Sulfur Solutions in Soybean

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SOYBEAN STATION
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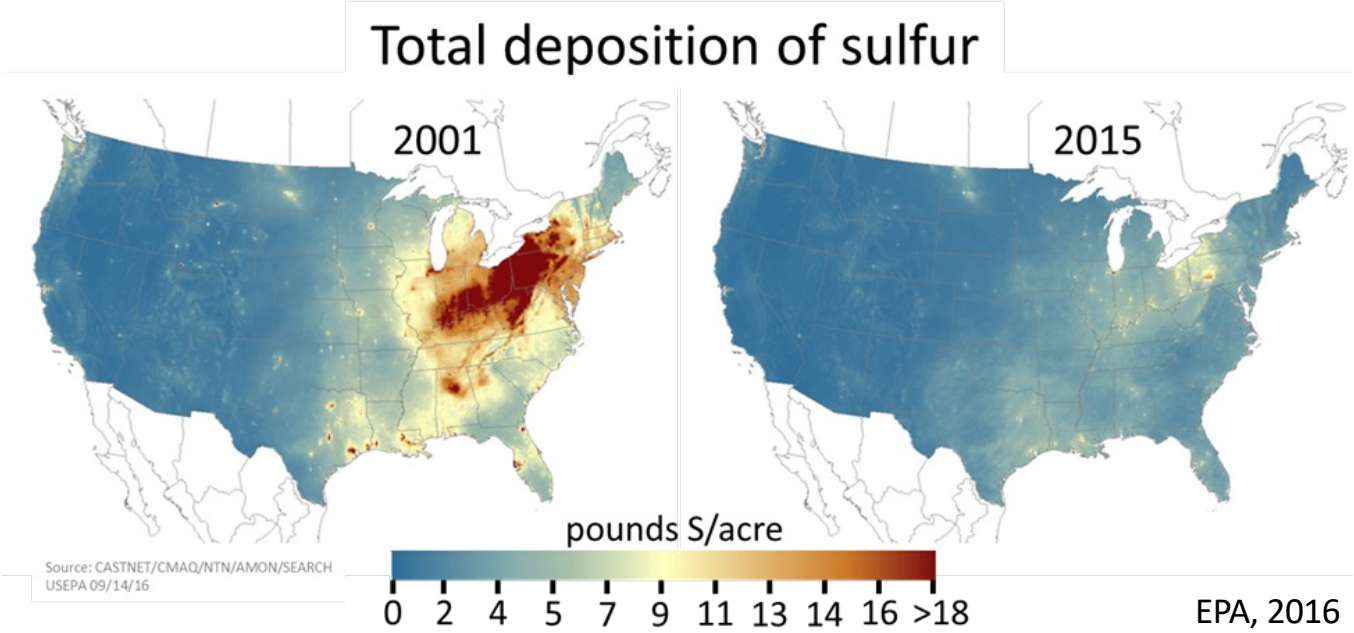
Sulfur: Who Needs It…Maybe You?



EPA, 2016

Which Crops Should Be the Most Responsive to Sulfur?

Sulfur Fertilizer Sources

No Sulfur

20 lb S/ac

No Sulfur

20 lb S/ac


AMS 20 lb S
AMS:ES
UTC
LaCrosse, IN - 2017

Supplying Sulfur to Our Fields

- **~3-4 lb S/ac mineralized per 1% OM per year**

- **Plant Residue – Mineralized or Immobilized?**
  - **C:S Ratio < 200:1 → MINERALIZED SO_4-S**
  - **C:S Ratio > 400:1 → IMMOBILIZED SO_4-S**
  - Corn Stover ~350:1
  - Soybean Stover ~125:1
  - Wheat Straw ~300:1
  - Cover Crop? Other Factors?

How Much S Does Soybean Need?

Grain	lb/bu	50 bu	75 bu	100 bu
Nitrogen	3.30	165	248	330
P_2O_5	0.73	37	55	73
K_2O	1.20	60	90	120
Sulfur	**0.18**	**9**	**14**	**18**
Total S	**0.35**	**18**	**26**	**35**

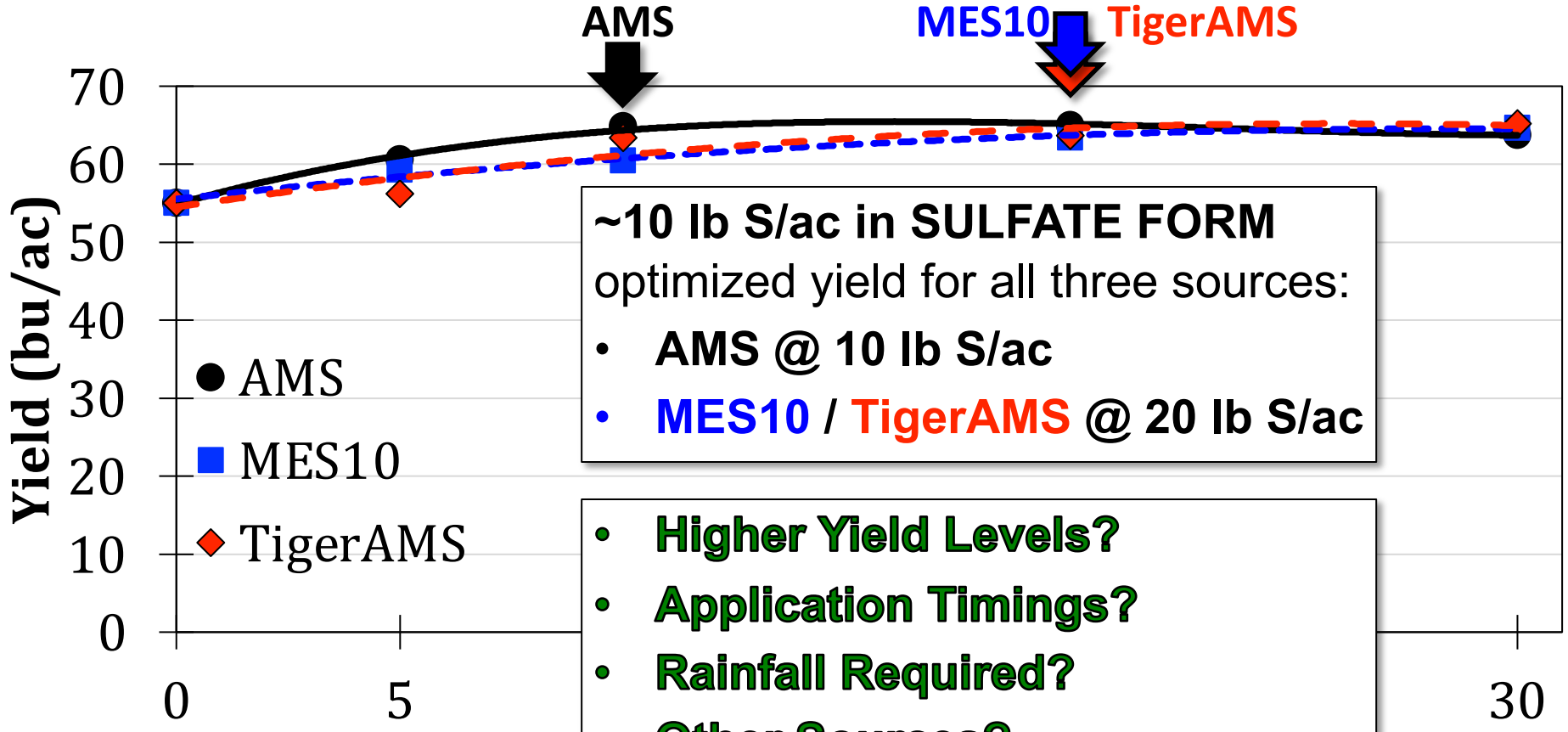
Doing the Math: Sulfur Needs (lb S/ac)

