The Sulfur Story From Fertilizer to Yield

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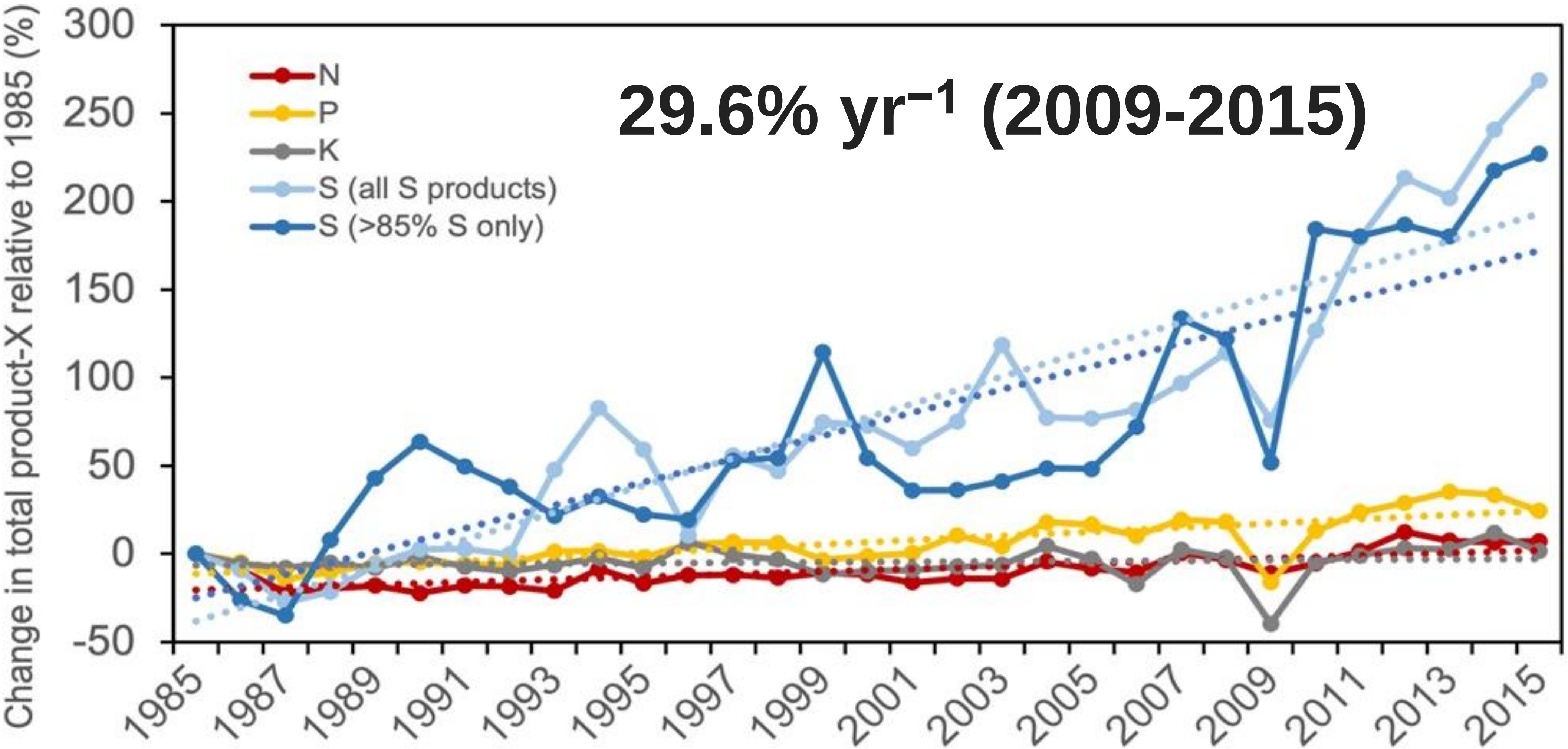
Presentation Outline

- Why sulfur?
- Sulfur fertilization on soybean.
- Sulfur fertilization on corn.
- Sulfur requirement: corn vs soybean.
- When to fertilize with sulfur in IL.

Crop Physiology

% Change in N, P, K, and S Products Relative to 1985

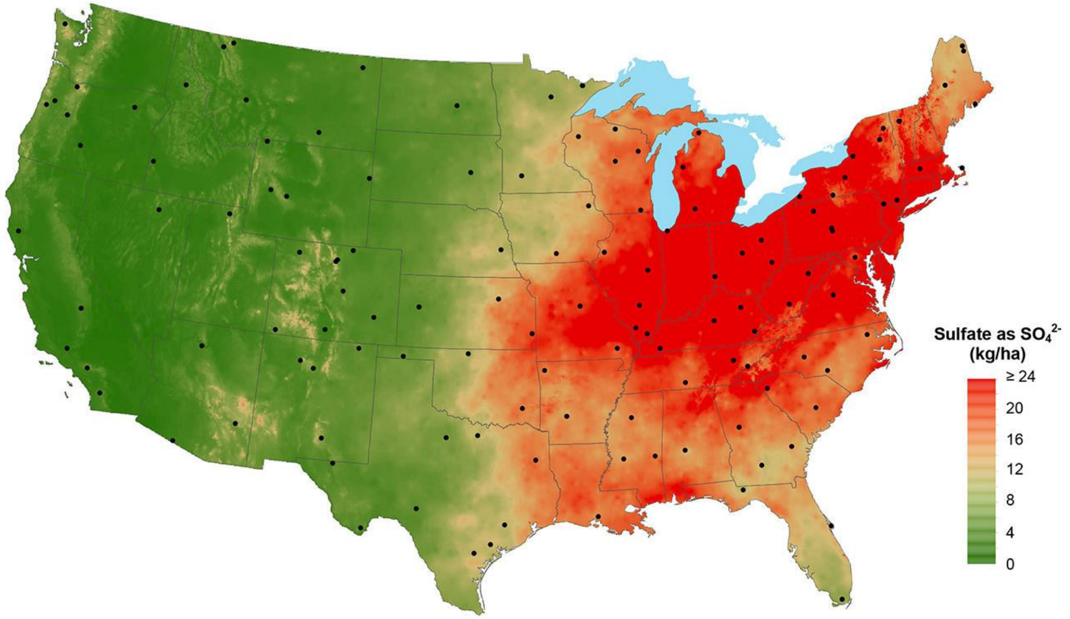


Hinckley & Driscoll (2022)

Crop Physiology

Why Sulfur?

