Year Two Research Update to the Michigan Soybean Promotion Committee 2nd Year - 2020

Evaluating Sulfur Fertilizer Products and Timing in Soybeans by Management Zones

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MSPC Priority Area: Resource Limitations – Nutrients

Procedures

Field trials were conducted in three locations in south central Michigan. This is the second year of the two-year study (2019 & 2020) with an optional third year based on early results. Treatments include three pre-plant applications, one in-season application, and a control. The pre-plant applications were dry ammonium sulfate (AMS) at 100 lb/ac or 24 lb S/ac, dry potassium magnesium sulfate (KMag) at 100 lb/ac or ~23 lb S/ac, and liquid ammonium thio sulfate (ATS) at 8 gal/ac or 23 lb S/ac. The in-season application was dry AMS at 100 lb/ac spread at the V3 to V4 growth stage. The fields have at least two management zones. The experiments were established with a randomized complete block design, with five treatments, and a minimum of three replications. The plots were field sized; length of field by 80 feet wide. The exact size of the individual plots was determined by the field and equipment size. The beans were planted in 15" rows.

- The first plot (Plot#1) was located in Hillsdale county Michigan, Allen Township, Section 3. This was a dryland sandy loam field in a soybean following corn rotation. It was planted on May 3, 2020 with a Case-IH 2140 Early Riser 15" planter. Each individual plot is 80 foot wide and the full length of the field. The seeding rate was based on a variable rate application (VRA) planting prescription with an average of 140,530 seeds per acre. The grower's normal dry fertilizer blend was spring applied on March 18, 2020. The normal blend contained KMag and was applied VRA across the field. Since the blend was variable rate the management zones received a range of 21 to 28 lb of sulfur per acre with an average of 24.5 lb of sulfur per acre. Having an average additional 24.5 lb/ac of sulfur spring applied in this field may affect the treatment responses to the sulfur treatments. The pre-plant application of AMS and K-Mag were applied on April 22, 2020. Pre-Plant ATS was applied on April 22, 2020. The in-season AMS application was applied at V3 growth stage on June 19, 2020.

- The second plot (Plot #2) was located in Branch county Michigan, Union Township, Section 13. This was a dryland sandy loam field in a soybean following corn rotation. It was planted on May 9, 2020 with the growers John Deere, 1790 JD CCS, 15" planter. Each individual plot was 80 foot wide and the full length of the field. The seeding rate was based on a variable rate application (VRA) planting prescription with an average of 130,460 seeds per acre. The pre-plant application of AMS and K-Mag were applied on April 16, 2020. Pre-Plant ATS was applied on April 24, 2020. The in-season AMS application was applied at V3 growth stage on June 26, 2020.

- The third plot (Plot #3) was located in Branch county Michigan, California Township, Section 16. This was a dryland sandy loam field in a soybean following soybean rotation. It was planted on April 28, 2020 with a Case-IH 2140 Early Riser 15" planter. Each individual plot was 80 foot wide and the full length. The seeding rate was based on a variable rate application (VRA) planting prescription with an average of 137,610 seeds per acre. The pre-plant application of AMS and K-Mag were applied on April 20, 2020. Pre-Plant ATS was applied on April 22, 2020. The in-season AMS application was applied at V3 growth stage on June 19, 2020.

Treatments

1. Pre-Plant AMS 100 lb/ac
2. Pre-Plant K-Mag 100 lb/ac
3. Pre-Plant ATS 8 gal/ac
4. In-Season V3-V4 AMS 100 lb/ac
5. Control

The treatments were designed to determine if sulfur fertilizer should be applied to the soybean crop in Michigan to increase yields and profitability. It will be determined if the type or timing of sulfur fertilizer changes the yield or economic response. Further it will be determined whether sulfur tissue levels in the plant can be improved with the sulfur applications. It will also compare the response by management zones to determine if variable rate application (VRA) of sulfur may improve economics. Analyzing the yield data by management zone will help determine if certain soil types are more responsive to the sulfur applications.

Evaluation

Several soil and plant measurements were taken to help evaluate the sulfur applications.

Data Collection

1. Stand counts
   A. By treatment
2. Soil test sulfur
   A. In spring prior to sulfur application
   B. By rep
   C. By management zones
3. Plant tissue analysis N & S Only
   A. R2 upper trifoliate tissue analysis
   B. R5 upper trifoliate tissue analysis
   C. Two subsamples per plot
   D. By treatment
   E. By two major management zones

4. Aerial or Drone imagery
    A. Imagery at least three times during the growing season
5. Yield analysis
    A. By treatment
    B. By management zones
6. Economic analysis
    A. By treatment
    B. By management zones

Stand Count

Soybean population stand counts were collected between June 3rd and June 17th at all three locations using the hula hoop method. Data was collected in two major management zones for each of the treatments: a lower target population zone and a higher target population zone. A minimum of ten sub counts were taken in each plot and zone.

The population in Plot #1 was measured on June 17th. Data was collected in two major management zones for each of the treatments. In rep one counts were done in E-L (130K) and C-H (160K) zones. In rep two counts were done in D-L (115K) and C-H (160K) zones. In rep three counts were done in A-L (115K), B-H (155K) and C-H (160K) zones. The population stand counts in Plot #1 averaged 141,355 plants per acre, which averaged 102% of the target across the zones (Table 1). There were no differences in final populations amongst the sulfur treatments or the control. The control averaged 139,889 plants per acre and the sulfur treatments were all within approximately 4200 or less plants per acre. The planter did overplant compared to the target prescriptions and more so in the lower population zones, but it was consistent across all treatments.

Table 1: Plot #1 2020 Soybean Plant Populations by Management Zone

	Zone	Avg Pl/ac	Target	% of Target	Average
Pre-Plant AMS 100lb/ac	**A-L/ D-L**	130,389	115,000	113%	**139,597**
	E-L	129,000	130,000	99%	
	B-H	140,000	155,000	90%	
	C-H	159,000	160,000	99%	
Pre-Plant K-Mag 100lbs/ac	**A-L/ D-L**	132,778	115,000	115%	**141,694**
	E-L	129,000	130,000	99%	
	B-H	143,333	155,000	92%	
	C-H	161,667	160,000	101%	
Pre-Plant ATS 8gal/ac	**A-L/ D-L**	124,000	115,000	108%	**141,500**
	E-L	127,000	130,000	98%	
	B-H	154,000	155,000	99%	
	C-H	161,000	160,000	101%	
In-Season V3-V4 AMS 100lb/ac	**A-L/ D-L**	124,037	115,000	108%	**144,093**
	E-L	135,000	130,000	104%	
	B-H	157,000	155,000	101%	
	C-H	160,333	160,000	100%	
Control	**A-L/ D-L**	128,000	115,000	111%	**139,889**
	E-L	128,000	130,000	98%	
	B-H	145,556	155,000	94%	
	C-H	158,000	160,000	99%	

The population in Plot #2 was measured on June 17th. Data was collected in two major management zones for each of the treatments. In rep one counts were done in A-L (110K) and B-H (135K) zones. In rep two counts were done in C-L (120K) and B-H (135K) zones. In rep three counts were done in C-L (120K) and D-H (145K) zones. The population stand counts in Plot #2 averaged 127,940 plants per acre, which averaged 100% of the target across the zones (Table 2). There were no major differences in final populations amongst the sulfur treatments or the control. The control averaged 127,915 plants per acre and the sulfur treatments were all within approximately 1,100 or less plants per acre.

Table 2: Plot #2 2020 Soybean Plant Populations by Management Zone					
	Zone	**Avg Pl/ac**	**Target**	**% of Target**	**Average**
Pre-Plant AMS 100lb/ac	**A-L**	105,000	110,000	95%	**126,977**
	C-L	123,500	120,000	103%	
	B-H	135,773	135,000	101%	
	D-H	143,636	145,000	99%	
Pre-Plant K-Mag 100lbs/ac	**A-L**	104,000	110,000	95%	**127,841**
	C-L	124,000	120,000	103%	
	B-H	134,364	135,000	100%	
	D-H	149,000	145,000	103%	
Pre-Plant ATS 8gal/ac	**A-L**	109,000	110,000	99%	**127,875**
	C-L	118,500	120,000	99%	
	B-H	134,000	135,000	99%	
	D-H	150,000	145,000	103%	
In-Season V3-V4 AMS 100lb/ac	**A-L**	111,000	110,000	101%	**129,091**
	C-L	120,500	120,000	100%	
	B-H	133,864	135,000	99%	
	D-H	151,000	145,000	104%	
Control	**A-L**	110,000	110,000	100%	**127,915**
	C-L	123,364	120,000	103%	
	B-H	133,750	135,000	99%	
	D-H	144,545	145,000	100%	

The population in Plot #3 was measured on June 3rd. Data was collected in two major management zones for each of the treatments. Counts were done in A-L (115K), C-H (140K) and B-H (165K) zones. The population stand counts in Plot #3 averaged 156,589 plants per acre, which averaged 112% of the target across the zones (Table 3). There were no major differences in final populations amongst the sulfur treatments or the control. The control averaged 156,589 plants per acre and the sulfur treatments were all within approximately 3700 or less plants per acre. The planter did overplant compared to the target prescriptions and more so in the lower population zones, but it was consistent across all treatments.

