Sulfur Synergies in Soybean Management: YEAR 1 REPORT

Shaun Casteel, Purdue University

Indiana Soybean Alliance
c/o Aly Wells
Project Period: 05/01/2018 to 04/30/2019

ABSTRACT

Sulfur (S) deposition from the atmosphere has been on the decline over the last few decades due to the improvements in air quality, especially due to the Clean Air Act amendment in 1990. Approximately 10 to 18 lb of S/acre was deposited from the atmosphere to the soils of Indiana in 2001; whereas, only 4 to 8 lb of S/acre was deposited in 2015. Sulfur is a macro-nutrient that is needed in large quantities for all crops including soybean. In fact, S is needed as a co-factor for proper nodulation and fixation by *Bradyrhizobium japonicum* for soybean. Soybean takes up 0.35 lb of S per bushel, so 50 to 75-bu soybeans would need 17.5 to 26 lb S/ac. A little over half of this S is removed in the grain (largely in amino acids of the protein), thus 9 to 13.5 lb S/ac is removed from the field in the grain (50 to 75 bu). Organic matter in the soil can help make up the difference in crop need and deposition from the atmosphere, but evidence is mounting that more S is needed in some fields for soybean.

Our research aimed to determine the best options (e.g., fertilizer sources to be broadcast applied prior to planting/emergence, foliar sprays during the growing season) to manage S for soybean and determine opportunities for synergies in management to optimize yield and quality (i.e., protein). First year results of this project has documented 10+ bu responses to ammonium sulfate (AMS, 21-0-0-24S), MES10 (12-40-0-10S), and pelletized Gypsum (21% Ca, 17% S) followed by ~6 bu responses to the other sulfur sources at LaCrosse (sulfur-deficient location) in 2018. At the same location, optimal foliar S application rate was ~4 lb S/ac regardless of growth stage applied (V4 or R3) with over 8 bu yield improvement. These yield improvements are also coupled with improvements with protein concentration. In the trials at the S-deficient location, protein concentration increased two percentage points of protein. Synergies in management seem to align more with combined applications of AMS prior to emergence and foliar protection at R4 than seed-applied inoculant and AMS application prior to emergence at Wanatah and West Lafayette in 2018. Protein improvements in combination with yield improvements at these locations were more modest to no change. These studies are being repeated in 2019 to confirm repeatability and fine-tune recommendations.

Sulfur Synergies in Soybean Management

We documented the first yield response of soybean to S in 2015 near LaCrosse Indiana (6 bu/ac as a rescue treatment). It was a sandy loam field with ~2.5% organic matter. In the same region of the state, we applied various S treatments in 2016 and 2017 with the highest yield responses to broadcast applications of 20 lb S/ac (granular fertilizer): 12.5 bu/ac in 2016 and 13 bu/ac in 2017 (Figure 1). Foliar S applications have shown some promise with 6 to 10 bu/ac responses in 2016 and 4 to 7 bu/ac responses in 2017.

Figure 1. Soybean plant on the left is well nodulated due to the application of 20 lb S/ac prior to planting; whereas, the plant on the right is poorly nodulated (i.e., no S applied). Picture taken Sept. 11, 2017 near La Crosse Indiana.

Current soil nutrient analyses can provide S concentration, but the correlation to crop need and yield response is unreliable due to the timing of the soil analyses and the mobility of S in the soil (sulfate movement is somewhat similar to nitrate leaching). Leaf nutrient analyses can provide a snapshot that S may be an issue. For example, the sulfur concentration in our untreated control in 2016 was 0.27% S at R3, which is not "deficient" but it is close (critical level is 0.25% S). Another indicator of S issues is the ratio of nitrogen to S in the leaf tissue. As this level approaches 18:1 (18 parts N to 1 part S), soybeans will be more responsive to S application. The "normal" N:S ratio of soybean is near 15:1.

Figure 2. Soybean on the left were not treated with S. The leaves contained 0.27% S with N:S ratio of 18:1. Soybeans on the right were treated with 20 lb S/ac from AMS at PRE. Their leaves contained 0.38%S with N:S ratio of 15:1. Pictures were July 15, 2016 near La Crosse Indiana.

OBJECTIVES

Our research aims to find synergies in soybean management to optimize S applications (where needed) for yield and quality responses. Our objectives are to:

1. Determine management practices to alleviate S deficiency of soybean in the most responsive and cost-effective manner,
2. Characterize the physiological changes that have improved soybean grain yield and quality in response to S applications.