- **Decreased atmospheric sulfate deposition**



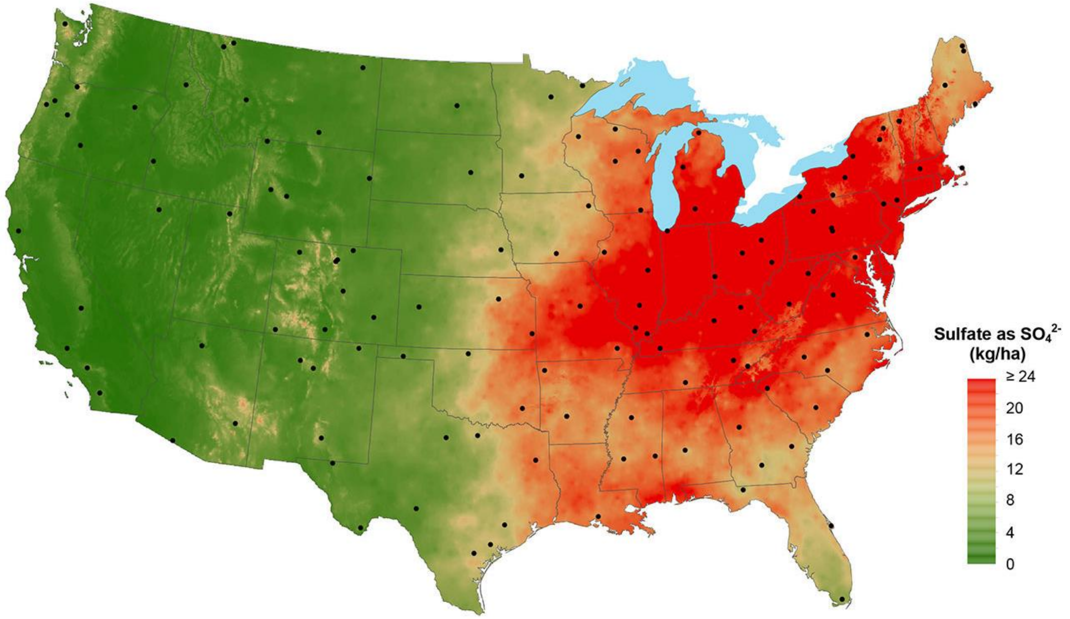
1985 = > 8 lbs S/A → **2021 = ~2 lbs S/A**

Source: National Atmospheric Deposition Program/National Trends Network

Crop Physiology

Why Sulfur?

- Decreased atmospheric sulfate deposition



1985 = > 8 lbs S/A

"During the 1980s, it was estimated that sulfur dioxide damage to agriculture in 11 European countries was causing a loss of $500 million per year" (Bell, 1984).

Source: National Atmospheric Deposition Program/National Trends Network

Crop Physiology

Why Sulfur?

- **Decreased atmospheric sulfate deposition.**
- **Use of higher purity phosphate fertilizers that do not contain or contain little S.**
- **Increasing crop yield (greater S uptake and removal).**
- **Depletion of soil S reserves?**

Reports of S deficiency are becoming more frequent and have been reported in the US Midwest (Sawyer et al., 2011; Camberato and Casteel, 2017)

Crop Physiology

In-season Applications of Sulfur Sources in Different Methods on Soybean

Fluid Fertilizer Foundation

Dr. Vitor Favoretto & Dr. Fred Below

Crop Physiology

FFF Soybean S Treatment List

Trt #	Sulfur Source	Placement
1	Untreated control (UTC)	-
2	Ammonium sulfate (AMS)	Topdress
3		
4		
5		
6		
7		
8		

†All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)

Crop Physiology

FFF Soybean S Treatment List

Trt #	Sulfur Source	Placement
1	Untreated control (UTC)	-
2	Ammonium sulfate (AMS)	Topdress
3	AMS	Mid-row surface band
4		
5	Ammonium thiosulfate (ATS)	Mid-row surface band
6		
7	Potassium thiosulfate (KTS)	Mid-row surface band
8		

†**All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)**

Crop Physiology

FFF Soybean S Treatment List

Trt #	Sulfur Source	Placement
1	Untreated control (UTC)	-
2	Ammonium sulfate (AMS)	Topdress
3	AMS	Mid-row surface band
4	AMS	"DRY-DROP"
5	Ammonium thiosulfate (ATS)	Mid-row surface band
6	ATS	Y-DROP
7	Potassium thiosulfate (KTS)	Mid-row surface band
8	KTS	Y-DROP

†All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)

Crop Physiology

Dr. Foxhoven (2021)

Dry-Drop (Dry Y-Drop)

FFF Soybean S Treatment List

Trt #	Sulfur Source	Placement
1	Untreated control (UTC)	-
2	Ammonium sulfate (AMS)	Topdress
3	AMS	Mid-row surface band
4	AMS	"DRY-DROP"
5	Ammonium thiosulfate (ATS)	Mid-row surface band
6	ATS	Y-DROP
7	Potassium thiosulfate (KTS)	Mid-row surface band
8	KTS	Y-DROP

†All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)

Crop Physiology

Trial Information and Soil Test Results

- **Location: Champaign, IL (2021)**
- **Planting date: May 14th**
- **Variety: GH3132E3**
- **Population: 140,000 plants $acre^{-1}$**
- **Row spacing: 30 inches**
- **Sidedress application: July 6th (R1 growth stage)**

SOM	pH	CEC	NO_3	NH_4	P§	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B
%	unit	meq/100g	ppm											
3.9	6.3	20.1	5.7	3.5	30	121	2623	507	8	1.2	27	127	1.9	0.7

Crop Physiology

FFF Soybean S Grain Yield

Sulfur Source	Placement	Grain Yield
		bushels/A
UTC	-	**83.4**
AMS	Topdress	
"	Mid-row surface band	
"	"DRY-DROP"	
ATS	Mid-row surface band	
"	Y-DROP	
KTS	Mid-row surface band	
"	Y-DROP	
	LSD (α=0.05)	NS

†**All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)**

Crop Physiology

FFF Soybean S Grain Yield

Sulfur Source	Placement	Grain Yield	
		bushels/A	
UTC	-	83.4	Δ UTC
AMS	**Topdress**	**81.0**	-2.4
"	Mid-row surface band		
"	"DRY-DROP"		
ATS	Mid-row surface band		
"	Y-DROP		
KTS	Mid-row surface band		
"	Y-DROP		
	LSD (α=0.05)	NS	

†All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)