Table 3: Plot #3 2020 Soybean Plant Populations by Management Zone					
	Zone	**Avg Pl/ac**	**Target**	**% of Target**	**Average**
Pre-Plant AMS 100lb/ac	**A-L**	131,111	115,000	114%	
	C-H	158,125	140,000	113%	**157,894**
	B-H	184,444	165,000	112%	
Pre-Plant K-Mag 100lbs/ac	**A-L**	131,102	115,000	114%	
	C-H	155,741	140,000	111%	**155,309**
	B-H	179,083	165,000	109%	
Pre-Plant ATS 8gal/ac	**A-L**	135,046	115,000	117%	
	C-H	153,611	140,000	110%	**157,052**
	B-H	182,500	165,000	111%	
In-Season V3-V4 AMS 100lb/ac	**A-L**	132,389	115,000	115%	
	C-H	146,607	140,000	105%	**154,480**
	B-H	184,444	165,000	112%	
Control	**A-L**	133,542	115,000	116%	
	C-H	158,083	140,000	113%	**158,208**
	B-H	183,000	165,000	111%	

Soil Sulfur Samples

Soil sulfur samples were collected by replication per soil management zone. A high ground (–H) and low ground (-L) management zone were selected. The samples for each plot were collected in management zones prior to the sulfur applications or in treatments where the sulfur applications had not yet been applied. The samples were collected using a soil probe to the depth of 6 2/3 inches. Twelve cores were collected for each sample. The samples were analyzed for sulfur with Mehlich III extractable by Brookside Laboratories in New Bremen, Ohio.

In Plot #1 soil samples for sulfur were collected on April 23, 2020. Plot #1 averaged 11 ppm of sulfur in the soil tests (Table 4). The samples ranged from a low of 9 ppm to a high of 13 ppm. Levels below 10 ppm would be considered very low. There was a slight trend in sulfur levels by management zones. The high ground sample zones averaged 10.3 ppm, while the low ground was slightly higher at 11.7 ppm. The average total exchange capacity (TEC) and organic matter across these management zones is 7.19 and 1.90%, respectively. The higher sulfur ppm levels in this field are not likely solely due to the spring fertilizer blend having sulfur in it; because the history of previous years (2014, 2016, 2018) soil test averaged about 9.5 ppm.

Table 4: Plot #1 2020 Sulfur Soil Test Analysis - Spring				
	Soluble Sulfur (ppm)			
Zone	**Rep 1**	**Rep 2**	**Rep 3**	**Average**
A-L			10	**10.0**
B-H			11	**11.0**
C-H	10	9	11	**10.0**
C-H2	9	11		**10.0**
D-L		12		**12.0**
E-L	13			**13.0**

In Plot #2 soil samples for sulfur were collected on April 21, 2020. Plot #2 averaged 6.6 ppm of sulfur in the soil tests (Table 5). The samples ranged from a low of 5 ppm to a high of 8 ppm. Levels below 10 ppm would be considered very low. The high ground sample zones averaged 6.8 ppm, while the low ground zones averaged 6.5 ppm. Overall soil sulfur levels are very low. The average TEC and organic matter across these management zones is 9.18 and 2.33%, respectively.

Table 5: Plot #2 2020 Sulfur Soil Test Analysis - Spring				
	Soluble Sulfur (ppm)			
Zone	**Rep 1**	**Rep 2**	**Rep 3**	**Average**
A-L	7			**7.0**
B-H	7	8		**7.5**
C-L	6	7	5	**6.0**
D-H		6	6	**6.0**

In Plot #3 soil samples for sulfur were collected on April 21, 2020. Plot #3 averaged 6.1 ppm of sulfur in the soil tests (Table 6). The samples ranged from a low of 5 ppm to a high of 8 ppm. Levels below 10 ppm would be considered very low. There was a trend in sulfur levels by management zones. The high ground sample zones averaged 5.7 ppm, while the low ground was higher at 7.0 ppm. The average TEC and organic matter across these management zones is 8.67 and 2.32%, respectively.

Table 6: Plot #3 2020 Sulfur Soil Test Analysis - Spring				
	Soluble Sulfur (ppm)			
Zone	**Rep 1**	**Rep 2**	**Rep 3**	**Average**
A-L	8	8	5	**7.0**
B-H	6	5	6	**5.7**
C-H	5	6	6	**5.7**

Plant Tissue Analysis – Nitrogen & Sulfur

Plant tissue samples for nitrogen and sulfur analysis were collected by treatment in two major management zones. At each sample location there were two subsamples collected. Tissue sample collection was completed by pulling the upper most fully developed trifoliate. Fifteen trifoliates were pulled for each sample collected. Samples were collected at the R2 and R5 growth stages. The samples were analyzed for nitrogen and sulfur with a Thermo Duo ICP by Brookside Laboratories in New Bremen, Ohio. According to a document by Purdue University, the N:S ratio of plant tissue as well as the sulfur concentration can be used to identify deficiencies or differences in the plant. The document stated "In the plant, S is a component of two amino acids and occurs in protein in a ratio of 1 part S to about 15 parts N. The lower the S concentration and the higher the N:S ratio the more likely S is deficient in the plant." (https://www.agry.purdue.edu/ext/corn/news/timeless/sulfurdeficiency.pdf).

In Plot #1 tissue samples for nitrogen and sulfur were collected at the R2 growth stage on July 13, 2020. The pre-plant sulfur applications resulted in a small increase of sulfur concentration in the plant and an improvement in the N:S ratio (Table 7). In comparing the pre-plant sulfur products, the AMS and ATS were similar averaging around 0.39% while the check was 0.327%. This was only about a 3.8% increase in sulfur concentrations levels compared to the check. The K-Mag was slightly behind the other products averaging 0.331% sulfur. The in-season V3 timing of AMS also improved sulfur concentration levels compared to the check but only by 3.9%, average 0.339% sulfur. A lower N:S ratio was achieved with the sulfur applications; averaging 17.7 compared to 18.5 in the check. The timing of AMS did not affect the sulfur concentration levels or the N:S ratio. Although all sulfur treatments also improved sulfur concentration levels in the plant and the N:S ratio compared to the check, the differences were small. This plot likely had a lower overall percent increase in sulfur concentrations compared to the check due to the additional spring sulfur application in the normal dry fertilizer blend of 24 lb S/ac and the higher sulfur soil test levels. There was no major difference in average nitrogen concentration levels in the plant with the sulfur treatments compared to the check.

Table 7: Plot #1 2020 Soybean Nitrogen and Sulfur Tissue Analysis at R2 Growth Stage on July 13th

	Zone	Nitrogen (%)	Sulfur (%)	N:S Ratio	Avg N (%)	Avg S (%)	Avg N:S Ratio	% Inc vs Control
Pre-Plant AMS 100lb/ac	**A-L/D-L/E-L**	5.86	0.337	17.4	**6.12**	**0.338**	**18.1**	**3.4%**
	B-H/C-H	6.39	0.339	18.9				
Pre-Plant K-Mag 100lbs/ac	**A-L/D-L/E-L**	5.58	0.331	16.8	**5.90**	**0.331**	**17.8**	**1.4%**
	B-H/C-H	6.23	0.332	18.8				
Pre-Plant ATS 8gal/ac	**A-L/D-L/E-L**	5.44	0.345	15.8	**5.76**	**0.340**	**16.9**	**4.2%**
	B-H/C-H	6.08	0.336	18.1				
In-Season V3 AMS 100lb/ac	**A-L/D-L/E-L**	5.81	0.342	17.0	**6.06**	**0.339**	**17.9**	**3.9%**
	B-H/C-H	6.31	0.337	18.7				
Control	**A-L/D-L/E-L**	5.70	0.324	17.6	**6.04**	**0.327**	**18.5**	
	B-H/C-H	6.38	0.330	19.3				

In Plot #1 tissue samples for nitrogen and sulfur were collected at the R5 growth stage on August 17, 2020. The pre-plant sulfur applications did not have a consistent increase of sulfur concentration in the plant but did improve in the N:S ratio (Table 8). There was a slight difference in pre-plant products with the AMS being the best averaging 0.352% sulfur while the check averaged 0.340%, a 3.6% increase. The in-season V3 timing of AMS was not better than the pre-plant. The N:S ratio was improved with the sulfur applications compared to the check, however the K-Mag had only a very slight difference. The check plot averaged 0.34% sulfur compared to the three plot locations in 2019 which averaged 0.27%, indicating good levels of sulfur in the control treatment in this plot. This plot location likely had a low overall percent increase in sulfur concentrations compared to the check due to the additional spring sulfur application in the normal dry fertilizer blend of 24 lb S/ac and the higher sulfur soil test levels. There was no major difference in average nitrogen concentration levels in the plant with the sulfur treatments compared to the check.