MATERIALS AND METHODS

Sulfur Source: *Untreated + 6 Dry + 2 Liquid = 9 Treatments*
The sulfur-deficient field near LaCrosse was selected for this trial. The previous crop was corn, and the field was not tilled. Pioneer 27T59R2 seed was treated with fungicide, insecticide, and inoculant. It was planted May 11, 2018 in 15-in rows. All sulfur sources, except the foliar treatment, were broadcasted or sprayed at 20 lb S/ac on May 16, 2018, which was prior to soybean emergence.

Six dry materials were broadcast spread and evaluated: ammonium sulfate (AMS), MES10, Gypsum (pelletized), K-Mag, Elemental Sulfur (Tiger 90CR), and AMS:ES (50-50 blend). Ammonium thiosulfate (ATS) was broadcast sprayed without herbicide. The second liquid treatment was a foliar application of spray grade AMS at R3 at 5 lb S/ac. Both liquid applications were at 15 GPA. An untreated control was also be included. These 9 treatments were replicated five times in a randomized complete block design (RCBD). Plots were 10-ft wide (eight 15-in rows) x 45 ft in length.

Whole plant samples were collected at R8 (maturity) to “map” nodal development, branching, pod distribution, and seed size on these treatments. Yield was determined with small plot harvest on Oct 9, 2018. Grain subsamples were collected to determine seed size, nutritional content, protein, and oil.

Foliar Sulfur Rates: *Untreated + (3 Timings x 4 S Rates) + Standard = 14 Treatments*
The sulfur-deficient field near LaCrosse was selected for this trial. The previous crop was corn, and the field was not tilled. Pioneer 27T59R2 seed was treated with fungicide, insecticide, and inoculant. It was planted May 11, 2018 in 15-in rows. The standard sulfur treatment was granular AMS at 20 lb S/ac. It was broadcasted on May 16th, which was prior to soybean emergence. Three foliar targets were V4, R3, and V4 + R3 (sequential). Four sulfur rates were 1, 2, 4, and 6 lb of S/ac at each growth stage, so the sequential applications (V4 + R3) would total 2, 4, 8, and 12 lb S/ac. Spray-grade AMS was dissolved in water (15 GPA). Untreated control represented the zero rate for each of the rate responses. Application dates were June 26th to V6 soybean and July 17th to R3 soybean. These treatments were replicated five times in a randomized complete block design (RCBD). Plots were 10-ft wide (eight 15-in rows) x 45 ft in length.

Most recent mature leaves were taken 10-14 days after the application (~ R3 and ~R5) for all treatments to determine nutritional status. Yield was determined with small plot harvest on Oct 9, 2018. Grain subsamples were collected to determine seed size, nutritional content, protein, and oil.

Management Synergies (two studies and two locations each):
The Inoculant Study had 2 varieties x 4 inoculant-broadcast combinations, which were untreated, seed-applied inoculant, AMS (20 lb S/ac) prior to emergence, and the combination of seed-applied inoculant + AMS to total 8 treatments. These treatments were replicated five times in a randomized complete block design (RCBD). Plots were 7.5-ft wide (six 15-in rows) x 40 ft in length. Asgrow 24X7 and Asgrow 34X6 were planted at West Lafayette on May 17, 2018 and at Wanatah on May 25, 2018. The previous crop was corn for both locations and the fields were

chiseled in the fall and leveled with field cultivation in the spring. Yield was determined with small plot harvest on Oct 3rd at West Lafayette and Oct 18th at Wanatah. Grain subsamples were collected to determine seed size, nutritional content, protein, and oil.

The Sulfur x Foliar Protection Study had 2 Sulfur Timings (V4 Foliar S application, AMS prior to emergence) x 2 Foliar Protection (none, fungicide + insecticide) plus untreated control to total 5 treatments. These treatments were replicated five times in a randomized complete block design (RCBD). Plots were 10-ft wide (four 30-in rows) x 40 ft in length. Pioneer 38A98X was planted in 30-in rows at West Lafayette on May 17, 2018. Pioneer 31A22X was planted in 30-in rows at Wanatah on May 25, 2018. The previous crop was corn for both locations and the fields were chiseled in the fall and leveled with field cultivation in the spring. Yield was determined with small plot harvest on Oct 3rd at West Lafayette and Oct 17th at Wanatah. Grain subsamples were collected to determine seed size, nutritional content, protein, and oil.