Crop Physiology

FFF Soybean S Grain Yield

Sulfur Source	Placement	Grain Yield	
		bushels/A	
UTC	-	83.4	Δ UTC
AMS	Topdress	81.0	
"	**Mid-row surface band**	**82.2**	-1.2
"	"DRY-DROP"		
ATS	**Mid-row surface band**	**80.8**	-2.6
"	Y-DROP		
KTS	**Mid-row surface band**	**81.7**	-1.7
"	Y-DROP		
	LSD (α=0.05)	NS	

†All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)

Crop Physiology

FFF Soybean S Grain Yield

Sulfur Source	Placement	Grain Yield	
		bushels/A	
UTC	-	83.4	Δ UTC
AMS	Topdress	81.0	
"	Mid-row surface band	82.2	
"	**"DRY-DROP"**	**82.5**	-0.9
ATS	Mid-row surface band	80.8	
"	**Y-DROP**	**83.5**	+0.1
KTS	Mid-row surface band	81.7	
"	**Y-DROP**	**80.0**	-3.4
	LSD (α=0.05)	NS	

† **All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)**

Crop Physiology

FFF Soybean S Grain Yield

Sulfur Source	Placement	Grain Yield	
		bushels/A	
UTC	-	83.4	Δ UTC
AMS	Topdress	81.0	-2.4
"	Mid-row surface band	82.2	-1.2
"	"DRY-DROP"	82.5	-0.9
ATS	Mid-row surface band	80.8	-2.6
"	Y-DROP	83.5	+0.1
KTS	Mid-row surface band	81.7	-1.7
"	Y-DROP	80.0	-3.4
	LSD (α=0.05)	NS	

†**All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)**

Crop Physiology

FFF Soybean S Grain Yield

Sulfur Source	Placement	Grain Yield
		bushels/A
UTC	-	83.4
AMS	Topdress	81.0
[illegible]	Mid-row surface band	82.2
"	"DRY-DROP"	82.5
ATS	Mid-row surface band	80.8
"	Y-DROP	83.5
KTS	Mid-row surface band	81.7
"	Y-DROP	80.0
	LSD (α=0.05)	NS

Yield tended to decrease….
Why?

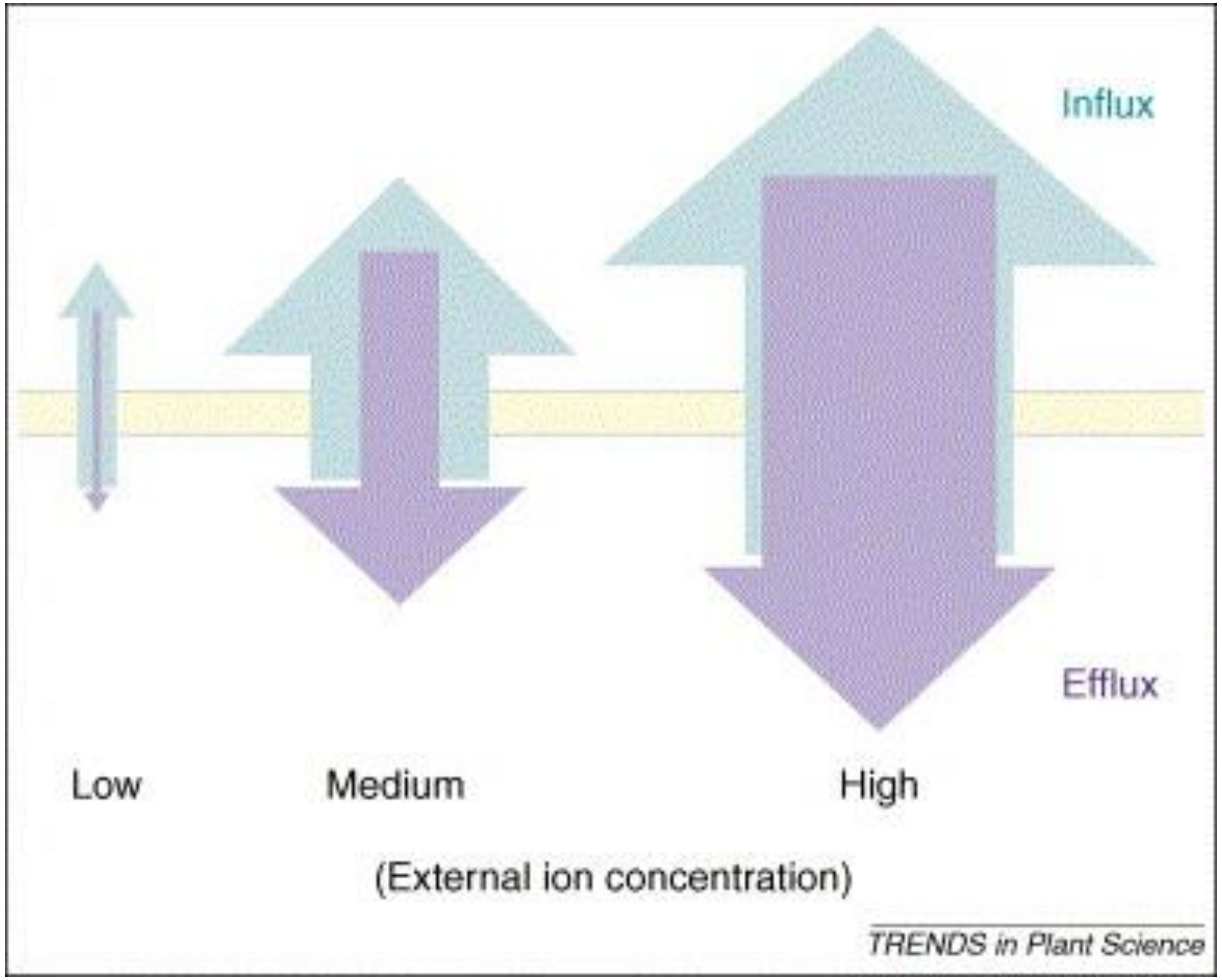
†All sources applied at 20 lbs.ac^{-1} of sulfur at beginning flowering (R1)

Crop Physiology

Futile Cycling of Sulfur?

- Root cells are not equipped to prevent an uptake of excess sulfate (Rennenberg, 1984)

- High rates of apparently “futile” cycling of SO_4^{2-} across the plasma membrane of root cells occur when these ions are present at high concentrations in the rhizosphere solution (Britto and Kronzucker, 2006).

