and time of application: 0	1.25 @ R1	1.25 @ R3	1.25 @ R1 and R3
	lb/a	------------------------ yield, bu/a			--------------------------
Non-GR/Conventional	0	30	29	31	27
	5	34	27	31	36
GR/Conventional	0	39	44	44	32
	5	32	41	37	37
GR/Glyphosate	0	43	36	45	36
	5	43	44	39	43

Source of variation:	*p*
Variety/herbicide (V)	0.19
Starter (S)	0.73
V x S	0.37
Foliar (F)	0.78
V x F	0.59
S x F	0.17
V x S x F	0.92

Treatment means:

Variety/herbicide	Yield	Starter Mn	Yield	Foliar Mn	Yield
	bu/a	lb/a	bu/a	lb/a	bu/a
Non-GR/Conventional	31	0	36	0	37
GR/Conventional	38	5	37	1.25 @ R1	37
GR/Glyphosate	41			1.25 @ R3	38
				1.25 @ R1 & R3	35

Table 8. Effect of soybean variety/herbicide, starter Mn, and foliar Mn on soybean grain yield at Dodge County, 2009.

Variety/herbicide	Starter Mn	Foliar Mn rate (lb/a) and time of application: 0	1.25 @ R1	1.25 @ R3	1.25 @ R1 and R3
	lb/a	------------------------ yield, bu/a			--------------------------
Non-GR/Conventional	0	50	47	52	48
	5	48	51	47	44
GR/Conventional	0	48	51	49	49
	5	49	49	49	47
GR/Glyphosate	0	52	48	48	46
	5	45	46	49	51

Source of variation:	*p*
Variety/herbicide (V)	0.91
Starter (S)	0.16
V x S	0.89
Foliar (F)	0.58
V x F	0.68
S x F	0.56
V x S x F	0.01

Treatment means:

Variety/herbicide	Yield	Starter Mn	Yield	Foliar Mn	Yield
	bu/a	lb/a	bu/a	lb/a	bu/a
Non-GR/Conventional	49	0	49	0	49
GR/Conventional	49	5	48	1.25 @ R1	49
GR/Glyphosate	48			1.25 @ R3	49
				1.25 @ R1 & R3	48

Table 9. Effect of soybean variety/herbicide, starter Mn, and foliar Mn on soybean grain yield at Jefferson County, 2009.

		Foliar Mn rate (lb/a) and time of application			
Variety/herbicide	Starter Mn	0	1.25 @ R1	1.25 @ R3	1.25 @ R1 and R3
	lb/a	yield, bu/a			
Non-GR/Conventional	0	45	48	47	48
	5	48	50	49	44
GR/Conventional	0	46	49	45	49
	5	45	50	44	48
GR/Glyphosate	0	51	43	50	43
	5	48	48	47	52

Source of variation:	*p*
Variety/herbicide (V)	0.94
Starter (S)	0.39
V x S	0.60
Foliar (F)	0.62
V x F	<0.01
S x F	0.19
V x S x F	<0.01

Treatment means:

Variety/herbicide	Yield
	bu/a
Non-GR/Conventional	47
GR/Conventional	47
GR/Glyphosate	48

Starter Mn	Yield
lb/a	bu/a
0	47
5	48

Foliar Mn	Yield
lb/a	bu/a
0	47
1.25 @ R1	48
1.25 @ R3	47
1.25 @ R1 & R3	47

Significant treatment interactions:

	Variety/herbicide		
Foliar Mn	Non-GR/Conv.	GR/Conv.	GR/Glyphosate
lb/a	yield, bu/a		
0	47	46 b†	49
1.25 @ R1	49	50 a	46
1.25 @ R3	48	45 b	48
1.25 @ R1 and R3	46	49 a	47
p	0.25	<0.01	0.42

† Values in columns followed by the same letter are not significantly different at the 0.10 probability level.

Table 10. Effect of soybean variety/herbicide, starter Mn, and foliar Mn on soybean grain yield at Outagamie County, 2010.

		Foliar Mn rate (lb/a) and time of application			
Variety/herbicide	Starter Mn	0	1.25 @ R1	1.25 @ R3	1.25 @ R1 and R3
	lb/a	yield, bu/a			
Non-GR/Conventional	0	53	55	53	54
	5	53	54	54	55
GR/Conventional	0	56	55	57	55
	5	58	55	58	57
GR/Glyphosate	0	59	55	57	55
	5	57	58	58	55

Source of variation:	*p*
Variety/herbicide (V)	<0.01
Starter (S)	0.29
V x S	0.81
Foliar (F)	0.47
V x F	0.16
S x F	0.64
V x S x F	0.63

Treatment means:

Variety/herbicide	Yield	Starter Mn	Yield	Foliar Mn	Yield
	bu/a	lb/a	bu/a	lb/a	bu/a
Non-GR/Conventional	54 b†	0	55	0	56
GR/Conventional	56 a	5	56	1.25 @ R1	55
GR/Glyphosate	56 a			1.25 @ R3	56
				1.25 @ R1 & R3	55

† Values in columns followed by the same letter are not significantly different at the 0.10 probability level.