RESULTS FROM 2018

Sulfur Source

Soybeans were most responsive to granular AMS, MES10, and Gypsum at our S-deficient site (LaCrosse, IN) in 2018 (Table 1). Yield improvements were ~10 bu above the untreated (62.4 bu/ac). The remaining S sources also improved yield (5.5 to 7 bu), except elemental S (Tiger 90CR). Interestingly, the protein concentration also increased 2 percentage points with the S sources (~34%) compared to the untreated (~32%). Increased yield and grain protein rarely coincide, so this an exciting discovery in increasing yield and quality. Conversely, the oil concentration did decrease as the S sources improved the protein.

The yield component with the most dramatic improvement due to S applications was the size of the seed. Similarly to overall yield, seed size was greatest for AMS, MES10, and Gypsum ranging from 16.9 to 17.3 g/100 seeds. The untreated controls were 15.2 to 15.5 g/100 seeds with the remaining S sources nearly 16 g/100 seeds). The total node and pod production also followed this trend numerically with about 1.5 more trifoliate nodes produced per plant and ~5 to 10 more pods per plant when compared to the untreated.

Table 1. The responses of soybean yield, seed size, protein, oil, nodes, mainstem pods, branch pods, and total pods to seven different sulfur sources at 20 lb S/ac and one foliar application at 5 lb S/ac at R3. Trial was at a S-deficient site near LaCrosse, Indiana in 2018. Adjusted to 13% grain moisture basis.

Treatment	Yield	Seed Size	Protein	Oil	Nodes	Main Pods	Br. Pods	Total Pods
	bu/ac	g/100 sd	%	%	$plant^{-1}$	$plant^{-1}$	$plant^{-1}$	$plant^{-1}$
Untreated	62.4 d	15.5 ef	32.1 c	22.2 a	13.5	22.8	14.1	37.4
AMS	72.0 ab	17.3 a	34.0 a	21.1 bc	15.1	28.8	14.0	42.1
MES10	73.4 a	17.2 ab	34.0 a	21.1 bc	15.0	32.6	13.9	47.3
Gypsum	72.8 ab	16.9 abc	34.0 a	20.9 c	13.6	29.2	14.9	45.1
K-Mag	67.9 bc	16.1 de	33.8 a	21.1 bc	14.2	25.5	15.1	41.6
Tiger 90CR	65.5 cd	16.2 cd	33.3 b	21.3 b	15.3	28.6	18.8	47.4
AMS:Tiger	68.7 abc	16.5 bcd	33.9 a	21.1 bc	12.6	26.0	19.3	45.9
Spray ATS	68.7 abc	16.3 cd	34.1 a	21.0 bc	14.8	28.5	14.7	43.4
R3 Foliar	69.4 abc	16.2 cde	34.0 a	21.2 bc	14.6	28.5	15.1	43.8
Untreated 2	60.9 d	15.2 f	31.8 c	22.5 a	13.2	26.5	17.1	43.9
$LSD_{0.05}$	***	***	***	***	NS	NS	NS	NS
CV(%)	5.9	3.7	1.0	1.2	12.6	17.4	32.9	15.8

Significance at alpha = 0.10, 0.05, 0.01, and 0.0001 are represented by X, *, **, and ***, respectively. NS, no significance. Means followed by the same letter do not differ from each other.

Figure 3. Subset of sulfur sources applied to soybean in 2018 near La Crosse Indiana. UTC is untreated. The remaining treatments were AMS, MES10, Gypsum, K-Mag, and ATS applied at 20 lb S/ac prior to soybean emergence. Notice the plant height and root systems of AMS and MES10 in particular. Picture taken on July 11, 2018.

Foliar Sulfur Rates

Leaf S concentrations plateaued near 0.35% S as the foliar S rate increased to 4 lb S/ac from the V6 application (Figure 4). The pre-emergence application of AMS had the highest leaf S concentration with 0.40% S. Another means of determining the potential response of soybeans to S application is the nitrogen to S ratio (N:S) in the leaves. In recent years, we have used leaf N:S of 18:1 or higher to predict a S-responsive situation. The N:S ratio of untreated control was 17:1 and it reduced to 15:1 as the foliar S rate increased to 4 lb S/ac. The highest rate of 6 lb S/ac did not improve the leaf S concentration nor the leaf N:S ratio. It is likely that any yield response to these applications will be closer to 4 lb S/ac than the 6 lb S/ac. Interestingly, the leaf N:S ratio of the preemergence AMS was much lower than the foliar S applications (13.5 vs. 15:1 at best, Figure 5).