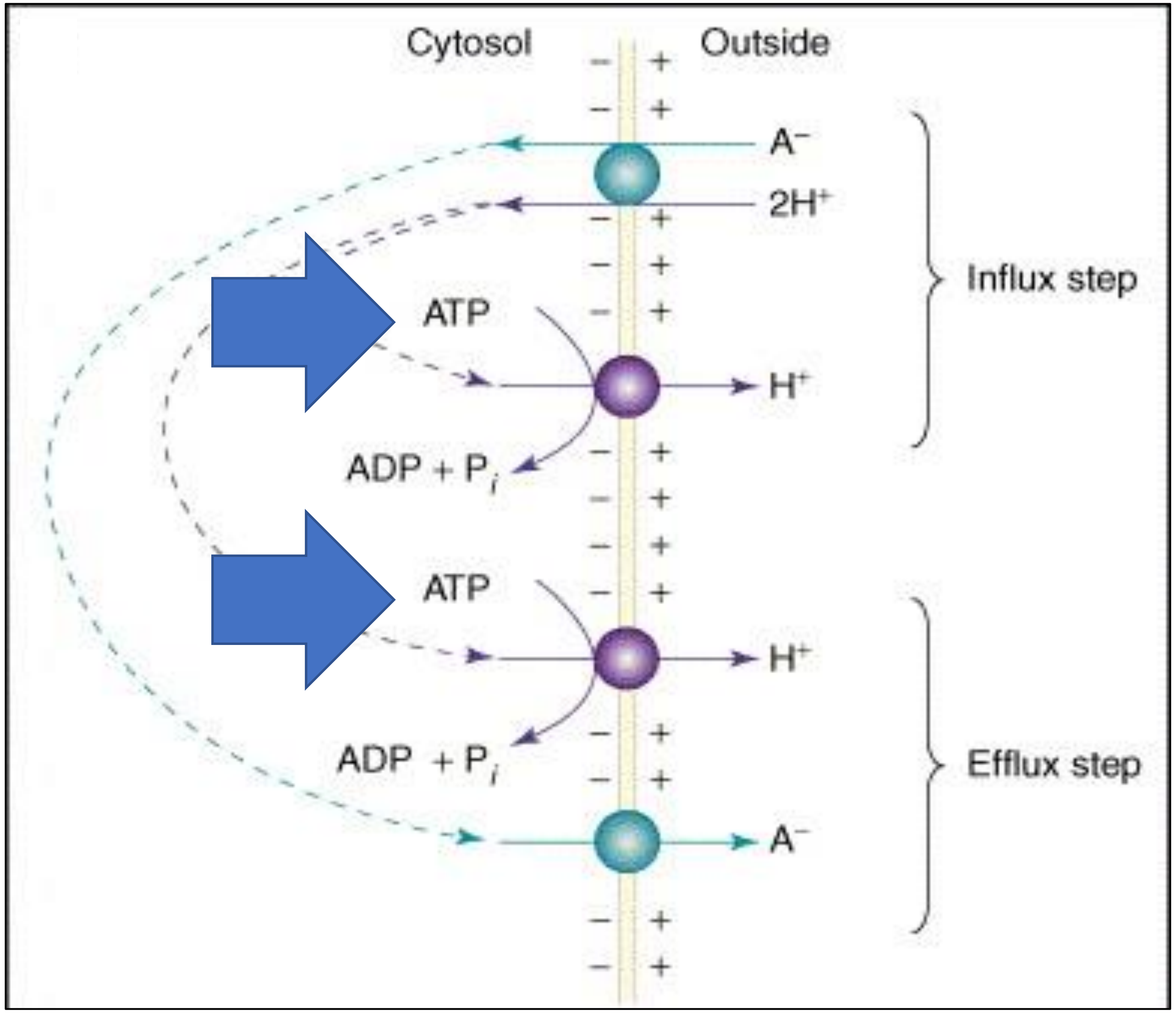


Britto & Kronzucker (2006)

Crop Physiology

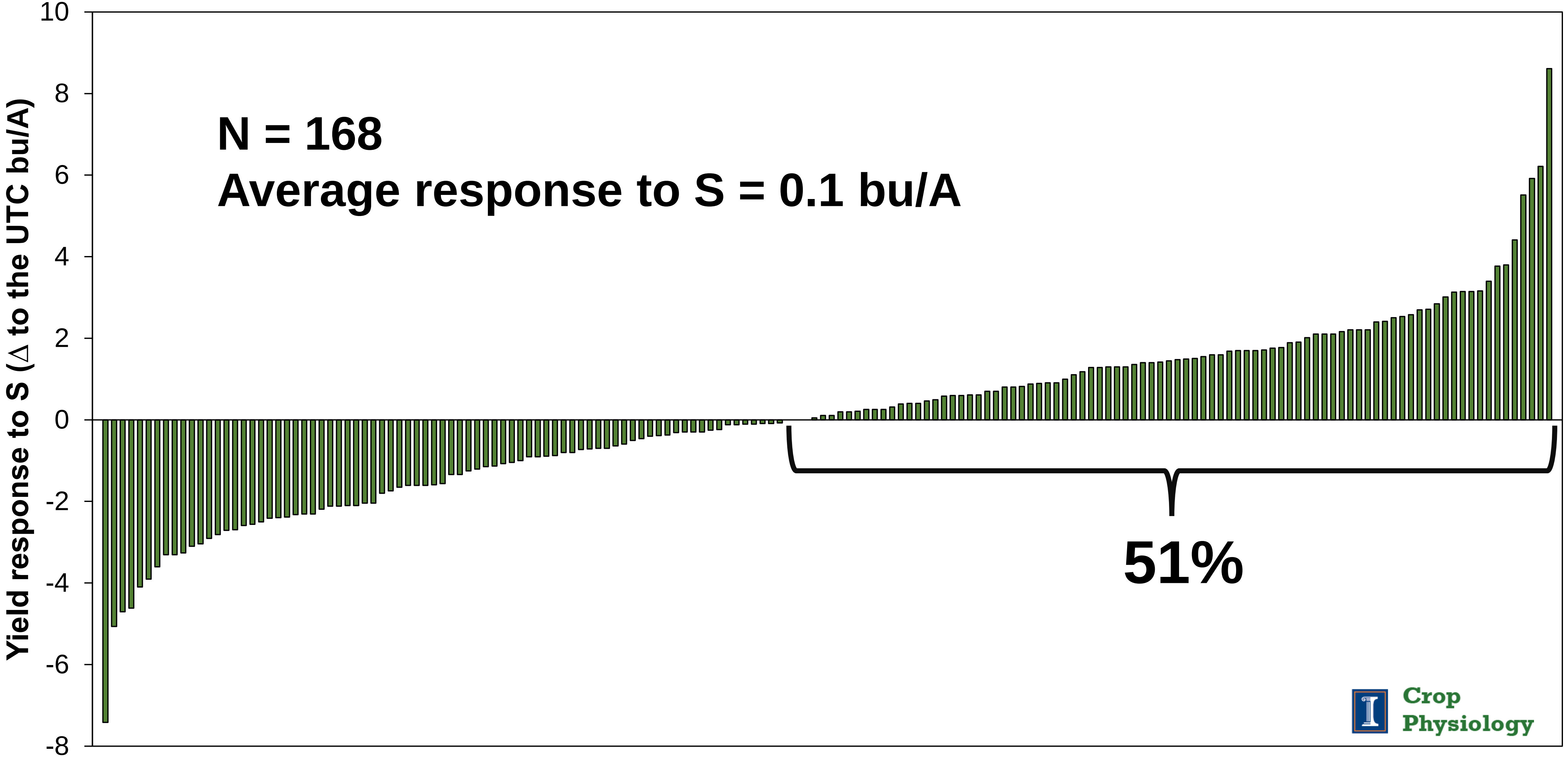
Futile Cycling of Sulfur?