(Rough Mass Balance)

Yield	Need	Sky	Soil Organic Matter			
			1%	2%	3%	4%
bu	lb S/ac		~4	~8	~12	~16
50	18	~5	9	5	1	+3
75	26	~5	17	13	9	5
100	35	~5	26	23	18	14

Soybean Sulfur Trials in Sandy Loam ~2.5% OM

Sulfur Rate x Source: 2016-17



~10 lb S/ac in SULFATE FORM
optimized yield for all three sources:

- **AMS @ 10 lb S/ac**
- **MES10 / TigerAMS @ 20 lb S/ac**

- **Higher Yield Levels?**
- **Application Timings?**
- **Rainfall Required?**
- **Other Sources?**

LaCrosse, IN

Nutrient Application After Planting (PRE)

- LaCrosse, IN. Sandy loam to Loamy Sand
  - pH 6.6, 2.5% O.M., 35 M3P, 125 M3K, 3-8 M3S

		2018	2019	2020	2021	2022
Planting Date		May 22	May 20	May 4	May 15	May 12
Nutrients (lb/ac)						
Sulfur	S Sources	20	15	15	15	15
Nitrogen	Urea (46-0-0)	.	20	20	20	20
P_2O_5	TSP (0-45-0)	.	60	60	60	60
K_2O	KCl (0-0-60)	.	60	50	.	.

Treatments	N	P_2O_5	K_2O	S	Sulfate	Thio	Elem. S	Ca	Mg
UTC	.	.	.	.	.	.	.	.	.
NPK	46	45	60	.	.	.	.	.	.
AMS	21	0	0	24	all	.	.	.	.
MES_10	12	40	0	10	half	.	half	.	
Sulf4R	0	0	0	17	all	.	.	22	.
K_Mag	0	0	22	21	all	.	.	.	10.5
TIger90CR	0	0	0	90	.	.	all	.	.
AMS_Tiger	21,0	0, 0	0,0	24,90	half	.	half	.	.
spray_ATS	12	0	0	26	.	all	.	.	.
MES_15	13	33	0	15	half	.	half	.	.
Super_Sulfur	11	0	0	75	.	.	all	.	.

2018-2022 Sulfur Sources: Leaf N @ R3

Leaf Nitrogen	2018		2019		2020		2021		2022		Trt*YR**	
UTC	5.0		5.7		4.6	e	5.2	e	.		5.1	
NPK (or NP)	.		5.6		4.9	de	5.5	d	.		5.3	
AMS	5.2		5.2		5.5	bc	5.8	bcd	.		5.4	
MES_10	5.3		5.3		5.8	ab	5.9	ab	.		5.6	
Sulf4R	5.2		5.3		5.7	ab	6.1	a	.		5.6	
K_Mag	5.1		5.1		5.8	ab	6.0	ab	.		5.5	
TIger90CR	5.0		5.2		5.2	cd	5.8	bc	.		5.3	
AMS_Tiger	5.1		5.4		5.5	bc	5.8	abc	.		5.4	
spray_ATS	5.2		5.0		5.6	abc	5.6	cd	.		5.3	
MES_15	.		5.6		5.9	a	6.0	ab	.		5.8	
Super_Sulfur	.		5.2		5.7	ab	5.8	bc	.		5.5	

2018-2022 Sulfur Sources: Leaf S @ R3

Leaf Sulfur	2018		2019		2020		2021		2022		Trt*YR**
UTC	0.28	d	0.30		0.24	c	0.28	d	.		0.28
NPK (or NP)	.	.	0.31		0.24	c	0.29	d	.		0.28
AMS	0.36	a	0.31		0.34	a	0.33	abc	.		0.34
MES_10	0.36	ab	0.32		0.33	a	0.34	a	.		0.34
Sulf4R	0.36	a	0.30		0.34	a	0.33	abc	.		0.33
K_Mag	0.36	a	0.33		0.33	a	0.34	ab	.		0.34
TIger90CR	0.30	c	0.30		0.29	b	0.32	c	.		0.30
AMS_Tiger	0.35	b	0.32		0.33	a	0.33	abc	.		0.33
spray_ATS	0.36	ab	0.32		0.31	b	0.32	bc	.		0.33
MES_15	.	.	0.30		0.33	a	0.33	abc	.		0.32
Super_Sulfur	.	.	0.32		0.29	b	0.32	bc	.		0.31