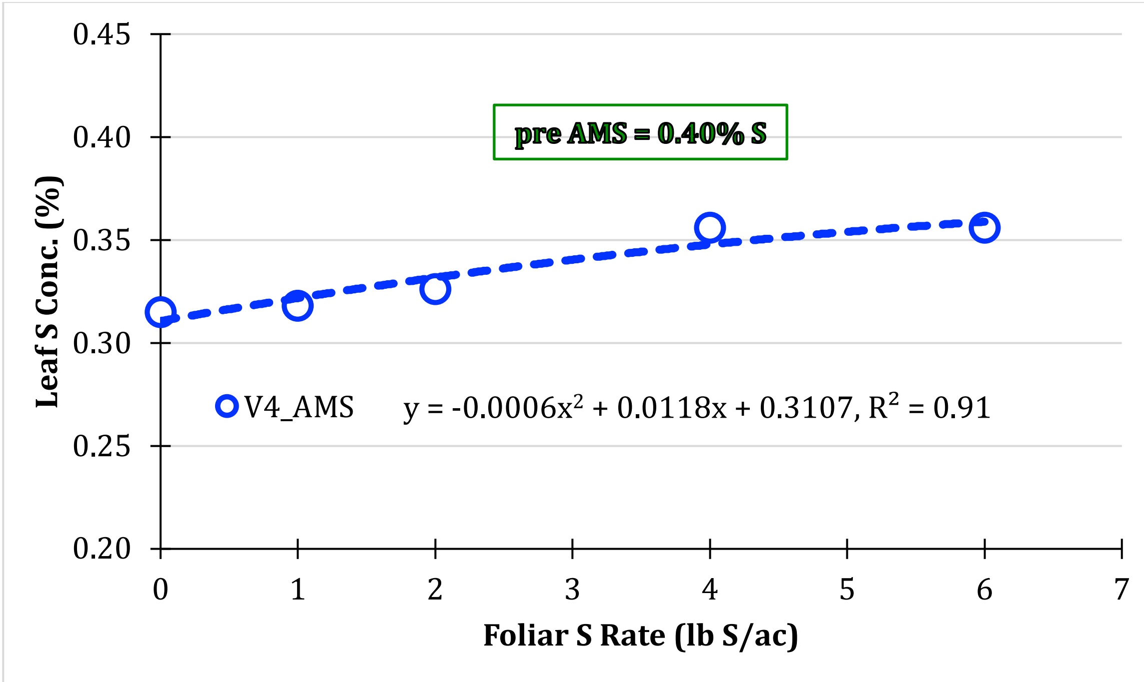

Figure 4. Sulfur concentration of soybean leaves 14 days after foliar S applications were made at V6 growth stage at LaCrosse, Indiana (sulfur-deficient site) in 2018. Spray grade AMS was dissolved to obtain 1, 2, 4, and 6 lb S/ac and applied at 15 GPA. Pre-AMS was granular AMS broadcast applied prior to emergence at 20 lb S/ac.