Table 8: Plot #1 2020 Soybean Nitrogen and Sulfur Tissue Analysis at R5 Growth Stage on August 17th								
	Zone	Nitrogen (%)	Sulfur (%)	N:S Ratio	Avg N (%)	Avg S (%)	Avg N:S Ratio	% Inc vs Control
Pre-Plant AMS 100lb/ac	A-L/D-L/E-L	5.97	0.365	16.4	5.77	0.352	16.4	3.6%
	B-H/C-H	5.56	0.339	16.4				
Pre-Plant K-Mag 100lbs/ac	A-L/D-L/E-L	6.15	0.339	18.2	5.69	0.329	17.3	-3.3%
	B-H/C-H	5.23	0.319	16.4				
Pre-Plant ATS 8gal/ac	A-L/D-L/E-L	5.93	0.358	16.5	5.65	0.340	16.6	0.0%
	B-H/C-H	5.36	0.322	16.7				
In-Season V3 AMS 100lb/ac	A-L/D-L/E-L	6.00	0.359	16.7	5.64	0.345	16.3	1.5%
	B-H/C-H	5.28	0.332	15.9				
Control	A-L/D-L/E-L	6.31	0.361	17.5	5.95	0.340	17.5	
	B-H/C-H	5.60	0.319	17.6				

In Plot #2 tissue samples for nitrogen and sulfur were collected at the R2 growth stage on July 13, 2020. The pre-plant sulfur applications resulted in an increase of sulfur concentration in the plant and an improvement in the N:S ratio (Table 9). In comparing the pre-plant sulfur products, the AMS had higher sulfur concentrations averaging 0.355%, while the K-Mag and ATS were similar but averaged about 0.347%. These were all better than the check which averaged 0.336% sulfur in the tissue. The pre-plant AMS had an increase of 5.5% in sulfur concentration compared to the check, while the KMag and ATS were 3.0% and 2.8%, respectively. The timing of the AMS did not change the sulfur concentration at R2, however the N:S ratio was lower in the pre-plant timing. A lower N:S ratio was achieved with the pre-plant timing; averaging 16.6 compared to 17.8. The in-season application was applied on June 26th and R2 was reached 17 days later, perhaps more time was needed to effectively get more of the sulfur into the plant. The plot received 0.28 inches of rain the day of the in-season application, however the first significant rain of greater than one inch was not until 14 days later. There was not a difference from the sulfur treatments in nitrogen concentration levels in the plant compared to the check.

Table 9: Plot #2 2020 Soybean Nitrogen and Sulfur Tissue Analysis at R2 Growth Stage on July 13th								
	Zone	Nitrogen (%)	Sulfur (%)	N:S Ratio	Avg N (%)	Avg S (%)	Avg N:S Ratio	% Inc vs Control
Pre-Plant AMS 100lb/ac	B-L	5.69	0.36	16.0	5.89	0.355	16.6	5.5%
	C-H	6.09	0.35	17.2				
Pre-Plant K-Mag 100lbs/ac	B-L	5.72	0.34	16.7	5.71	0.347	16.5	3.0%
	C-H	5.69	0.35	16.3				
Pre-Plant ATS 8gal/ac	B-L	5.93	0.34	17.3	6.12	0.346	17.7	2.8%
	C-H	6.31	0.35	18.1				
In-Season V3 AMS 100lb/ac	B-L	6.13	0.35	17.6	6.28	0.354	17.8	5.1%
	C-H	6.43	0.36	18.0				
Control	B-L	5.87	0.33	17.7	6.14	0.336	18.2	
	C-H	6.40	0.34	18.7				

In Plot #2 tissue samples for nitrogen and sulfur were collected at the R5 growth stage on August 18, 2020. The pre-plant sulfur applications resulted in an increase of sulfur concentration in the plant and an improvement in the N:S ratio (Table 10). In comparing the pre-plant products, the AMS and KMag were similar; they averaged 0.383% (9.8% increase to check) and a N:S ratio around 17.6 while the ATS was behind with an average of 0.374% sulfur (7.2% increase to check) and an N:S ratio of 18.4. The check averaged 0.349% sulfur and an N:S ratio of 19.3. The in-season V3 timing of AMS also improved sulfur concentration levels compared to the check by 11.9%. The in-season AMS had a higher sulfur concentration averaging 0.390% compared to the pre-plant at 0.383%, the N:S ratio was also slight lower. By the R5 growth stage the in-season application had enough time and rainfall to get into the plant. The in-season V3 application resulted in the highest R5 tissue levels for sulfur and the lowest N:S ratio. There is limited research on soybeans with detailed information on what levels sulfur concentration and N:S ratios should be at for the R5 growth stage. However, all sulfur applications improved sulfur levels in the plant and reduced the N:S ratio which is the goal. There was not a major difference from the sulfur treatments in nitrogen concentration levels in the plant compared to the check.

Table 10: Plot #2 2020 Soybean Nitrogen and Sulfur Tissue Analysis at R5 Growth Stage on August 18th

	Zone	Nitrogen (%)	Sulfur (%)	N:S Ratio	Avg N (%)	Avg S (%)	Avg N:S Ratio	% Inc vs Control
Pre-Plant AMS 100lb/ac	B-L	6.72	0.38	17.7	6.78	0.383	17.7	9.7%
	C-H	6.85	0.39	17.8				
Pre-Plant K-Mag 100lbs/ac	B-L	6.73	0.38	17.6	6.76	0.383	17.6	9.9%
	C-H	6.80	0.38	17.7				
Pre-Plant ATS 8gal/ac	B-L	6.84	0.37	18.3	6.89	0.374	18.4	7.2%
	C-H	6.93	0.37	18.5				
In-Season V3 AMS 100lb/ac	B-L	6.66	0.39	17.3	6.76	0.390	17.3	11.9%
	C-H	6.87	0.40	17.3				
Control	B-L	6.68	0.34	19.5	6.72	0.349	19.3	
	C-H	6.76	0.36	19.0				

In Plot #3 tissue samples for nitrogen and sulfur were collected at the R2 growth stage on July 13, 2020. The pre-plant sulfur applications resulted in a big increase of sulfur concentration in the plant and an improvement in the N:S ratio (Table 11). In comparing the pre-plant sulfur products, the AMS and K-Mag were similar and had higher sulfur concentrations averaging 0.341%, while the ATS was slightly behind averaging 0.336%. These were all better than the check which averaged 0.299% sulfur in the tissue. The pre-plant AMS and KMag had an increase of 14.5% and 14.0%, respectively in sulfur concentration compared to the check, while the ATS was 12.6% higher than the check. The in-season V3 timing of AMS improved sulfur concentration levels compared to the check significantly by 20.4%. The timing of AMS did affect the sulfur concentration levels and the N:S ratio; concentration levels averaged 0.342% with the pre-plant and 0.359% with the in-season (a 5.9% increase). A lower N:S ratio was also achieved with the in-season timing; averaging 18.6 compared to 19.3. The in-season application was applied on June 19th and R2 was reached 24 days later. The strong response to the in-season application could be weather related. From the time of application on June 19th, the field did receive a 0.36 inches rainfall within 3 days and a second rain of 0.67 inches 7 days after application, which may have improved early uptake. Plot #2 location had a small rain of 0.28 inches the day of application but never received a significant rainfall for 14 days after application which was only 3 days before the R2 sampling. All sulfur treatments also improved nitrogen concentration levels in the plant compared to the check. The K-Mag treatment which would have not had any extra nitrogen applied did not have any major difference in nitrogen concentration levels compared to the other sulfur treatments.