2018-2022 Sulfur Sources: Leaf N:S @ R3

Leaf N:S	2018		2019		2020		2021		2022		Trt*YR**	
UTC	18.0	a	19.3	a	19.3	b	18.9	a	.		18.9	
NPK (or NP)	.	.	18.1	ab	20.9	a	18.7	ab	.		19.2	
AMS	14.4	cd	17.2	bcd	16.0	f	17.4	d	.		16.2	
MES_10	14.7	c	16.6	cd	17.6	cde	17.4	d	.		16.6	
Sulf4R	14.2	cd	17.7	abc	16.8	def	18.3	ab	.		16.7	
K_Mag	13.9	d	15.3	d	17.5	cde	17.8	cd	.		16.1	
TIger90CR	16.9	b	17.6	abc	18.1	bcd	18.3	abc	.		17.7	
AMS_Tiger	14.7	c	16.7	bcd	16.6	ef	17.9	cd	.		16.5	
spray_ATS	14.4	cd	15.4	d	18.1	bc	17.6	cd	.		16.4	
MES_15	.	.	18.6	ab	17.8	cde	18.3	abc	.		18.2	
Super_Sulfur	.	.	16.0	cd	19.3	b	18.1	bcd	.		17.8	

2018-2022 Sulfur Sources: Yield

Yield (bu/ac)	2018		2019		2020		2021		2022		Avg.	
UTC	61.7	d	54.9		51.6	e	61.8	d	50.8	c	56.1	c
NPK	.	.	55.2		55.8	de	63.3	cd	56.5	abc	57.7	c
AMS	72.0	ab	53.6		63.2	ab	70.1	b	59.7	ab	63.7	ab
MES_10	73.4	a	59.3		63.8	ab	68.9	bc	60.8	ab	65.2	a
Sulf4R	72.8	ab	53.8		61.6	bc	72.3	ab	58.2	ab	63.7	ab
K_Mag	67.9	bc	56.2		60.2	bcd	69.1	bc	56.8	ab	62.1	b
TIger90CR	65.5	cd	57.9		62.8	abc	73.3	ab	55.4	bc	63.0	ab
AMS_Tiger	68.8	abc	60.9		66.3	a	72.7	ab	57.2	ab	65.2	a
spray_ATS	68.6	abc	59.0		63.1	ab	69.2	bc	61.2	ab	64.2	ab
MES_15	.	.	56.5		64.0	ab	76.3	a	61.6	a	64.6	ab
Super_Sulfur	.	.	58.5		63.9	ab	74.5	ab	57.7	ab	63.7	ab

2018-2022 Sulfur Sources

- **Yield Trend:**
  - Low S rate (15 lb S / ac) needed a blend of sulfate and elemental S
  - Higher rate (20 lb S / ac) seem to displace the differences and more soluble sources
  - Cl effects in 2019, 2020 masked some S benefits
- **Protein Trend:**
  - Most S sources improved absolute protein 2 to 4%, K-Mag and Tiger occasionally did not improve protein as much.
  - N treatment did not improve protein.

2023 Sulfur Sources

- Let sources stand on their own. No additional or balancing nitrogen and phosphorus. TSP is providing ~1.5% S, so we were adding ~2 lb S/ac with the 15 lb S rate.

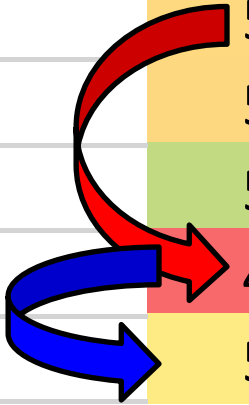
S Fertilizer Blends Broadcasted at Planting of Soybean

Treatment	Sulfur	Nitrogen	Phosphorus	Potassium
	lb S/ac	lb N/ac	lb P_2O_5/ac	lb K_2O/ac
Untreated	.	.	.	.
N	.	17.5	.	.
P	.	.	40	.
K	.	.	.	60
NPK	.	17.5	40	60

Treatment	Sulfur	Nitrogen	Phosphorus	Potassium
	lb S/ac	lb N/ac	lb P_2O_5/ac	lb K_2O/ac
Untreated	.	.	.	.
N	.	17.5	.	.
P	.	.	40	.
K	.	.	.	60
NPK	.	17.5	40	60
Sulfur + N	20	17.5	.	.
Sulfur + P	20	17.5	40	.
Sulfur + K	20	17.5	.	60
Sulfur + NPK	20	17.5	40	60

2019 Sulfur x NPK

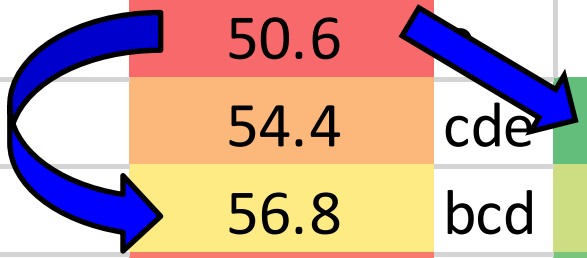
	No AMS		AMS	
UTC	50.0	b		
N	50.0	b	53.4	b
P	53.5	b	57.8	a
K	45.3	c	50.9	b
NPK	50.8	b	50.7	b



- K impeded yield ~ 5 bu/ac
  - Addition of N and P alleviated the yield hit (same as UTC)
  - Addition of N and S alleviated the yield hit (same as UTC)
- ~8 bu/ac improvement with AMS + P

2020 Sulfur x NPK

	No AMS		AMS	
UTC	50.6			
N	54.4	cde	63.3	a
P	56.8	bcd	58.9	abc
K	51.4	e	62.3	a
NPK	53.7	de	60.2	ab



- K did not have negative impact
- 6.2 bu/ac improvement with P
- 12.7 bu/ac improvement with AMS
  - 3.8 bu/ac numeric improvement with N (urea alone)

S-NPK

LaCrosse

Aug 4, 2021

UTC **KCl + AMS** **AMS**

22 LaCrosse: S+NPK

Source	No AMS		AMS	
UTC	50.8	a		
N	48.8	a	52.1	a
P	51.4	a	52.8	a
K	43.2		50.9	a
NPK	43.6	b	52.0	a

Sulfur Management Considerations

- **Nutrient interactions** can mask or limit yield effects based on timing of potash (i.e., Cl) in low CEC soil.
  - Cl appears to be limiting root development and therefore, nodule development
- **Phosphorus blending** is promising (additional S?)

- What about higher CEC soil?
- What about varieties with Cl tolerance?