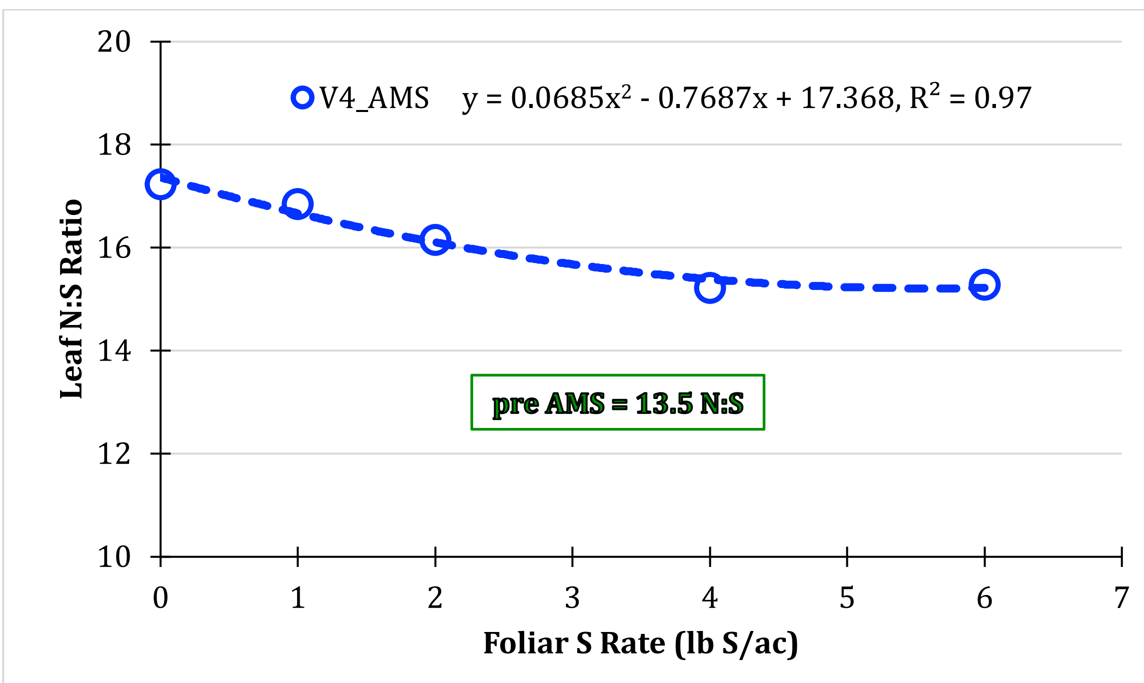

Figure 5. Ratio of nitrogen to sulfur in soybean leaves 14 days after foliar S applications were made at V6 growth stage at LaCrosse, Indiana (sulfur-deficient site) in 2018. Spray grade AMS was dissolved to obtain 1, 2, 4, and 6 lb S/ac and applied at 15 GPA. Pre-AMS was granular AMS broadcast applied prior to emergence at 20 lb S/ac.

Soybean response to foliar applications of S were similar for the V4 (actually V6) and R3 (first pod) timing at LaCrosse Indiana in 2018 (Figure 6). The optimal rate was 4 lb S/ac for the single application timing regardless if it was V4 or R3 with 9.1 and 8.4 bu/ac improvement, respectively. The highest S rate of 6 lb S/ac did cause some crop phytotoxicity, which is reflected in the slight yield suppression. The sequential application of foliar S at V4 and R3 did not increase yields above single application timings of V4 or R3. The benchmark application of 20 lb S/ac prior to emergence with granular AMS yielded 68.9 bu/ac, which was 13 bu higher than the untreated (55.9 bu/ac).