Table 11: Plot #3 2020 Soybean Nitrogen and Sulfur Tissue Analysis at R2 Growth Stage on July 13th								
	Zone	Nitrogen (%)	Sulfur (%)	N:S Ratio	Avg N (%)	Avg S (%)	Avg N:S Ratio	% Inc vs Control
Pre-Plant AMS 100lb/ac	A-L	6.59	0.35	18.8	6.59	0.342	19.3	14.5%
	B-H/C-H	6.58	0.33	19.7				
Pre-Plant K-Mag 100lbs/ac	A-L	6.55	0.35	18.8	6.59	0.340	19.4	14.0%
	B-H/C-H	6.63	0.33	20.0				
Pre-Plant ATS 8gal/ac	A-L	6.51	0.34	19.3	6.45	0.336	19.2	12.6%
	B-H/C-H	6.39	0.33	19.1				
In-Season V3 AMS 100lb/ac	A-L	6.72	0.35	19.1	6.68	0.359	18.6	20.4%
	B-H/C-H	6.65	0.37	18.1				
Control	A-L	6.34	0.29	21.7	6.36	0.299	21.3	
	B-H/C-H	6.38	0.31	20.9				

In Plot #3 tissue samples for nitrogen and sulfur were collected at the R5 growth stage on August 17, 2020. The pre-plant sulfur applications resulted in an increase of sulfur concentration in the plant and an improvement in the N:S ratio (Table 12). In comparing the pre-plant products, the AMS and KMag were similar; they averaged 0.390% (11.9% increase to check) and a N:S ratio around 17.4 while the ATS was behind with an average of 0.280% sulfur (7.4% increase to check) and an N:S ratio of 17.9. The check averaged 0.261% sulfur and an N:S ratio of 18.7. The in-season V3 timing of AMS also improved sulfur concentration levels compared to the check by 13.8%. The in-season AMS had a higher sulfur concentration averaging 0.297% (a 3% increase) compared to the pre-plant at 0.289%. A slightly lower N:S ratio was also achieved with the in-season timing; averaging 17.1 compared to 17.6. The in-season V3 application resulted in the highest R5 tissue levels for sulfur and the lowest N:S ratio. There is limited research on soybeans with detailed information on what levels sulfur concentration and N:S ratios should be at for the R5 growth stage. However, all sulfur applications improved sulfur levels in the plant and reduced the N:S ratio which is the goal. All sulfur treatments also improved nitrogen concentration levels in the plant compared to the check. The K-Mag treatment which would have not had any extra nitrogen applied did have slightly lower nitrogen concentration levels compared to the other sulfur treatments, but the differences were miner.

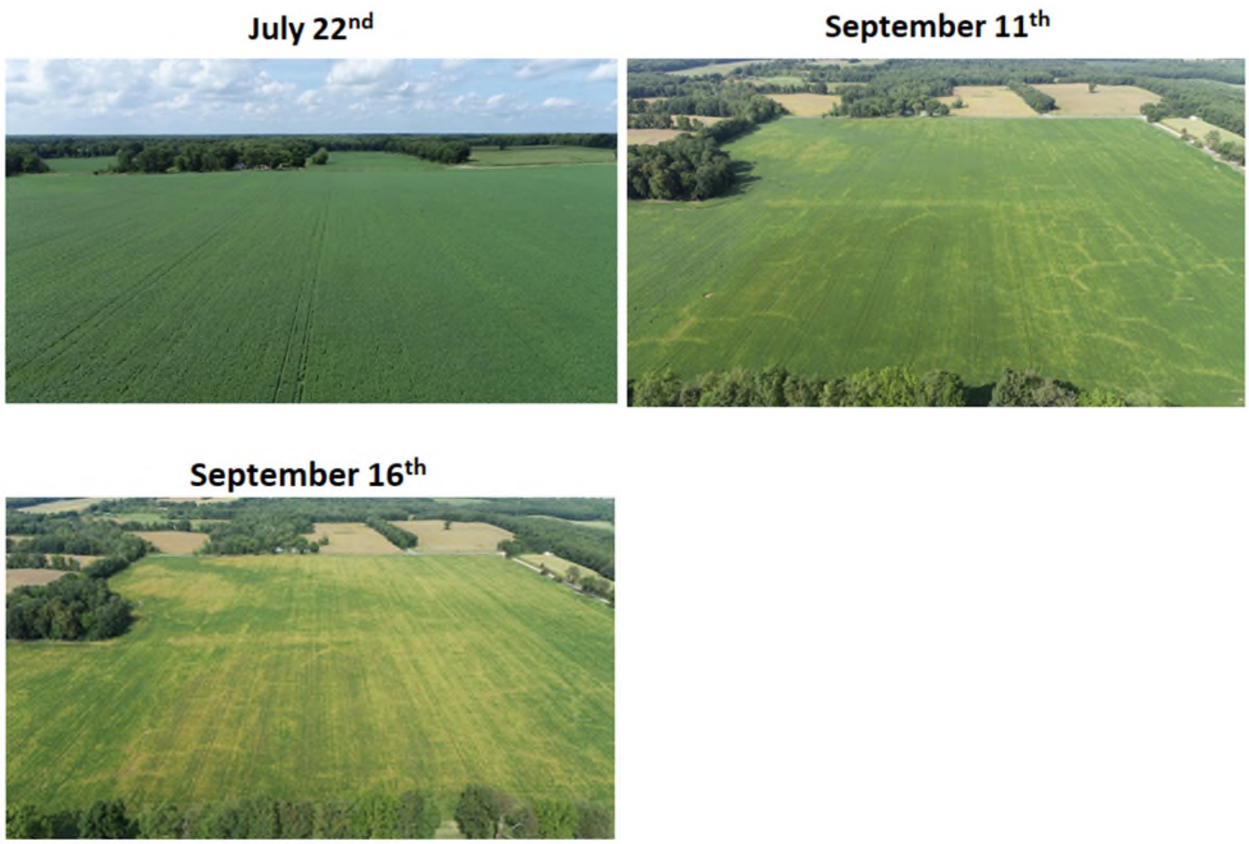
Table 12: Plot #3 2020 Soybean Nitrogen and Sulfur Tissue Analysis at R5 Growth Stage on August 17th								
	Zone	Nitrogen (%)	Sulfur (%)	N:S Ratio	Avg N (%)	Avg S (%)	Avg N:S Ratio	% Inc vs Control
Pre-Plant AMS 100lb/ac	A-L	5.14	0.28	18.2	5.08	0.289	17.6	10.8%
	B-H/C-H	5.02	0.30	16.9				
Pre-Plant K-Mag 100lbs/ac	A-L	4.92	0.29	17.2	4.94	0.290	17.1	11.0%
	B-H/C-H	4.96	0.29	16.9				
Pre-Plant ATS 8gal/ac	A-L	4.92	0.27	18.2	5.02	0.280	17.9	7.4%
	B-H/C-H	5.12	0.29	17.7				
In-Season V3 AMS 100lb/ac	A-L	5.07	0.30	16.9	5.06	0.297	17.1	13.8%
	B-H/C-H	5.06	0.29	17.2				
Control	A-L	4.80	0.26	18.5	4.88	0.261	18.7	
	B-H/C-H	4.96	0.26	18.9				

Drone Imagery (Visual)

Drone imagery was taken on the plots to look at visual photos during the growing season. The photos were taken from a DJI Phantom 4 Pro drone. The camera on this drone uses a 1 inch 20-megapixel CMOS sensor. The mechanical shutter lens and wide-angle capabilities capture sharp photos at higher resolutions.

Drone images for Plot #1 are shown below from July 22nd, September 11^{th,} and September 16th (Figure 1). There are no major difference showing up the from the sulfur treatments in the images. The September 16th image shows plant growth and maturity differences in the different management zones however, it is difficult to see any treatment differences.

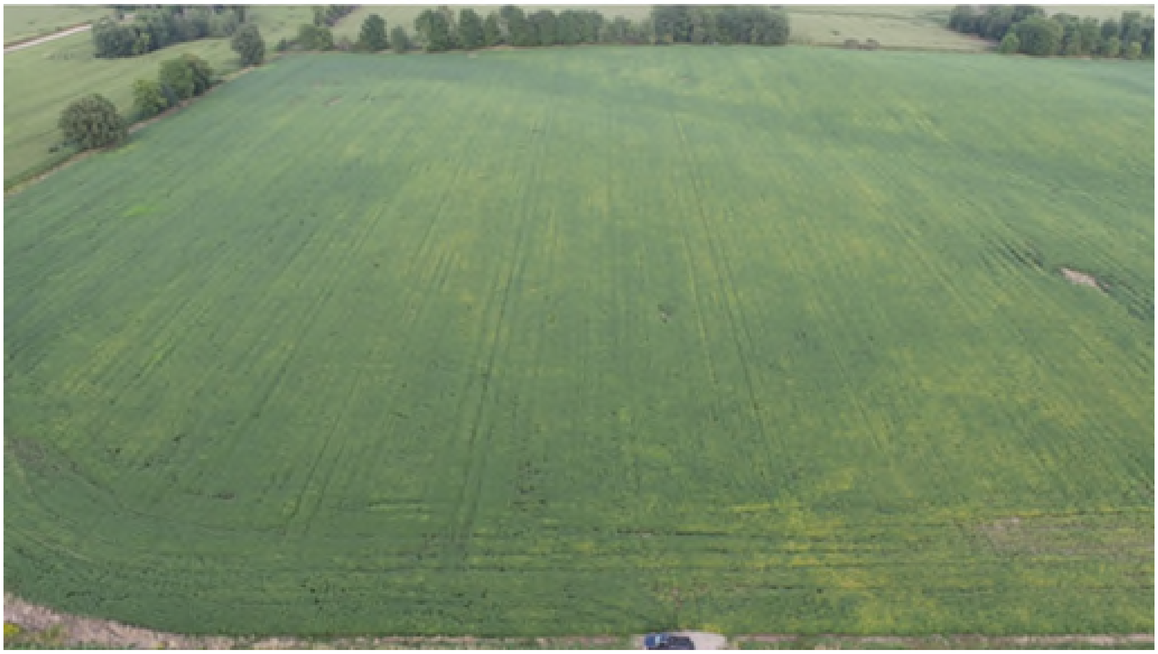
Figure 1: Plot #1 Drone Imagery (Visual)