The energy costs associated with the "futile" cycling are believed to constitute a significant portion of the total respiratory energy expenditure of the root



Britto & Kronzucker (2006)

CPL Soybean Yield Response to S



13 site-year and six replications average yield response to sulfur containing fertilizer. Champaign, IL (2023)

Soybean Yield Response to S

What about Corn?

13 site-year and six replications average yield response to sulfur containing fertilizer. Champaign, IL (2023)

In-season Applications of Sulfur Sources in Different Methods on Corn

Dr. Connor Sible & Dr. Fred Below

Crop Physiology

2022 Treatment List and Illinois Location

Treatment	Product, Application†	Nutrients Supplied
Untreated Control	-	-
Liquid Sidedress	UAN-32, Y-Drop (V5)	60 lbs N
Liquid Sidedress	ATS + UAN-32, Y-Drop (V5)	60 lbs N, 20 lbs S
Dry Topdress	AMS + Urea (V5)	60 lbs N, 20 lbs S

† All treatments applied at the V5 growth stage. UAN-32; urea ammonium nitrate (32-0-0), AMS; ammonium sulfate (21-0-0-24S), ATS, ammonium thiosulfate (12-0-0-26S). Total N rate for all treatments = 220 lbs. N/A

Crop Physiology

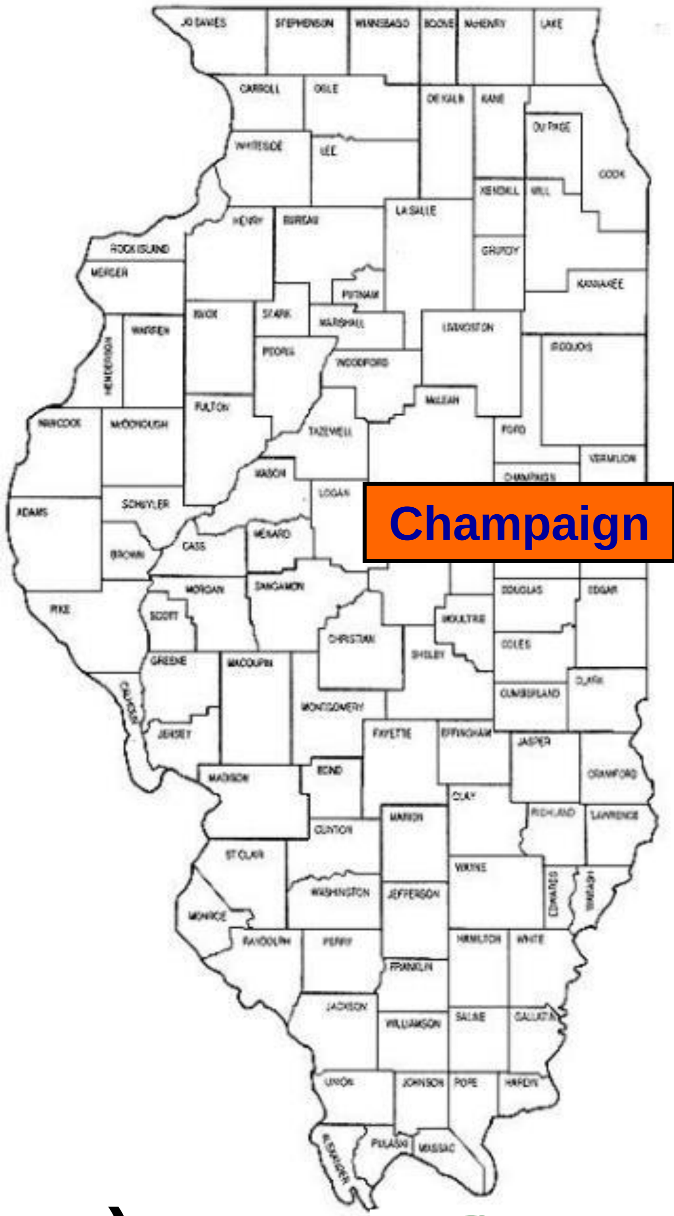
Trial Information at Champaign, Illinois

Soil Test

OM†	CEC	pH	P††	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B
%	meq/100g	unit	———	———	———	———	ppm	———	———	———	———	———
3.9	21.1	6.4	22	103	2858	500	8	2	54	116	1.8	0.7

† OM, Organic Matter; CEC, Cation Exchange Capacity
†† Mehlich-3 extraction

- **Preplant N → 160 lbs N as UAN-32**
- **Planting Rate → 34,000 plants/A**
- **Row Spacing → 30 inches**
- **Sidedress Application → June 15th (V5 Growth Stage)**