21 W. Lafayette: S+NPK x Variety

Var ***

Fert***

V x Fert: ns

Cl Incl. → 68.2

Cl Intermed. → 74.6

ACRE 21	Pooled Over Varieties			
Source	No AMS		AMS	
UTC	67.9	c		
N	68.5	c	75.0	b
P	69.1	c	78.5	a
K	67.1	c	74.9	b
NPK	68.3	c	73.4	b

22 W. Lafayette: S+NPK x Variety

YIELD

Var ns

Fert**

V x Fert: ns

Cl Incl. → 69.9

Cl Intermed. → 69.7

W.Laf. 22	Pooled Over Varieties			
Source	No AMS		AMS	
UTC	66.7	d		
N	69.3	c	70.5	bc
P	73.1	a	72.8	ab
K	68.1	cd	68.5	cd
NPK	69.9	c	69.4	c

$LSD_{0.10}$

23 PKS x Variety: W. Laf, Wanatah

Yield	W. Laf 23			
	No AMS		AMS	
UTC	73.4	c	89.0	a
P	79.5	b	89.6	a
K	72.8	c	85.2	a

P or S? **Sulfur: 12 to 16 bu**

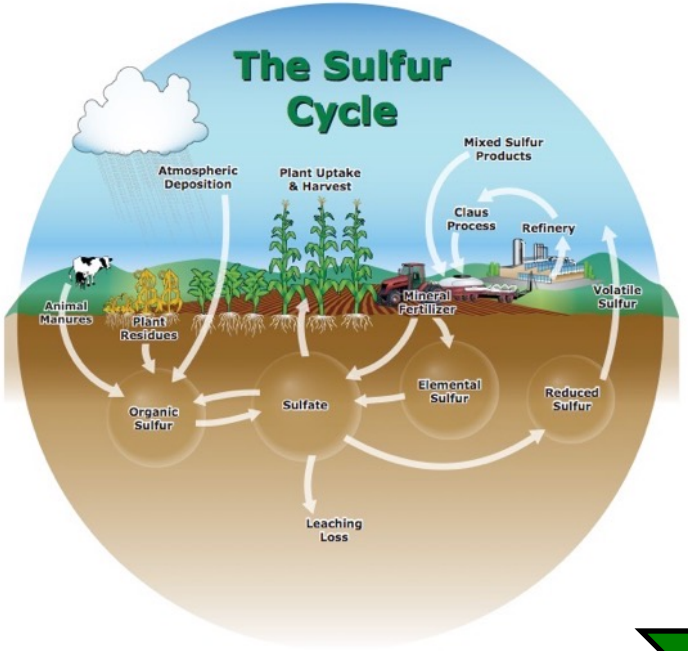
Pooled over varieties, $LSD_{0.10}$

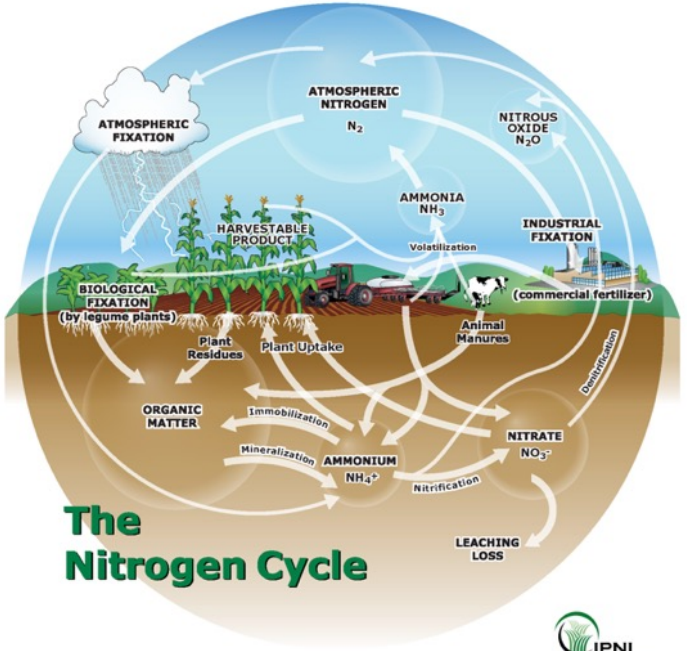
23 PKS x Variety: W. Laf, Wanatah

Yield	W. Laf 23				Wanatah 23	
	No AMS		AMS		No AMS	AMS
UTC	73.4	c	89.0	a	75.9	75.2
P	79.5	b	89.6	a	77.5	74.6
K	72.8	c	85.2	a	76.1	73.9