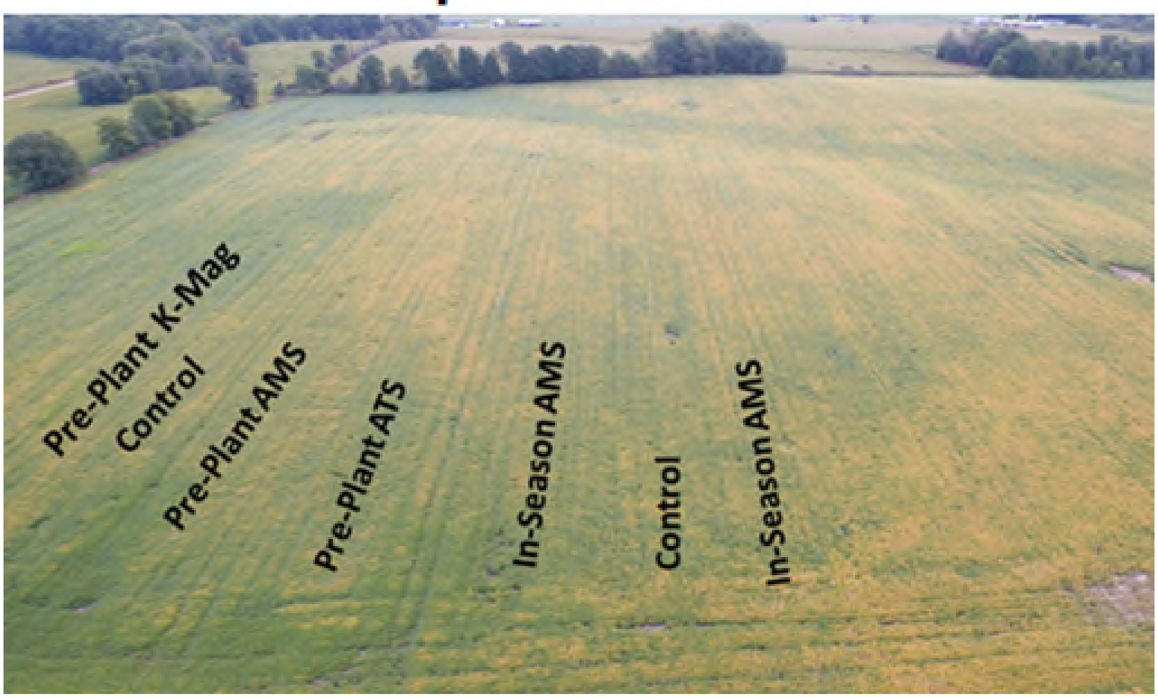
Drone images for Plot #2 are shown below from September 11th, September 16th, and September 24th (Figure 2). All three dates are showing plant growth difference in the different management zones. In the September 16th and 24th images, there is a slight difference in the maturity of the control strips. The control strips appear to have a slight delay in maturity, showing a slower dry down compared to the sulfur treatments. Perhaps the lack of sulfur in the plant causes some plant stress which can delay maturity. There are no major difference showing up the from the different sulfur treatments in the images.

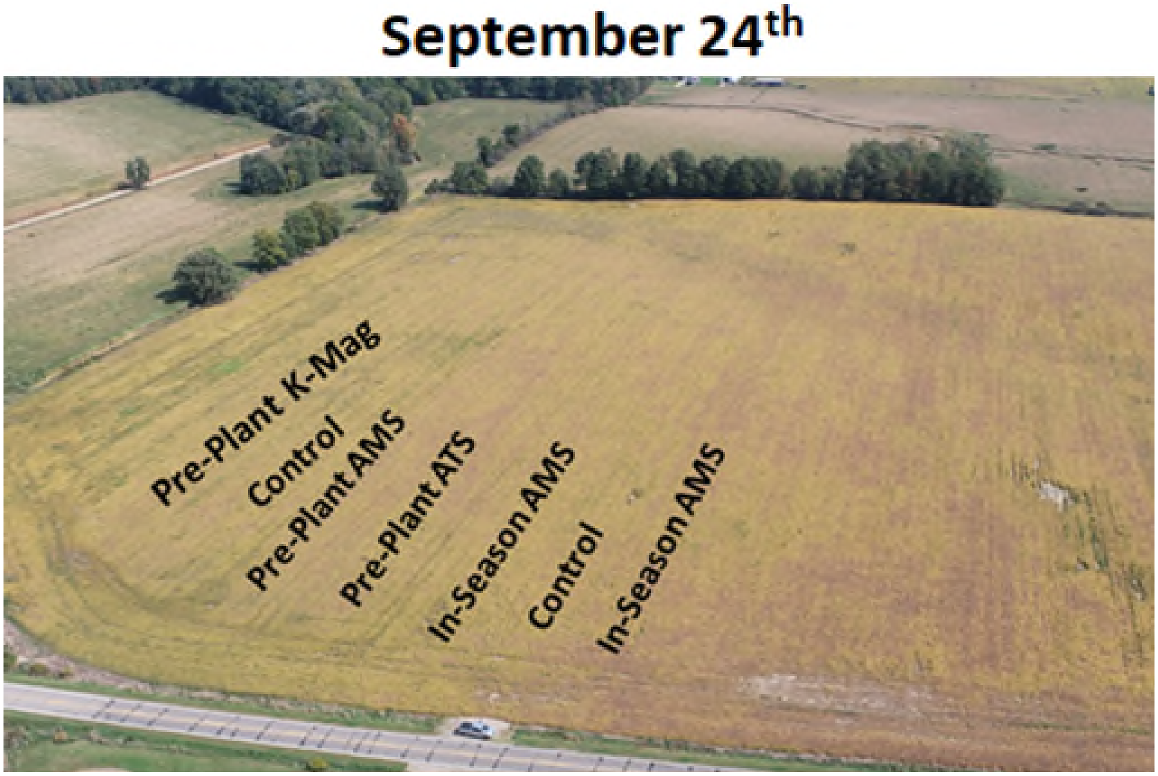
Figure 2: Plot #2 Drone Imagery (Visual)