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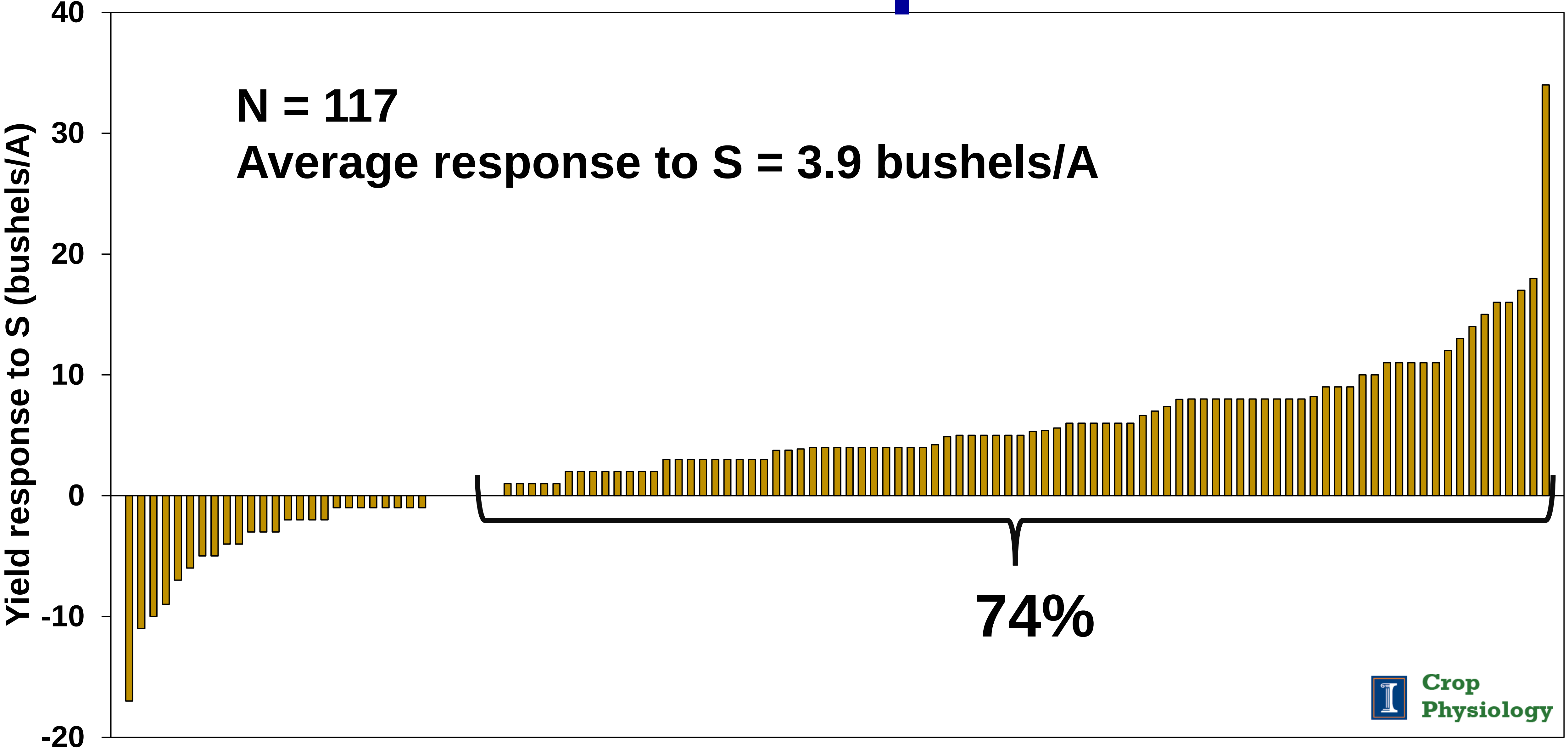
Grain Yield and Yield Components

Treatment Description†	Grain Yield	
	bushels per acre	
Untreated Control	**252**	Δ UTC
Liquid Sidedress (UAN)		**+6**
Liquid Sidedress (UAN/ATS)		**+11**
Dry Topdress (Urea/AMS)		**+4**
LSD (α = 0.1)	NS (p = 0.11)	

† All treatments applied at the V5 growth stage. UAN-32; urea ammonium nitrate (32-0-0), AMS; ammonium sulfate (21-0-0-24S), ATS, ammonium thiosulfate (12-0-0-26S)
* Statistically different from the untreated control using a paired t-test at α = 0.1

Crop Physiology

Corn Yield Response to S



15 site-year and six replications average yield response to sulfur containing fertilizer. Champaign, IL (2023)

Sulfur on Soybean vs Corn

Sulfur on Soybean vs Corn

IL Corn & Soybean Average Yield

Illinois record average corn yield is **215** bushels/A in 2022

Illinois record average soybean yield is **65** bushels/A in 2021

Corn & Soybean Sulfur Needs

	Corn (215 bu/A)	Soybean (65 bu/A)
Need	lbs/A	
Uptake	22	18
Removal	12	11

Adapted from: Ross Bender (2019)

Crop Physiology

Sulfur Sources

- Atmospheric deposition = 2-3 lbs S/A
- Soil organic matter (~95%) = 3-5 lbs S/A per %OM
- Soil solution (adsorbed - AEC)
- Crop residue (corn vs soybean)