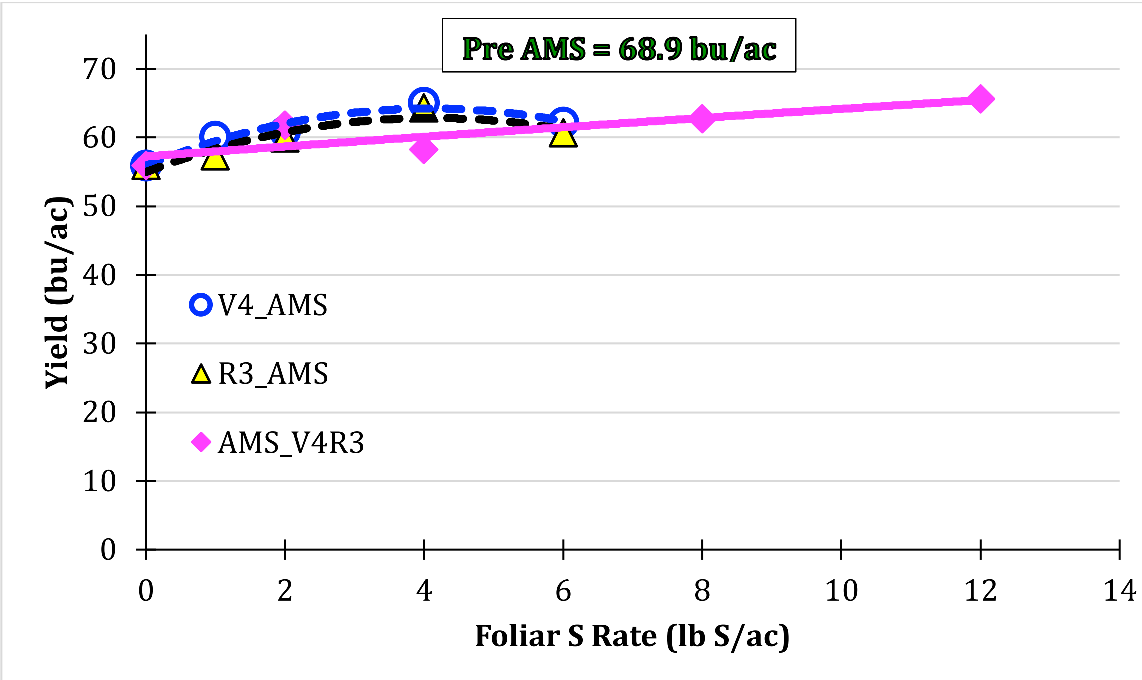

Figure 6. Soybean Yield (bu/ac) response to total foliar sulfur rates at V4, R3, and V4 + R3 at LaCrosse, Indiana (sulfur-deficient site) in 2018. Spray grade AMS was dissolved to obtain 1, 2, 4, and 6 lb S/ac and applied at 15 GPA. Pre-AMS was granular AMS broadcast applied prior to emergence at 20 lb S/ac.

As noted in the previous study of S sources, the concentration of protein in the seed improved with the supply of S. The untreated or the zero rate of S was ~33% protein and it improved in a stepwise fashion as more S was supplied at V4, R3, and the combination of foliar sprays (Figure 7). The maximum protein improvement was ~1.5 to 2.0 percentage points to nearly 35% protein with foliar sprays and the standard pre-AMS application of 20 lb S/ac. Yield and protein improvements were once again coupled, whereas, oil concentration decreased from 23 to 21.5% as S supplied increased (Figure 8).

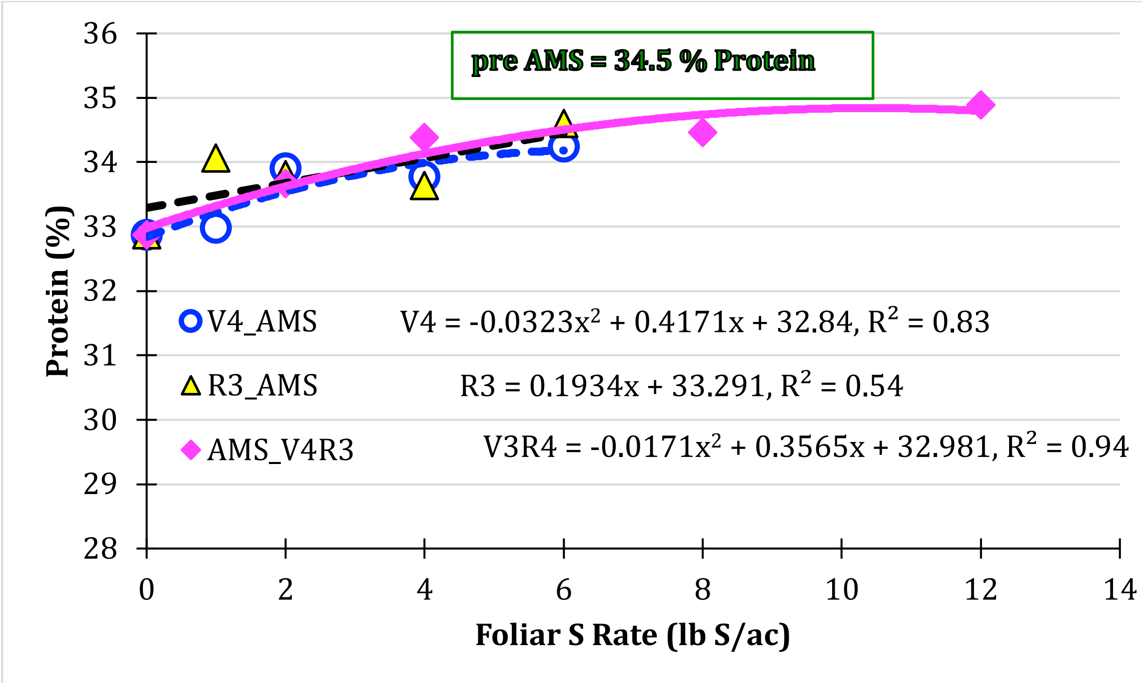

Figure 7. Soybean Protein (%) response to total foliar sulfur rates at V4, R3, and V4 + R3 at LaCrosse, Indiana (sulfur-deficient site) in 2018. Spray grade AMS was dissolved to obtain 1, 2, 4, and 6 lb S/ac and applied at 15 GPA. Pre-AMS was granular AMS broadcast applied prior to emergence at 20 lb S/ac. Adjusted to 13% grain moisture basis.