P or S? **Sulfur: 12 to 16 bu**

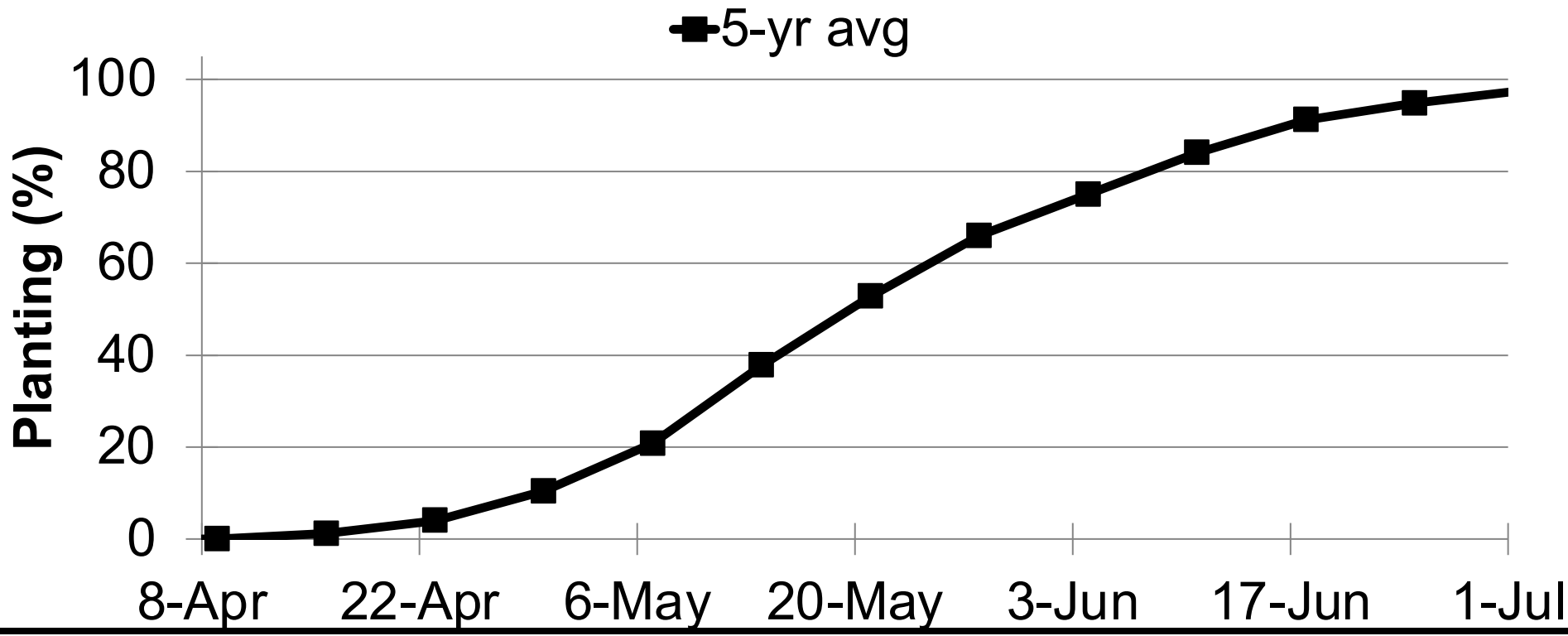
Pooled over varieties, $LSD_{0.10}$





High Yielding Soybeans!

Indiana Soybean Planting: Earliest Years



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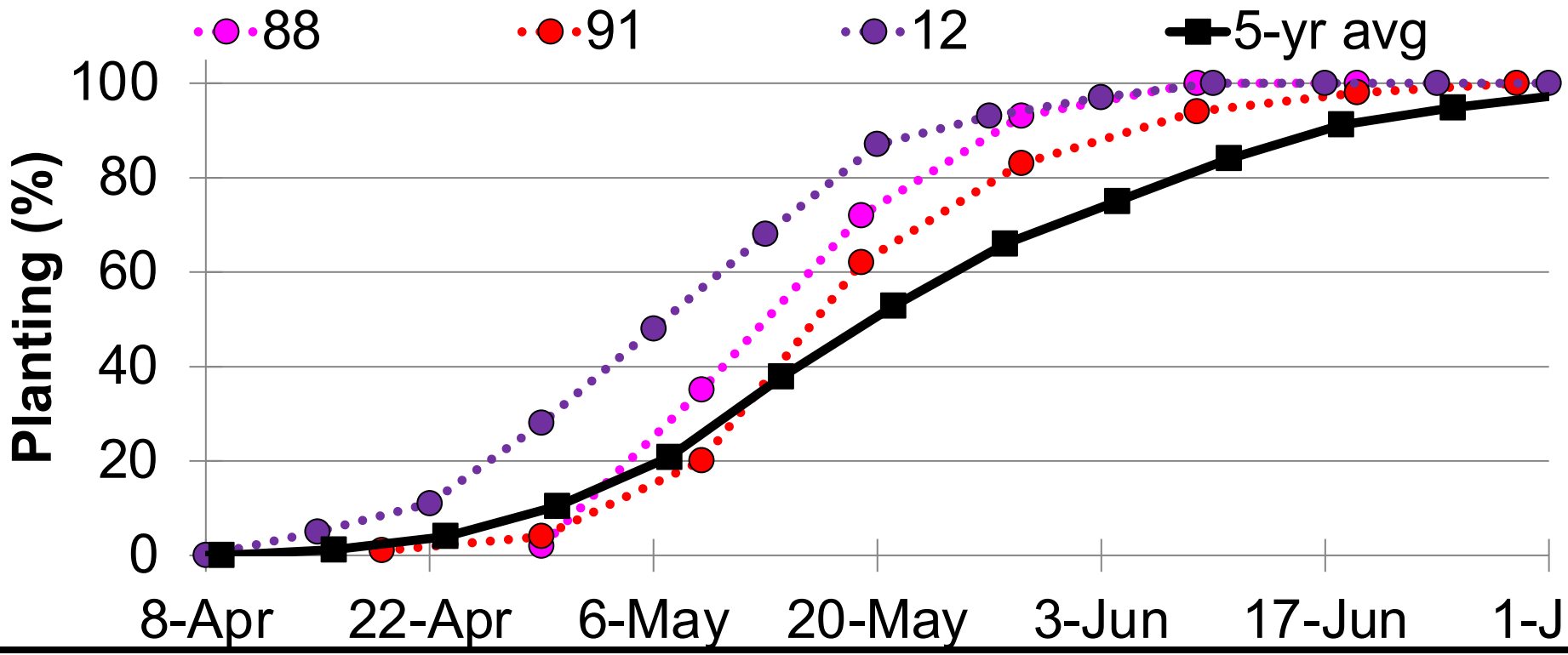

