Nutrients to Soybean: Enhanced, Supplied, or Suppressed?

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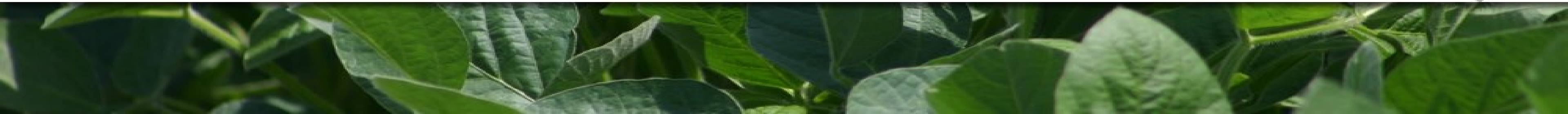
@PurdueSoybean and **Purdue Crop Chat podcast**

SOYBEAN STATION
DELIVERING FIRST CLASS SOYBEAN INFORMATION



Classic Sulfur Deficiency

- Coarse-textured: Sand, Loamy Sand, Sandy Loam
- Low Organic Matter < 2%

Situational Sulfur Deficiency: Factors Affecting Sulfur Availability

Early to Timely Planting

cool soils, limited mineralization

Situational Sulfur Deficiency: Factors Affecting Sulfur Availability

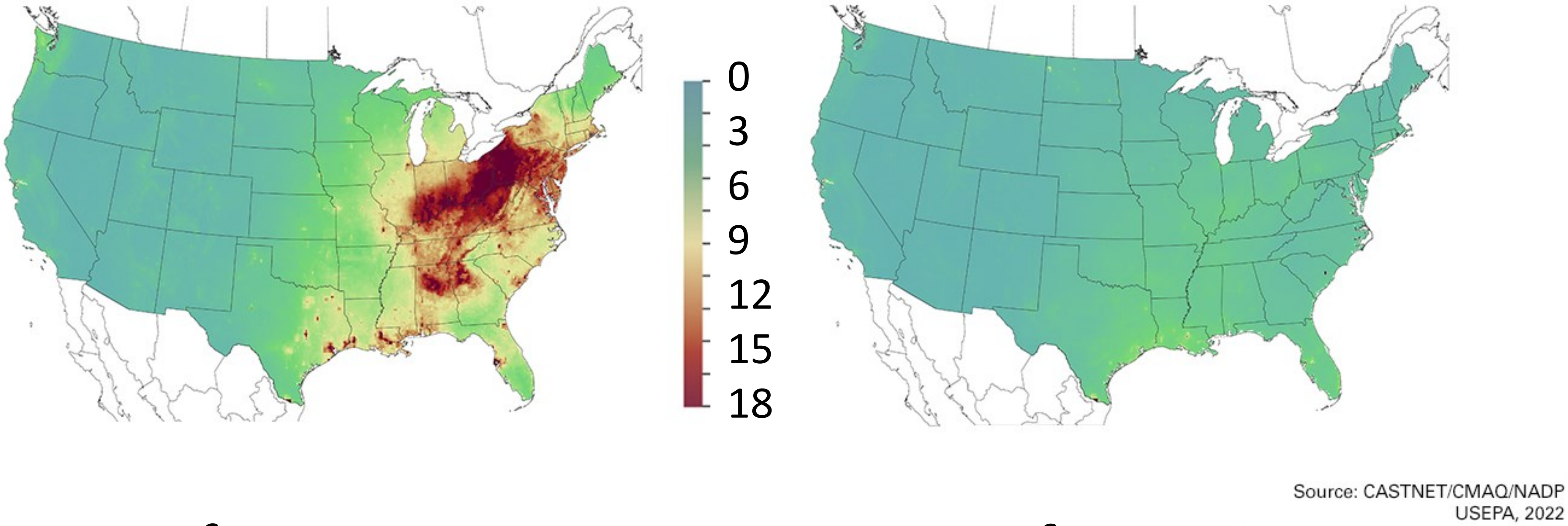


Residue with High Carbon

Immobilization of Sulfur

Sulfur: Who Needs It…Maybe You?

Total Sulfur Deposition (lb/ac)



Avg. of 2000-2002

Avg. of 2019-2021

Sulfur Effects on Soybean

No Sulfur

20 lb S/ac

No Sulfur

20 lb S/ac

LaCrosse, IN – Sept 7, 2017


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?