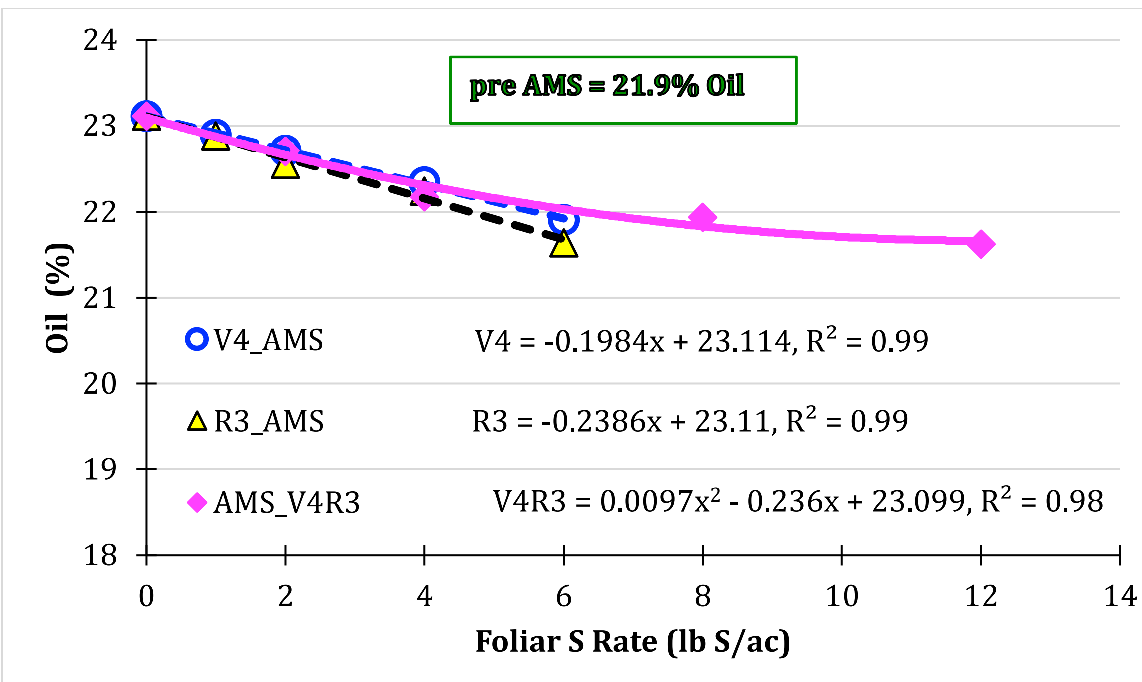

Figure 8. Soybean Oil (%) response to total foliar sulfur rates at V4, R3, and V4 + R3 at LaCrosse, Indiana (sulfur-deficient site) in 2018. Spray grade AMS was dissolved to obtain 1, 2, 4, and 6 lb S/ac and applied at 15 GPA. Pre-AMS was granular AMS broadcast applied prior to emergence at 20 lb S/ac. Adjusted to 13% grain moisture basis.

Management Synergies:

Inoculant-Sulfur. The addition of seed-applied inoculant did not improve the yields with or without AMS application across two varieties and two locations in 2018 (Table 2). However with the addition of AMS (20 lb S/ac), the two varieties yielded 5 to 6.5 bu/ac more at Wanatah and ~2.5 bu/ac at West Lafayette in 2018.

Table 2. Soybean yield response to AMS and inoculant (seed-applied) to two varieties (AG24X7, AG34X6) near Wanatah and West Lafayette in 2018.