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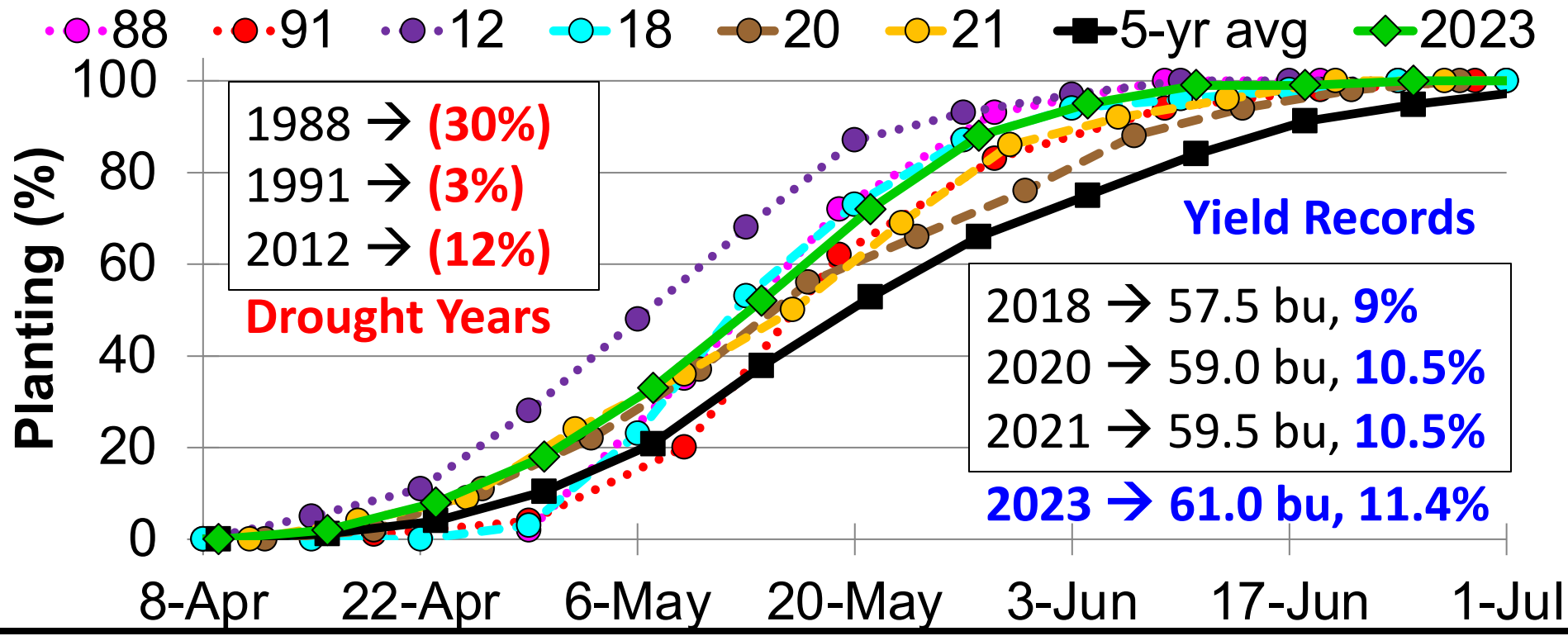


Materials and Methods

- **Location:** 5 site-years (2018 to 2022), West Lafayette, IN
- **Soil**
  - Drummer (fine-silty, mixed, superactive, mesic Typic Endoaquolls)
  - OM: 3.8%, CEC: 24 cmolc/kg, pH 6.6, M3P: 25 mg/kg, M3K: 176 mg/kg
- **Design**: Two-way factorial
  - Whole-Plot Factor: Planting Date
  - Sub-Plot Factor: Fertility (nitrogen + sulfur)
  - Arranged in split-plot design with 5 reps

		2018	2019†	2020	2021	2022
PLANTING						
	EARLY	**11-May**	**11-Jun**	**12-May**	**14-May**	**12-May**
	LATE	**5-Jun**	**27-Jun**	**8-Jun**	**10-Jun**	**6-Jun**

FERTILITY		**SULFUR (S lb/ac**	**NITROGEN (N lb/ac)**
UTC	Untreated	.	.
AMS	Ammonium sulfate	20	17.5
ATS	Ammonium thiosulfate	20	9.3
Gyp	Calcium sulfate	20	.
N + S	AMS or Gyp + Urea	20	40
Urea		.	40

Yield (bu/ac)	2018	
Early Planting	**11-May**	
UTC	62.4	de
AMS	69.5	bc
ATS	71.5	abc
Gypsum	.	
N + S	74.2	ab
Urea	.	
Late Planting	**5-Jun**	
UTC	59.2	e
AMS	60.7	e
ATS	61.9	e
Gypsum	.	
N + S	62.8	de
Urea	.	

Yield (bu/ac)	2018		2020	
Early Planting	11-May		12-May	
UTC	62.4	de	61.9	de
AMS	69.5	bc	79.8	a
ATS	71.5	abc	76.0	ab
Gypsum	.		75.2	abc
N + S	74.2	ab	82.6	a
Urea	.		.	
Late Planting	5-Jun		8-Jun	
UTC	59.2	e	61.9	de
AMS	60.7	e	68.6	bcd
ATS	61.9	e	66.1	de
Gypsum	.		66.7	cde
N + S	62.8	de	66.5	cde
Urea	.		.	.

Yield (bu/ac)	2018		2020		2021	
Early Planting	11-May		12-May		14-May	
UTC	62.4	de	61.9	de	69.0	cde
AMS	69.5	bc	79.8	a	72.3	abcd
ATS	71.5	abc	76.0	ab	.	.
Gypsum	.		75.2	abc	76.9	a
N + S	74.2	ab	82.6	a	75.2	ab
Urea	.		.		67.3	def
Late Planting	5-Jun		8-Jun		10-Jun	
UTC	59.2	e	61.9	de	54.1	g
AMS	60.7	e	68.6	bcd	56.0	g
ATS	61.9	e	66.1	de	.	.
Gypsum	.		66.7	cde	55.4	g
N + S	62.8	de	66.5	cde	56.0	g
Urea	.		.	.	57.3	g

Yield (bu/ac)	2018		2020		2021		2022	
Early Planting	**11-May**		**12-May**		**14-May**		**12-May**	
UTC	62.4	de	61.9	de	69.0	cde	61.8	def
AMS	69.5	bc	79.8	a	72.3	abcd	64.0	bcde
ATS	71.5	abc	76.0	ab	.	.	69.3	ab
Gypsum	.		75.2	abc	76.9	a	67.1	abcd
N + S	74.2	ab	82.6	a	75.2	ab	67.9	abc
Urea	.		.		67.3	def	64.4	bcde
Late Planting	**5-Jun**		**8-Jun**		**10-Jun**		**6-Jun**	
UTC	59.2	e	61.9	de	54.1	g	59.0	efg
AMS	60.7	e	68.6	bcd	56.0	g	61.4	def
ATS	61.9	e	66.1	de	.	.	53.4	g
Gypsum	.		66.7	cde	55.4	g	64.6	abcde
N + S	62.8	de	66.5	cde	56.0	g	65.3	abcd
Urea	.		.	.	57.3	g	63.9	bcde