September 11th



September 16th

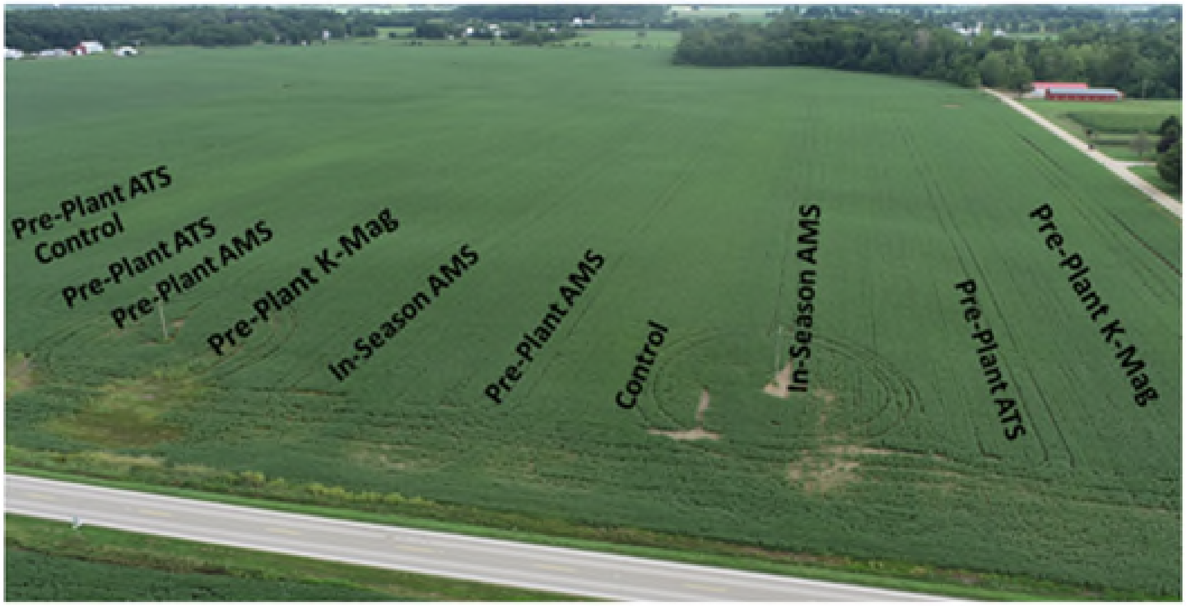




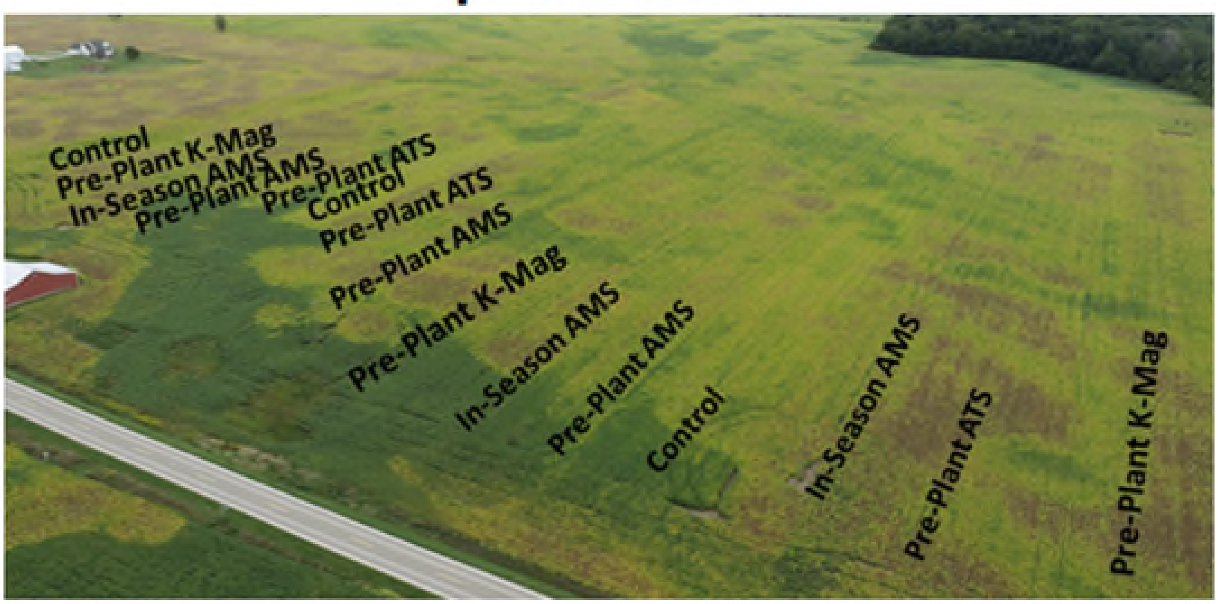
Drone images for Plot #3 are shown below from July 24th, September 10th, and September 15th (Figure 3). The image on July 24th has good visual differences showing that control treatments are showing more yellowing. The yellowing can be related to the lack of sulfur uptake in the control strips. The control treatment strips continued to show up the rest of season. The September 10th and 15th images show the control strips having a delay in maturity and a slower dry down than the sulfur treatments. Perhaps the lack of sulfur in the plant caused some plant stress which can delay maturity. Amongst the sulfur treatments it is difficult to pick out differences. These images also show the difference in the soil management zones.

Figure 3: Plot #3 Drone Imagery (Visual)

July 24th



September 10th



Yield & Economic Analysis

The plots were harvested with the growers combine equipped with a calibrated yield monitor. Each individual plot strip was also weighed with a scale cart. The scaled data was analyzed across the soil management zones using Ag Leader SMS software. Some zones did not have enough data points to use in the analysis and therefore were left out.

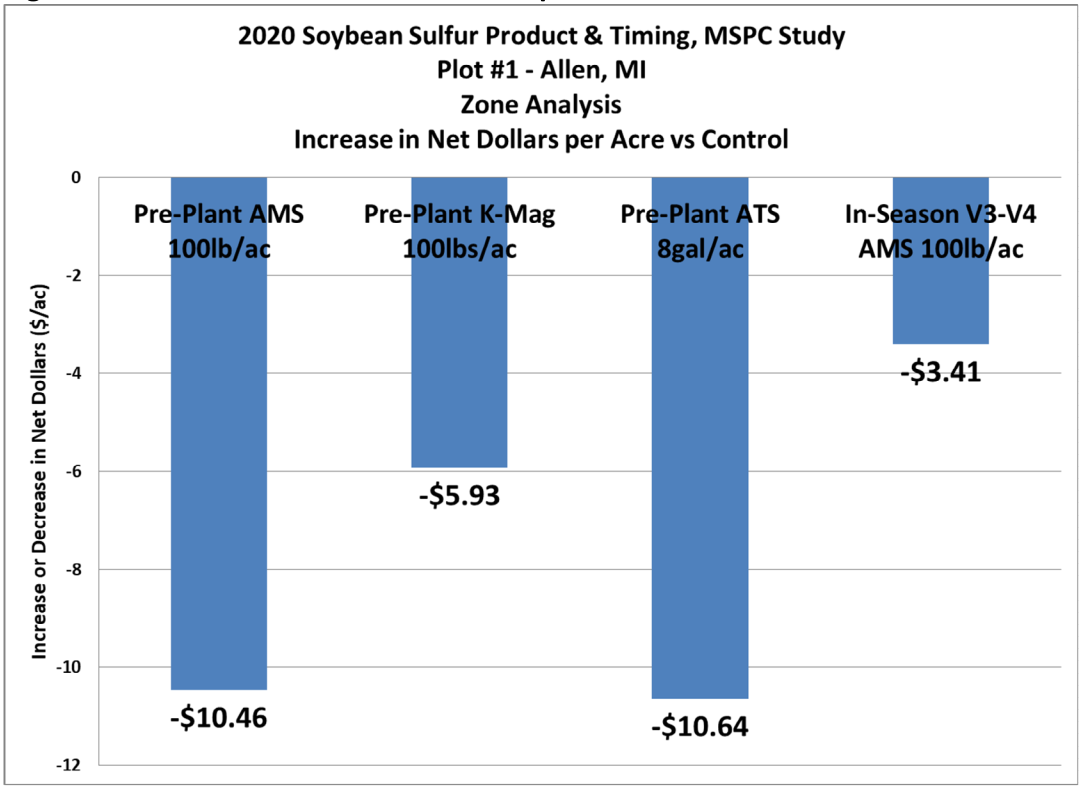
Plot #1 was harvested on November 4th. In Plot #1 there was little response to the sulfur treatments compared to the control. The overall response to sulfur in this plot was the lowest of the three locations averaging only 1.52 Bu/ac increase compared to the control (Table 13). This plot likely had a lower overall increase in yield for sulfur treatments compared to the check due to the additional spring sulfur application in the normal dry fertilizer blend of 24 lb S/ac. The highest yield increase came from pre-plant K-Mag and the in-season V3 AMS with 1.94 and 1.85 Bu/ac, respectively. The pre-plant AMS only yield 1.17 Bu/ac better than the control. The pre-plant ATS increased yields compared to the control on average by only 1.13 Bu/ac.

Table 13. Plot #1 Soil Zone Yield Analysis

Treatment	A-L	C-H	C-H2	D-L	E-L	F-H	Average	Diff vs Control
Pre-Plant AMS 100lb/ac	67.1	48.7	55.3	63.7	59.3	55.3	**58.3**	**1.17**
Pre-Plant K-Mag 100lbs/ac	68.0	47.7	60.6	62.7	62.0	53.2	**59.0**	**1.94**
Pre-Plant ATS 8gal/ac	67.2	48.3	59.0	62.6	59.0	53.2	**58.2**	**1.13**
In-Season V3-V4 AMS 100lb/ac	68.2	49.3	58.2	64.0	59.9	54.1	**58.9**	**1.85**
Control	65.5	49.2	55.4	63.3	58.1	51.0	**57.1**	

In Plot#1 the sulfur applications were not profitable averaging a loss per acre of $7.61 per acre (Figure 4). Again, this plot likely had a lower overall economic response for sulfur treatments compared to the check due to the additional spring sulfur application in the normal dry fertilizer blend of 24 lb S/ac.

Figure 4. Plot #1 Increase in Net Dollars per Acre vs Control



The yield response to the sulfur applications varied based on the management zone. Two of the high ground management zones with medium yield (C-H2, F-H, avg 56.1 Bu/ac) did have an economic response to the sulfur applications, averaging an $6.99/ac advantage (Table 14). However, the high ground zone with low yields (C-H, avg 48.5 Bu/ac) did not economically respond to the sulfur treatments. Water was likely the yield limiting factor here, more so than sulfur in that zone. On average none of the low ground treatments had an economical response to the sulfur treatments.