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	[illegible]		
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	[illegible]	50.9	a
NPK	43.6	b	52.0	a

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

$LSD_{0.10}$

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		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**

23 PKS x Variety: W. Laf, Wanatah

Yield	W. Laf 23				Wanatah 23	
	No AMS		AMS		No AMS	AMS
UTC	73.4		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**

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)

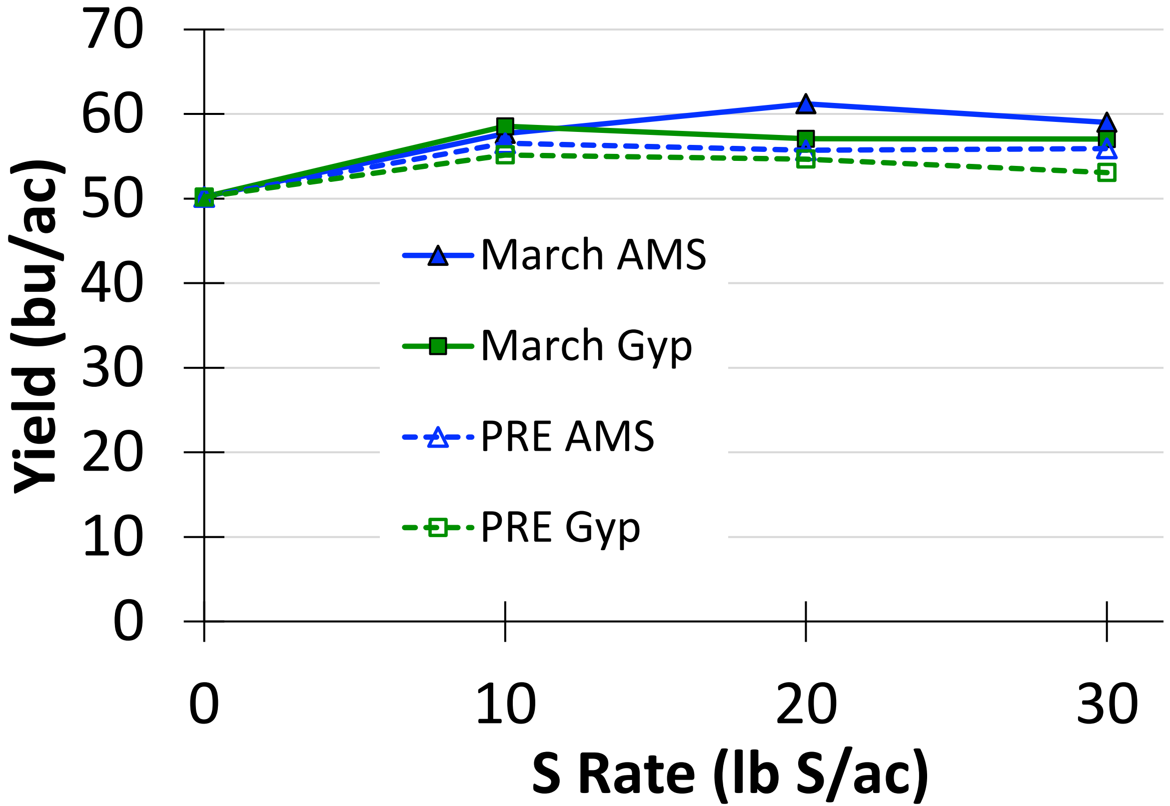
22 Sulfur Timing: March vs. PRE

- LaCrosse
- Timing: March vs. PRE
- Source:
  - **AMS** 21-0-0-24S
  - **PolyS** 0-14-0-19S, 3.6Ca, 12.2Mg
  - **Gypsum** 0-0-0-17S, 22Ca
- Rate: 0, 10, 20, 30 lb S/ac

S Timing: Other Nutrients Applied

S Rate	AMS	PolyS	PolyS	PolyS	Gypsum
lb S/ac	lb N/ac	lb K_2O/ac	lb Mg/ac	lb Ca/ac	lb Ca/ac
0	.	.			.
10	8.8	7.4	6.4	1.9	12.9
20	17.5	14.7	12.8	3.8	25.9
30	26.3	22.1	19.3	5.7	38.8

22 Sulfur Timing: March vs. PRE



Timing

- March 58.0 a
- PRE 55.5 b
- UTC 50.2 c

Rate by Timing

- March → ~20 lb S/ac
- PRE → ~10 lb S/ac

- 1200 companies have "Products derived from naturally occurring from micro and macro organisms, plant extracts, and other natural materials used to enhance crop production."