Yield (bu/ac)	2018		2020		2021		2022		Avg
Early Planting	**11-May**		**12-May**		**14-May**		**12-May**		**EARLY**
UTC	62.4	de	61.9	de	69.0	cde	61.8	def	63.8
AMS	69.5	bc	79.8	a	72.3	abcd	64.0	bcde	71.4
ATS	71.5	abc	76.0	ab	.	.	69.3	ab	72.3
Gypsum	.		75.2	abc	76.9	a	67.1	abcd	73.1
N + S	74.2	ab	82.6	a	75.2	ab	67.9	abc	75.0
Urea	.		.		67.3	def	64.4	bcde	65.9
Late Planting	**5-Jun**		**8-Jun**		**10-Jun**		**6-Jun**		**LATE**
UTC	59.2	e	61.9	de	54.1	g	59.0	efg	58.6
AMS	60.7	e	68.6	bcd	56.0	g	61.4	def	61.7
ATS	61.9	e	66.1	de	.	.	53.4	g	60.5
Gypsum	.		66.7	cde	55.4	g	64.6	abcde	62.2
N + S	62.8	de	66.5	cde	56.0	g	65.3	abcd	62.7
Urea	.		.	.	57.3	g	63.9	bcde	60.6

Minimum Soil Temperature near Plantings

		2018	2020	2021	2022	Avg
Planting	Week	Minimum Soil Temp @ 4-in (F)				
Early	-1	58.5	47.3	48.2	59.0	53.2
Early	1	63.2	57.9	58.0	66.5	61.4
Early	2	63.4	63.7	65.0	66.4	64.6
Early	3	72.4	65.8	61.3	69.7	67.3
LATE	-1	68.3	69.5	70.5	71.1	69.8
LATE	1	69.1	69.4	72.1	70.7	70.3
LATE	2	73.2	72.3	71.3	76.7	73.4
LATE	3	70.8	70.4	74.8	76.2	73.0

EARLY Planting @ 23 West Lafayette

UTC R3 leaf S ~0.26% S

R3 leaf N:S 19:1

Sulfur R3 leaf S ~0.31% S

R3 leaf N:S 17:1

Picture taken August 30, 2023

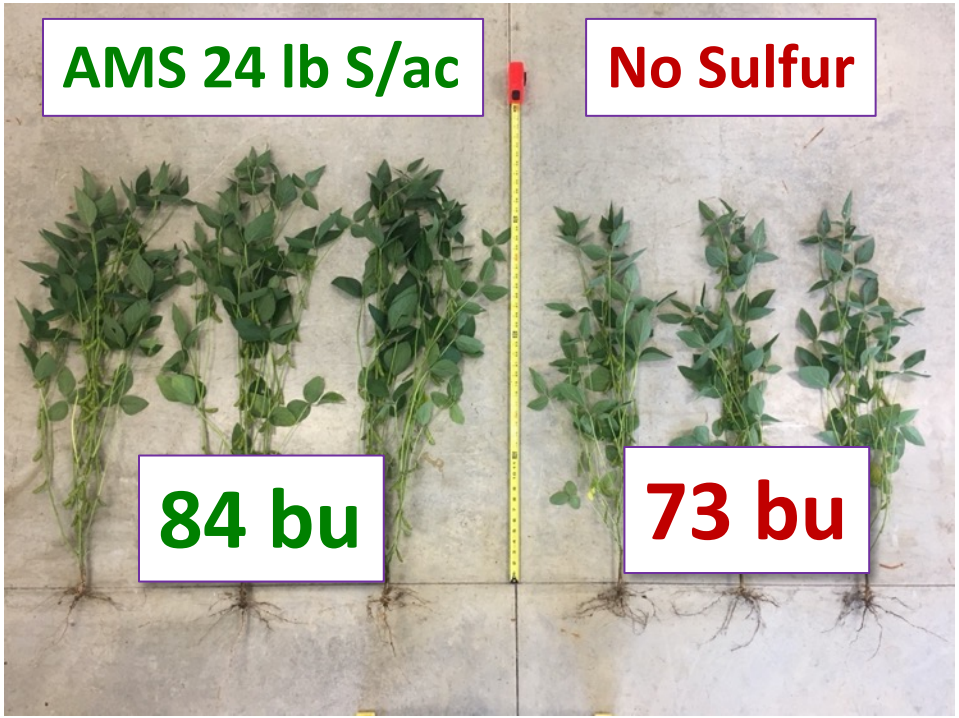
2023 S x Planting: Yield

Yield (bu/ac)	18-Apr		12-May		7-Jun	
UTC	77.5	de	75.4	def	66.6	g
AMS	98.8	a	90.6	b	71.9	efg
ATS	.		84.5	c	70.9	fg
Gypsum	98.9	a	90.5	b	69.0	g
N + S	101.1	a	92.9	b	72.1	efg
Urea	80.9	cd	77.8	d	68.4	g

Conclusions

- **Sulfur Fertility** increased yield in **EARLY** plantings (2018, 2020-23) due to better S supply, N fixation, and leaf retention and seed size increases.
- **Sulfur Fertility** did not affect the yield of **LATE** plantings (2018-23).
- **Cool soil conditions prior to and following EARLY** plantings likely limited mineralization of soil organic matter (e.g., S and N supply), nodulation and fixation, and soybean development (e.g., nodule, plant).

18 INFA Tipton

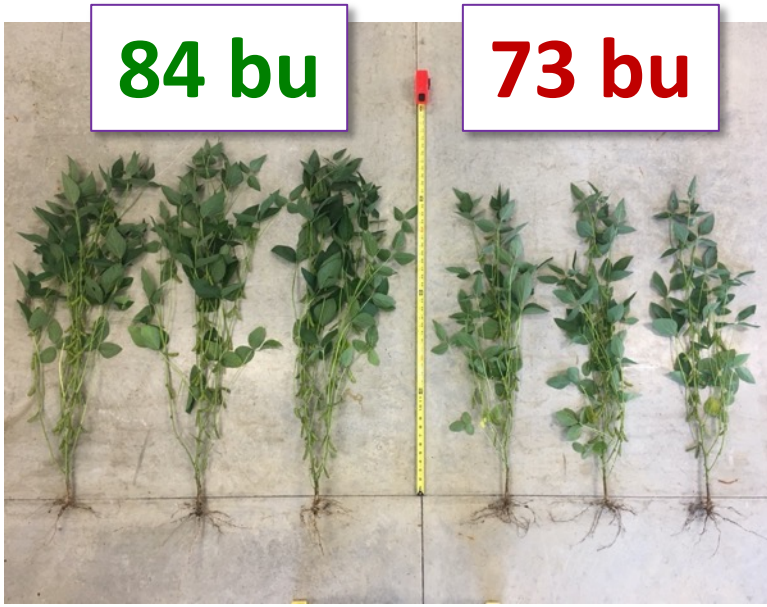


66 pods/plant
18.4 nodes

44 pods/plant
16.6 nodes

2022-23 Cereal Rye x NS in Soybean

- **2 x 4 Factorial** at field-scale
- **2 Cereal Rye** → Yes, No
- **4 NS Fertility**
  - None
  - Sulfur: 20 lb S/ac (pelletized Gypsum)
  - Nitrogen: 40 lb N/ac (Urea)
  - N+S: 40 lb N, 20 lb S
- **Terminate** ~12-16 inches (April-ish)
- **Indiana**: Columbia City, W. Lafayette, Butlerville
- **Illinois**: Effingham, Urbana