			Wanatah		West Lafayette	
Treatment	**Inoculant**	**AMS**	**AG24X7**	**AG34X6**	**AG24X7**	**AG34X6**
		lb S/ac	**bu/ac**		**bu/ac**	
UTC	.	.	59.1	60.2	64.3	64.7
Seed	X	.	58.3	60.1	61.1	65.6
AMS	.	20	65.6	65.2	66.4	67.6
Seed+AMS	X	20	67.5	65.0	65.9	67.1

Sulfur Timing x Foliar Protection. At Wanatah (Pinney PAC) in 2018, the foliar application of S at V4 did not improve yields, but the pre-AMS application numerically increased yield 3 bu/ac. Marginal improvements were seen in the seed size and the protein concentration. The largest improvement was the combination of V4 S and R4 foliar protection of over 7 bu/ac and nearly one percentage point of protein (Table 3).

At West Lafayette (ACRE) in 2018, the foliar application of S at V4 improved yield 5.6 bu/ac with a modest improvement seed size (Table 4). The addition of foliar protection (Priaxor and Fastac) at R4 did not improve the yield response in the presence of V4 S application. Whereas, the AMS application prior to emergence increased yields ~6 bu at West Lafayette. The R4 foliar protection added another 3 to 4 bu when it followed the AMS preemergence application. It seems there is some synergy with the base application of AMS prior to emergence followed by the foliar protection at R4. Seed size increased from 16.6 g/100 seeds with the untreated to 17.2 g/100 seeds with the pre-AMS and finally to 17.6 g/100 seeds with the full combination. This combination needs to be separated to determine if it is related to the fungicide or insecticide or the combination. Adding other fungicides and insecticides would be another consideration. Protein concentration was not affected (Table 4).

Table 3. Soybean Yield, Seed Weight, and Protein responses to sulfur-based management combinations applied near Wanatah (Pinney PAC) in 2018 (subset of treatments). Variety P31A22X was treated with insecticide and fungicide. Full Kitchen Sink also has in-furrow application of O-Phos, broadcast application of 0-45-0, foliar feeding at V4, and plant growth regulator at R2. All data adjusted to 13% grain moisture.

Pinney 2018	**Sulfur**	**R4 Foliar**	**Yield**	**Seed Weight**	**Protein**
Treatment		**Protection**	bu/ac	g /100 sd	%
Untreated	.	.	68.6	19.2	33.0
V4 Sulfur	5 lb S @ V4	.	69.5	19.6	33.4
V4 S + Priaxor-Fastac	5 lb S @ V4	Priaxor, Fastac	76.0	19.4	33.9
AMS	20 lb S @ PRE	.	71.9	19.3	33.8
AMS + Priaxor-Fastac	20 lb S @ PRE	Priaxor, Fastac	71.8	19.8	33.6
Full Kitchen Sink	20 lb S @ PRE	Viathon, Sultrus	72.3	20.2	34.1

Table 4. Soybean Yield, Seed Weight, and Protein responses to sulfur-based management combinations applied near West Lafayette (ACRE) in 2018 (subset of treatments). Variety P38A98X was treated with insecticide and fungicide. Full Kitchen Sink also has in-furrow application of O-Phos, broadcast application of 0-45-0, foliar feeding at V4, and plant growth regulator at R2. All data adjusted to 13% grain moisture.

W. Lafayette 2018	Sulfur	R4 Foliar	Yield	Seed Weight	Protein
Treatment		Protection	bu/ac	g /100 sd	%
Untreated	.	.	57.0	16.6	34.8
V4 Sulfur	5 lb S @ V4	.	62.6	17.0	34.8
V4 S + Priaxor-Fastac	5 lb S @ V4	Priaxor, Fastac	63.3	16.9	34.8
AMS	20 lb S @ PRE	.	62.8	17.2	35.1
AMS + Priaxor-Fastac	20 lb S @ PRE	Priaxor, Fastac	65.8	17.6	34.6
Full Kitchen Sink	20 lb S @ PRE	Viathon, Sultrus	67.7	17.5	34.6

COMMUNICATION

Preliminary results from the 2016 and 2017 seasons have already been shared across Indiana. The results from 2018 studies have been shared throughout the 2018-19 Extension winter workshops, meetings, and conferences of producers, Extension educators, and crop professionals across Indiana. Conclusions from the experiments in 2018 and 2019 will be shared with Extension audiences in presentations, newsletter articles, and Web sites. We will also share these findings at the American Society of Agronomy meetings. Our preliminary studies have indicated the protein concentration is also improved with our S applications. Thus, we could also provide an underpinning for management strategies to maintain yield and improve quality.