Corn & Soybean Sulfur Needs

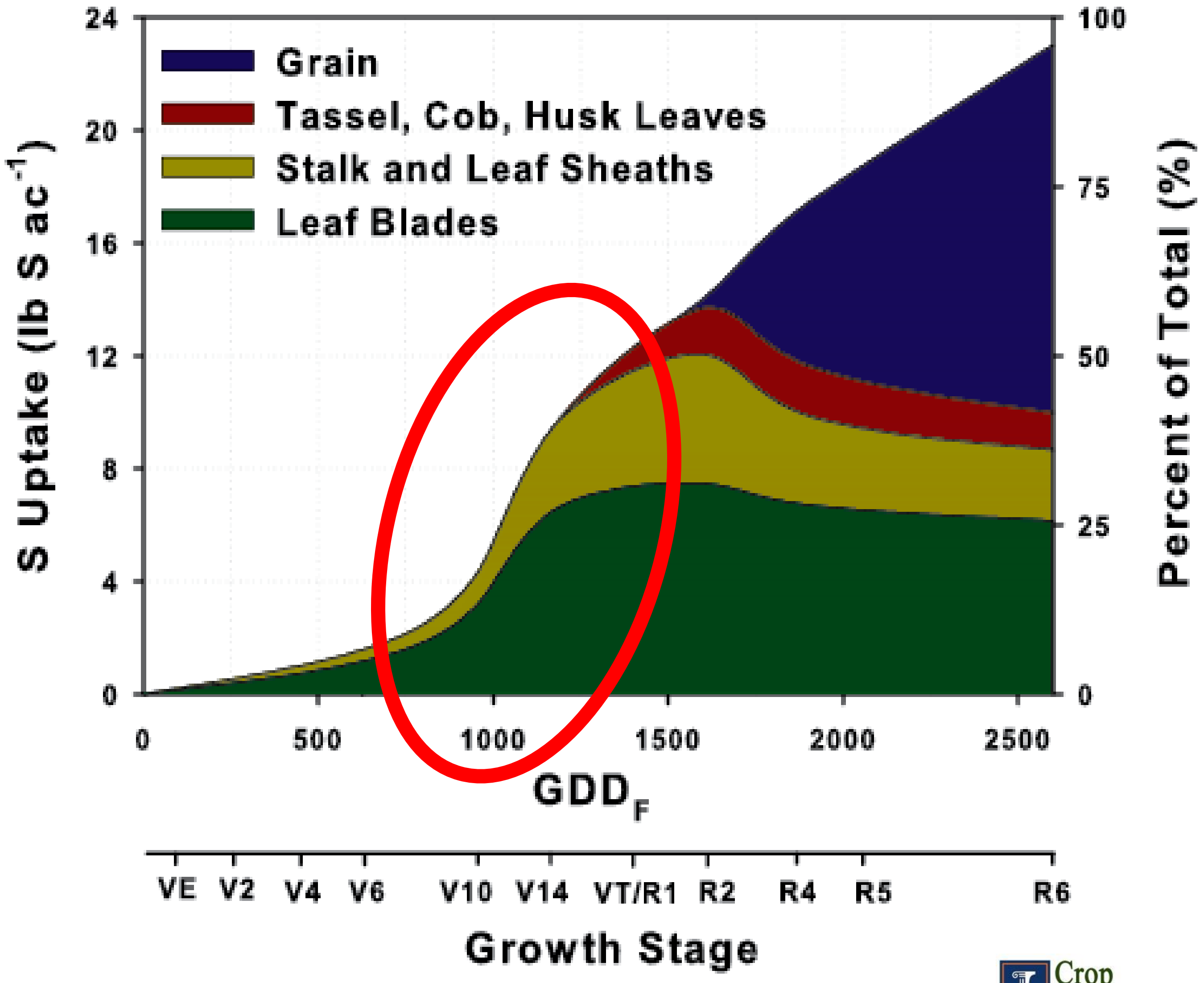
	Corn (215 bu/A)	Soybean (65 bu/A)
Need	lbs/A	
Uptake	22	18
Removal	12	11
Supply		
Atmosphere	2	2
Organic matter (3.7%)	15	15

Adapted from: Ross Bender (2019)

Crop Physiology

Sulfur Uptake for Corn Yielding 230 Bu Ac^{-1}

- **Maximum uptake rate (V10-V14) = 0.62 lbs/A day**
- **25% of total sulfur taken up in 10 days (~6 lbs)**

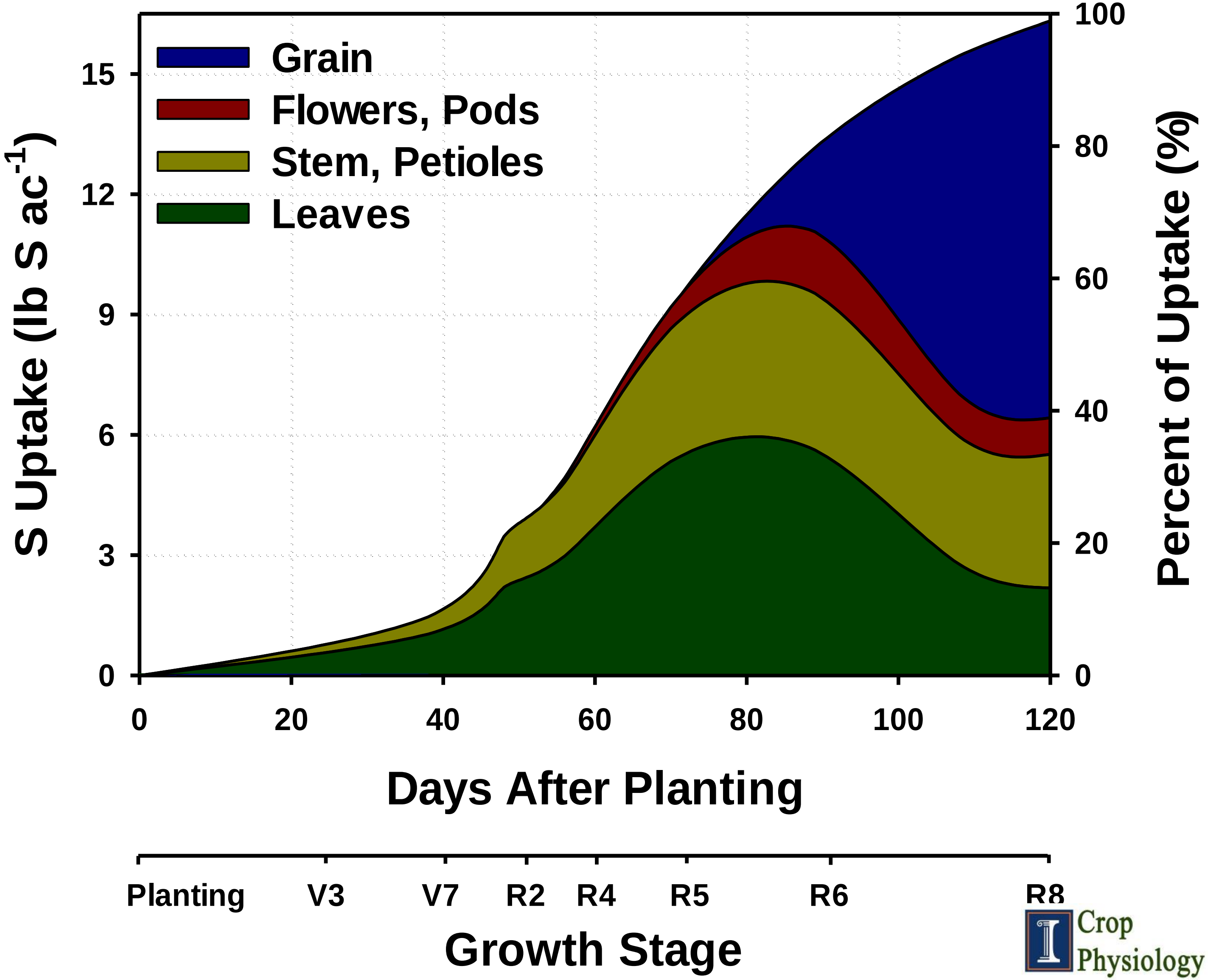


Bender et. al (2013)

Crop Physiology

Sulfur Uptake for Soybean Yielding 60 Bu Ac^{-1}

- **Maximum uptake rate (R4) = 0.25 lbs/A day**
- **Season long S uptake**



Bender et. al (2015)