Table 14. Plot #1 Soil Zone Analysis Economic Sulfur Response per Acre by Zone

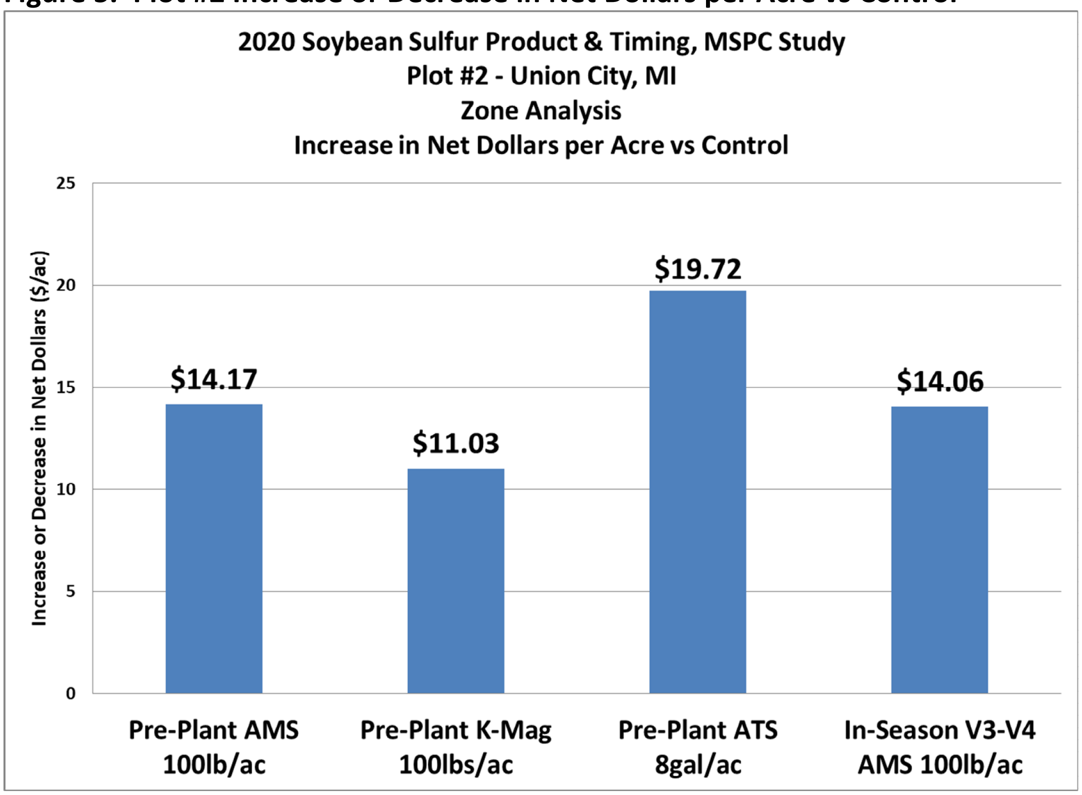
Treatment	A-L	C-H	C-H2	D-L	E-L	F-H
Sulfur Response by Zone	$ (0.94)	$ (30.70)	$ 6.81	$ (24.43)	$ (3.56)	$ 7.16

Plot #2 was harvested on October 10th. In Plot #2 once the data was analyzed across the management zones it was determined that the highest yield was from the pre-plant ATS application (Table 15). The pre-plant ATS yielded 4.03 Bu/ac better than the control. The pre-plant and in-season AMS and pre-plant K-Mag treatments all yielded similar to each other, increasing yields about 3.5 Bu/ac compared to the control. There was no difference in yield for the timing of the AMS preplant or in-season. On average there was a yield increase to the sulfur applications across all the management zones.

Table 15. Plot #2 Soil Zone Yield Analysis							
Treatment	A-L	B-H	C-L	D-H	D-H2	Average	Diff vs Control
Pre-Plant AMS 100lb/ac	70.0	64.4	64.2	67.5	60.4	**65.3**	**3.52**
Pre-Plant K-Mag 100lbs/ac	67.2	66.2	65.3	67.8	60.3	**65.3**	**3.55**
Pre-Plant ATS 8gal/ac	70.8	65.9	63.9	68.8	59.7	**65.8**	**4.03**
In-Season V3-V4 AMS 100lb/ac	67.1	65.9	66.0	68.5	59.0	**65.3**	**3.51**
Control	65.6	62.7	59.1	66.3	55.1	**61.8**	

In Plot #2, the highest net return was with the pre-plant K-Mag application; $19.72 per acre increase versus the control (Figure 5). The pre-plant and in-season AMS were similar in their economic response averaging $14.17 and $14.06/ac increase over the control, respectively. Overall, all sulfur applications were profitable averaging a net increase of $14.74 per acre versus the control. This plot averaged single digit sulfur levels on the soil test and did not have any sulfur in the normal fertilizer blend, both indicating a potential greater response.

Figure 5. Plot #2 Increase or Decrease in Net Dollars per Acre vs Control



There was a positive net increase to the sulfur applications across four of the five management zones (Table 16). The response really varied across the zones, ranging from a -$4.90 in D-H zone to a positive $37.17 net return per acre. There was no clear indicator of why the D-H zone had a lower response.

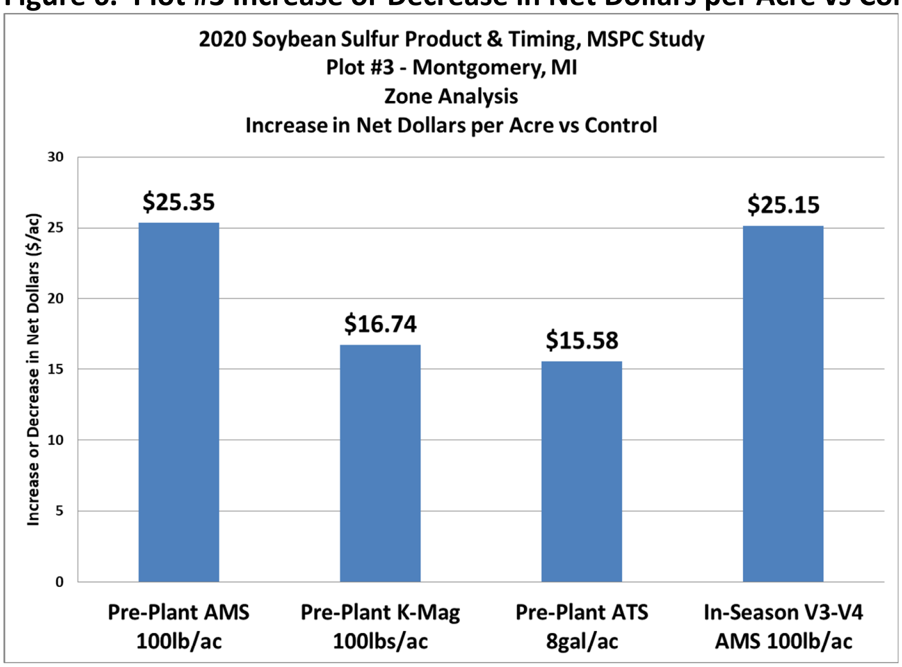
Table 16. Plot #2 Soil Zone Analysis Economic Sulfur Response per Acre by Zone					
Treatment	A-L	B-H	C-L	D-H	D-H2
Sulfur Response by Zone	$ 9.40	$ 6.29	$ 37.17	$ (4.90)	$ 25.76

Plot #3 was harvested on October 8th. In Plot #3 once the data was analyzed across the management zones it was determined that the highest yields were from the pre-plant and in-season V3 AMS application (Table 17). The was no difference between the pre-plant and the in-season V3 AMS, both increased yields 4.58 and 4.57 Bu/ac respectively compared to the control. The pre-plant K-Mag increased yields 4.09 Bu/ac, while the pre-plant ATS increased yields 3.63 Bu/ac. On average the sulfur treatments increased yields 4.22 Bu/ac. On average there was a yield increase to the sulfur applications across all the management zones.

Table 17. Plot #3 Soil Zone Yield Analysis						
Treatment	A-L	B-H	B-H2	C-H	Average	Diff vs Control
Pre-Plant AMS 100lb/ac	64.8	47.2	43.6	59.3	**53.71**	**4.58**
Pre-Plant K-Mag 100lbs/ac	66.1	48.1	40.7	57.9	**53.22**	**4.09**
Pre-Plant ATS 8gal/ac	66.6	45.5	42.2	56.8	**52.76**	**3.63**
In-Season V3-V4 AMS 100lb/ac	63.9	50.9	43.3	56.8	**53.70**	**4.57**
Control	61.8	43.1	38.9	52.8	**49.13**	

In Plot #3, the highest net return was with the pre-plant and in-season V3 AMS applications; $25.35 and $25.15 per acre increase versus the control, respectively (Figure 6). The pre-plant K-Mag increased returns $16.74 per acre, while the pre-plant ATS increased returns $15.58 per acre. Overall, all sulfur applications were profitable averaging a net return of $20.71 per acre.

Figure 6. Plot #3 Increase or Decrease in Net Dollars per Acre vs Control



There was a positive net increase to the sulfur applications across all the management zones (Table 18). Two of the high ground management zones with medium to high yield (B-H, C-H) had the biggest economic response to the sulfur applications, averaging an $27.69/ac net return. The high ground management zones have lower CEC, lower OM, and lower sulfur ppm. The third high ground management zone (B-H2) was the lowest yielding and had the lowest net return ($13.40/ac). Water was likely the yield limiting factor here, more so than sulfur. The low ground, high yield zone (A-L) had a lower response than the high ground medium to high yield zones, but still had a net return per acre of $14.03. In this highly responsive plot, it would pay to apply sulfur in all the management zones.