18 INFA Tipton

23 Cereal Rye x NS: West Lafayette

April 18th
Terminate Cereal Rye

May 6th
Apply Fertilizer, Plant Soy

Sept 1st
Response of Soybean

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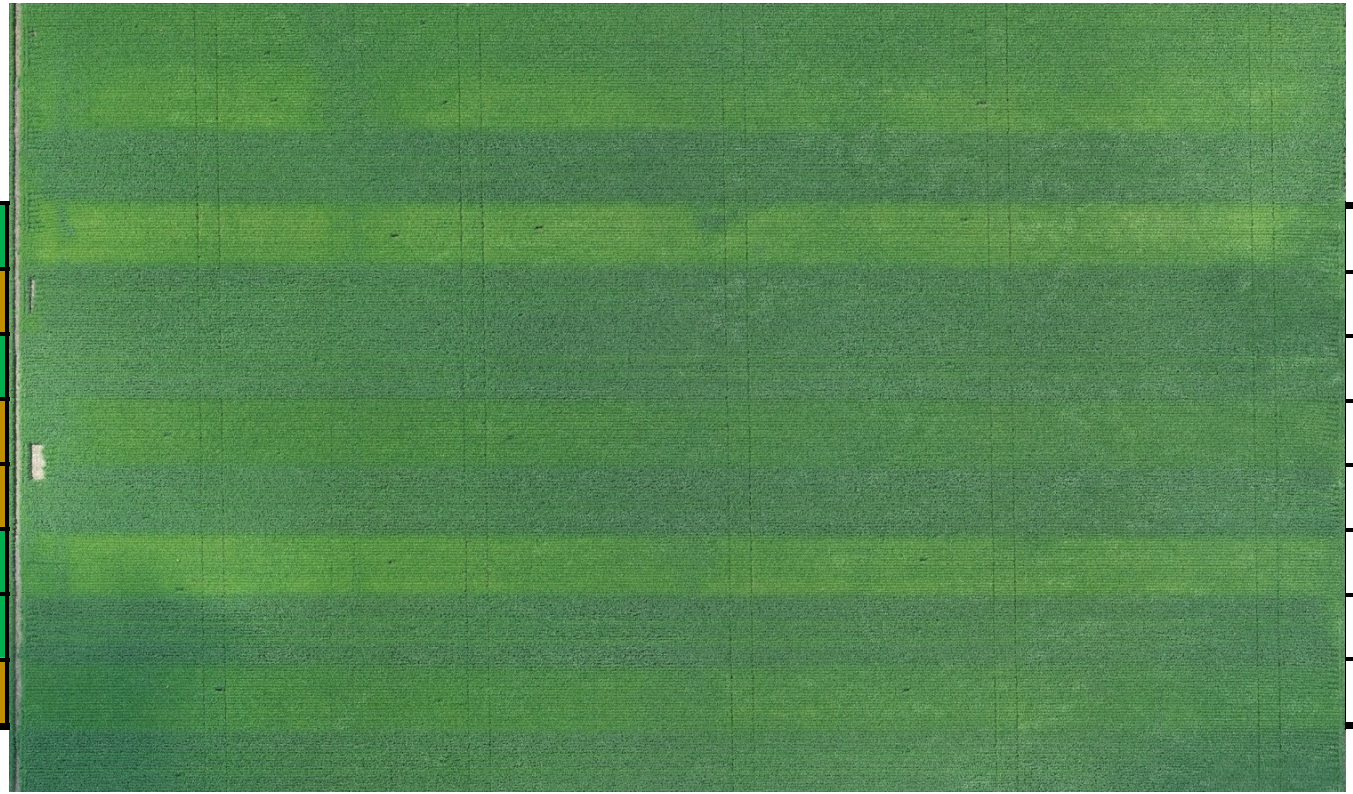
2023 Cereal Rye x NS: West Lafayette

Cereal Rye		Urea
No Cover		Urea + Gypsum
Cereal Rye		Gypsum
No Cover		Urea
No Cover		Gypsum
Cereal Rye		None
Cereal Rye		Urea + Gypsum
No Cover		None

C. Rye x NS in Soybean: 23 West Lafayette

Cover Crop	Fertilizer	Yield (bu/ac)	
None	None	61.2	b
None	Urea	62.4	b
None	Gypsum	71.4	a
None	Urea + Gypsum	74.3	a
Cereal Rye	None	54.7	c
Cereal Rye	Urea	58.2	bc
Cereal Rye	Gypsum	71.0	a
Cereal Rye	Urea + Gypsum	74.8	a

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Sulfur Management Considerations

- **Soluble S Fertilizer applied prior to planting (less than 6 weeks)** of greatest benefit and flexibility
- **Broadcast of 15 to 20 lb S/ac** with soluble source near planting such as AMS, MES10, pelletized Gypsum, or before emergence with ATS.
- **Leaf Nutritional Snapshots then Apply Sulfur**
  - "Close" to **critical S levels (0.25%)**
  - **N:S ~18:1 or higher**

Sulfur Management Considerations

- **Nutrient interactions** can mask or limit yield effects based on timing of potash (i.e., Cl) in low CEC soil.
- **Phosphorus blending** is promising.
- **Timely planting is foundational** for high yielding soybeans; which seems to be intensified when coupled with PRE applications of N + S.
- **Field conditions** that affect S availability and nodulation + N fixation (soil temp, planting, residue)

Thanks for the support!

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