Sulfur on Soybean vs Corn

Corn max. uptake rate is 148% higher than Soybean

Soil mineralization

> demand

Maximum S Uptake Rate
0.25 lbs S/A day (60bu)

< demand

Maximum S Uptake Rate
0.62 lbs S/A day (230 bu)

Sulfur Fertilization Strategy For Soybean

- **Fertilization usually not responsive for soybean in IL when growing for average yield (~60 bu/A)**

- **Don’t fertilize?**

- **Grain removal = depletion of the organic S pool**

- **Fertilize corn and residual S for soybean**

Crop Physiology

Corn & Soybean Sulfur Needs

	Corn (215 bu/A)	Soybean (65 bu/A)
Need	lbs/A	
Uptake	22	18
Removal	12	11
Supply		
Atmosphere	2	2
Organic matter (3.7%)	15	15
Deficit	5	1

Adapted from: Ross Bender (2019)

Crop Physiology

Corn & Soybean Sulfur Needs

	Corn (230 bu/A)	Soybean (60 bu/A)
Need	———lbs/A———	
Uptake	22	18
Removal	12	11
Supply		
Atmosphere	2	2
Organic matter (3.7%)	15	15
Fertilizer	20	
Deficit/Surplus	15	

Adapted from: Ross Bender (2019)

Crop Physiology

Corn & Soybean Sulfur Needs

	Corn (230 bu/A)	Soybean (60 bu/A)
Need	lbs/A	
Uptake	22	18
Removal	12	11
Supply		
Atmosphere	2	2
Organic matter (3.7%)	15	15
Fertilizer	20	
Deficit/Surplus	15	

Adapted from: Ross Bender (2019)

Crop Physiology

Sulfur Fertilization Strategy For Corn/Soybean Rotation

- Sulfur application for corn have shown to also benefit soybean the following year without applying sulfur to the soybean crop. Soybean tends to scavenge and recycle sulfur better than corn (Kaiser and Strok, 2018)

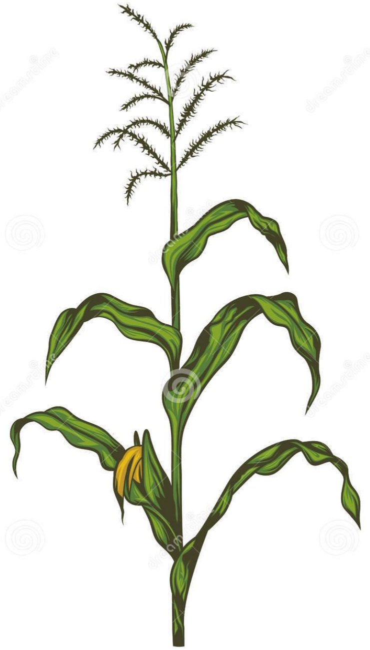
Where to expect response to S Fertilization

- Soils with low OM%
- Sandy soils
- High precipitation and well drained soils
- High nitrogen loss induces S response
- No history of manure application
- **High yields**

Sulfur on Soybean & Corn

Higher yield = ↑ S requirement & uptake rate

Your soil might not keep up with the plant demand!



High Yielding Soybean

"In order to produce high soybean yields, a systems approach must be taken, combining various management factors to optimize yield."

2022 - Six Secrets of 80 Bushel Soybean

Rank	Factor	Value bu/acre
1	Weather (Planting date)	35+
2	Genetics/Variety	25
3	Row Spacing	9
4	Foliar Protection	5
5	Fertility	4
6	Seed Treatment	2
	TOTAL	80 bu

Given key prerequisites

Crop Physiology

Soybean S Sources & Timing Treatments

Fall or Spring	x	UTC (0 S) AMS MES10 Polyhalite Sus-terra Gypsum

All sulfur fertilizers applied at 20 lbs. S $acre^{-1}$

All treatments balanced for N (18), P (80), and K (60).

Champaign, IL (2021)

Crop Physiology

Soybean S Sources & Timing
Trial Information

Soil Test

OM	CEC	pH	P†	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B
%	meq/100g	units	ppm									
4.7	29.9	6.0	48	144	3626	792	14	2	19	185	3.3	0.8

† Mehlich-3 extraction

- Fall Fertilization → November 6th, 2020
- Spring Fertilization → April 2nd, 2021
- Planting Date → April 2nd, 2021
- Population → 160,000/A
- Variety → GH3582E3
- Fungicide + Insecticide @ R3

Champaign, IL 2021

Crop Physiology

Effect of S Source and Fertilization Timing on Soybean Grain Yield

Treatment	Grain Yield		
	Fall		Spring
	bushels/acre		
UTC	89.2	Δ UTC	
AMS		+3.1	
MES10		+0.8	
Polyhalite		+1.5	
Sus-terra		+1.9	
Gypsum		+1.9	
Average			

LSD_{timing} (.10) = 1.4; $LSD_{source\ x\ timing}$ (.10) = NS

Champaign, 2021

Crop Physiology

Effect of S Source and Fertilization Timing on Soybean Grain Yield

Treatment	Grain Yield: Fall	Grain Yield: Spring	Δ UTC
	bushels/acre		
UTC	89.2	87.8	
AMS	92.3	88.9	+1.1
MES10	90.0	86.5	-1.3
Polyhalite	90.7	90.3	+2.5
Sus-terra	91.1	88.7	+0.9
Gypsum	91.1	88.7	+0.9
Average	90.7	88.5	

LSD_{timing} (.10) = 1.4; $LSD_{source\ x\ timing}$ (.10) = NS

Champaign, 2021

Crop Physiology

Effect of S Source on Soybean Grain Quality

Treatment	Oil	Protein
	———— % ————	
UTC	20.8	32.5
AMS	20.6	32.9
MES10	20.7	33.0
Polyhalite	20.7	32.8
Sus-terra	20.7	32.9
Gypsum	20.6	33.0
LSD (.10)	0.1	0.3

Champaign, 2021

Crop Physiology

Key Takeaways

- Maintaining adequate levels of sulfur through fertilization is essential to prevent depletion of organic sulfur.

- Corn tends to be more responsive to sulfur fertilization, likely due to its higher uptake rate.

- High-yielding soybeans generally exhibit greater responsiveness to sulfur fertilization.

Crop Physiology Laboratory Team – 2022

Principal Investigator
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- Thomas Alwardt

Crop Physiology

Special thanks to the Fluid Fertilizer Foundation!

Fluid Fertilizer Foundation

For More Information:

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