Table 18. Plot #3 Soil Zone Analysis Economic Sulfur Response per Acre by Zone				
Treatment	**A-L**	**B-H**	**B-H2**	**C-H**
Sulfur Response by Zone	$ 14.03	$ 27.35	$ 13.40	$ 28.03

Summary

In summary the sulfur treatments improved yields across the three locations. The highest yield increase was from the in-season V3 AMS application (Table 19). The in-season AMS yielded 3.3 Bu/ac better than the control across the plot locations. It also had the highest net return of $11.94 per acre (Table 20). Amongst the pre-plant treatments the AMS, K-Mag, and ATS were very similar in their increase compared to the control increasing yields 3.1, 3.2, and 2.9 Bu/ac respectively across the three plot locations. The location that had additional sulfur (24 lb/ac) from the spring dry fertilizer program was not economically responsive, even though yields were increased. When the non-responsive location is taken out the average increase to pre-plant or in-season AMS is about $17/ac. The yield gains can be attributed to the increase in sulfur concentrations in the tissues and a reduced N:S Ratio. The response in yield correlated with the percent increase in sulfur tissue concentrations compared to the control. Plot #3 had the highest increases in sulfur tissue concentrations and the highest yield increase on average. Plot #1 had the lowest increase in sulfur tissue concentrations and the lowest yield gains. A correlation with yield response may also be linked to soil test sulfur levels, the two economically responsive sites had single digit soil sulfur ppm (6.6 and 6.1 respectively), while the non-responsive site averaged 11 ppm.

Table 19. Multi-Location Average Yield Increase vs Control				
Treatment	**Plot #1**	**Plot #2**	**Plot #3**	**Average**
Pre-Plant AMS 100lb/ac	1.2	3.5	4.6	**3.1**
Pre-Plant K-Mag 100lbs/ac	1.9	3.6	4.1	**3.2**
Pre-Plant ATS 8gal/ac	1.1	4.0	3.6	**2.9**
In-Season V3 AMS 100lb/ac	1.8	3.5	4.6	**3.3**

Table 20. Multi-Location Net Dollars Increase or Decrease to Control				
Treatment	**Plot #1**	**Plot #2**	**Plot #3**	**Average**
Pre-Plant AMS 100lb/ac	$ (10.46)	$ 14.17	$ 25.35	**$ 9.68**
Pre-Plant K-Mag 100lbs/ac	$ (5.93)	$ 11.03	$ 16.74	**$ 7.28**
Pre-Plant ATS 8gal/ac	$ (10.64)	$ 19.72	$ 15.58	**$ 8.22**
In-Season V3 AMS 100lb/ac	$ (3.41)	$ 14.06	$ 25.15	**$ 11.94**

2019 & 2020 Two Year Summary

In summary the sulfur treatments improved yields across the three locations in both 2019 and 2020. On average sulfur treatments increased yields 3.6 Bu/ac over the six site years (Table 21). Of the sulfur treatments the in-season V3 AMS had the best response averaging a 4.5 Bu/ac increase compared to the control. The second-best treatment was the pre-plant AMS at 3.7 Bu/ac increase followed by pre-plant ATS at 3.4 Bu/ac increase. The pre-plant K-Mag treatment had the lowest average response at 2.9 Bu/ac. However, most of the yield drag from the K-Mag come from the 2019 season not the 2020. A third year of testing will hopefully help determine the effectiveness of the K-Mag product. In both years, the site plot locations that had sulfur (21-24 lb S) applied from the normal spring fertilizer blend were not as responsive to the sulfur treatments as the other sites and often were not economical treatments. They also were sites with double digit soil sulfur test ppm (13.2 ppm 2019 and 11 ppm 2020) compared to responsive sites which averaged 6 to 7 ppm.

Table 21. 2019-2020 Multi-Location Average Soybean Yield Increase vs Control

Treatment	2019 Plot #1	2019 Plot #2	2019 Plot #3	2020 Plot #1	2020 Plot #2	2020 Plot #3	Average	Sulfur Advantage
Pre-Plant AMS 100lb/ac	5.7	2.9	4.2	1.2	3.5	4.6	**3.7**	**3.6**
Pre-Plant K-Mag 100lbs/ac	3.7	1.9	2.4	1.9	3.6	4.1	**2.9**	
Pre-Plant ATS 8gal/ac	5.4	2.5	3.9	1.1	4.0	3.6	**3.4**	
In-Season V3-V4 AMS 100lb/ac	6.8		5.8	1.8	3.5	4.6	**4.5**	

Of the sulfur treatments the in-season V3 AMS had the best economic response averaging a $22.77/acre increase compared to the control (Table 22). The second-best treatment was the pre-plant AMS at $14.52/ac increase followed by pre-plant ATS at $12.17/ac increase. The pre-plant K-Mag treatment has the lowest average economic response at $3.67 Bu/ac. In both years, the site plot locations that had sulfur (21-24 lb S) applied from the normal spring fertilizer blend were not as responsive to the sulfur treatments as the other sites and often were not economical treatments.

Table 22. 2019-2020 Multi-Location Net Dollars Increase or Decrease vs Control

Treatment	2019 Plot #1	2019 Plot #2	2019 Plot #3	2020 Plot #1	2020 Plot #2	2020 Plot #3	Average
Pre-Plant AMS 100lb/ac	$ 33.80	$ 5.78	$ 18.50	$ (10.46)	$ 14.17	$ 25.35	$ 14.52
Pre-Plant K-Mag 100lbs/ac	$ 10.37	$ (7.35)	$ (2.86)	$ (5.93)	$ 11.03	$ 16.74	$ 3.67
Pre-Plant ATS 8gal/ac	$ 30.46	$ 1.73	$ 16.16	$ (10.64)	$ 19.72	$ 15.58	$ 12.17
In-Season V3-V4 AMS 100lb/ac	$ 44.10		$ 33.94	$ (3.41)	$ 14.06	$ 25.15	**$ 22.77**

When averaging only the sites **without** the additional sulfur in the normal fertilizer blend in 2019 and 2020 the best treatment was still the in-season V3 application with a $29.31/ac net return (Table 23). Based on the two-year plot results, AMS and ATS may be the better product choices. Although K-Mag performed better economically in the second year compared to the first year. The in-season timing was better than the pre-plant timing in the two years of trials. The ATS would not be able to be applied in-season since it would cause foliar burn to the soybeans. The yield and economic gains can be attributed to the increase in sulfur concentrations and a reduce N:S Ratio in the tissues. Based on tissue tests the K-Mag treatment did not seem to lag in yield due to the lack of nitrogen in the plant.

Table 23. 2019-2020 Multi-Location Net Dollars Increase or Decrease vs Control					
Treatment	**2019 Plot #1**	**2019 Plot #3**	**2020 Plot #2**	**2020 Plot #3**	**Average**
Pre-Plant AMS 100lb/ac	$ 33.80	$ 18.50	$ 14.17	$ 25.35	$ 22.95
Pre-Plant K-Mag 100lbs/ac	$ 10.37	$ (2.86)	$ 11.03	$ 16.74	$ 8.82
Pre-Plant ATS 8gal/ac	$ 30.46	$ 16.16	$ 19.72	$ 15.58	$ 20.48
In-Season V3-V4 AMS 100lb/ac	$ 44.10	$ 33.94	$ 14.06	$ 25.15	**$ 29.31**

When comparing the response by management zones at the responsive plot locations (without S in normal spring dry fertilizer blend) 95% of the management zones had a positive net return per acre (Table 24). Variable rate (on vs off) application of sulfur would not likely be needed at sites with expected sulfur response. However, at the two non-responsive sites (had additional spring S of 21-24 lb from dry fertilizer blend and higher soil test ppm) the high ground management zones which typically have lower cec, organic matter, and low ppm of sulfur were still economical while the low ground (high organic matter, higher cec) zones were not. The only exception was one high ground zone in 2020 which also had low yields. Therefore, fields with expected lower sulfur response, maybe able to improve yield and economics with applying sulfur only in the more responsive zones (lower organic matter, lower cec, single digit S ppm) within the field.

Table 24. Economic Responsive Zones	
Plot & Year	**% Economic Responsive Zones**
2019 Plot 1	100%
2019 Plot 3	100%
2020 Plot 2	80%
2020 Plot 3	100%
Avg	95%

In summary, based on 2019 and 2020 plot data, an in-season V3 sulfur application would be recommended for sandy loam soybean fields in Michigan. The six fields in this study had an average total exchange capacity (TEC) of 7.6 and an average organic matter of 2.0%. If a field is receiving sulfur with the normal dry fertilizer blend in the spring additional in-season sulfur would not be recommended. Unless it was applied VRA only on the management zones with the lower organic matter, lower cec, and single digit sulfur numbers. A third year of plots would help to confirm this as well as provide better data on the K-Mag product.