Chris Taylor
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www.MixingBowlhub.com

Western Growers

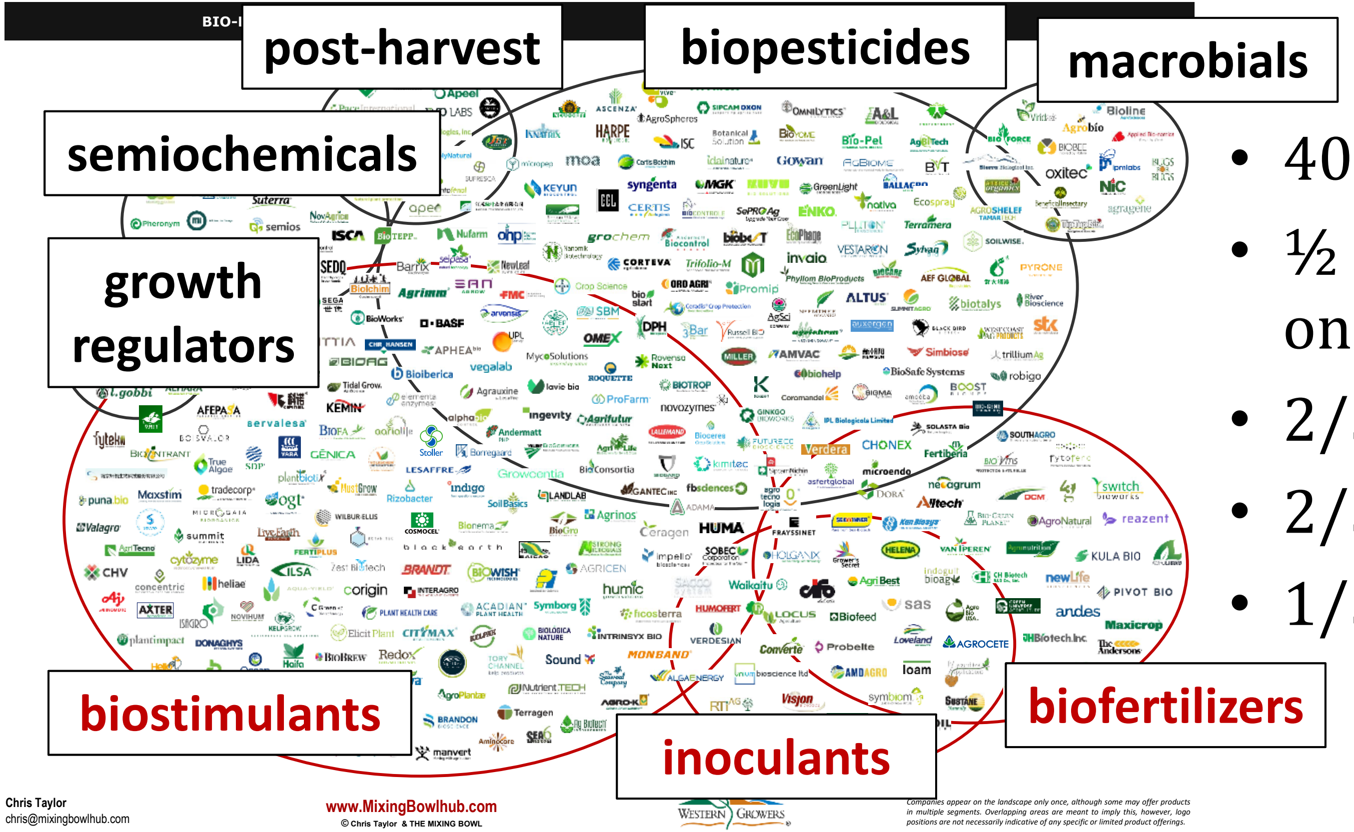
Companies appear on the landscape only once, although some may offer products in multiple segments. Overlapping areas are meant to imply this, however, logo positions are not necessarily indicative of any specific or limited product offerings.

https://mixingbowlhub.com/ag-biologicals-landscape-2023/

Bio-Based Substances | Living Organisms

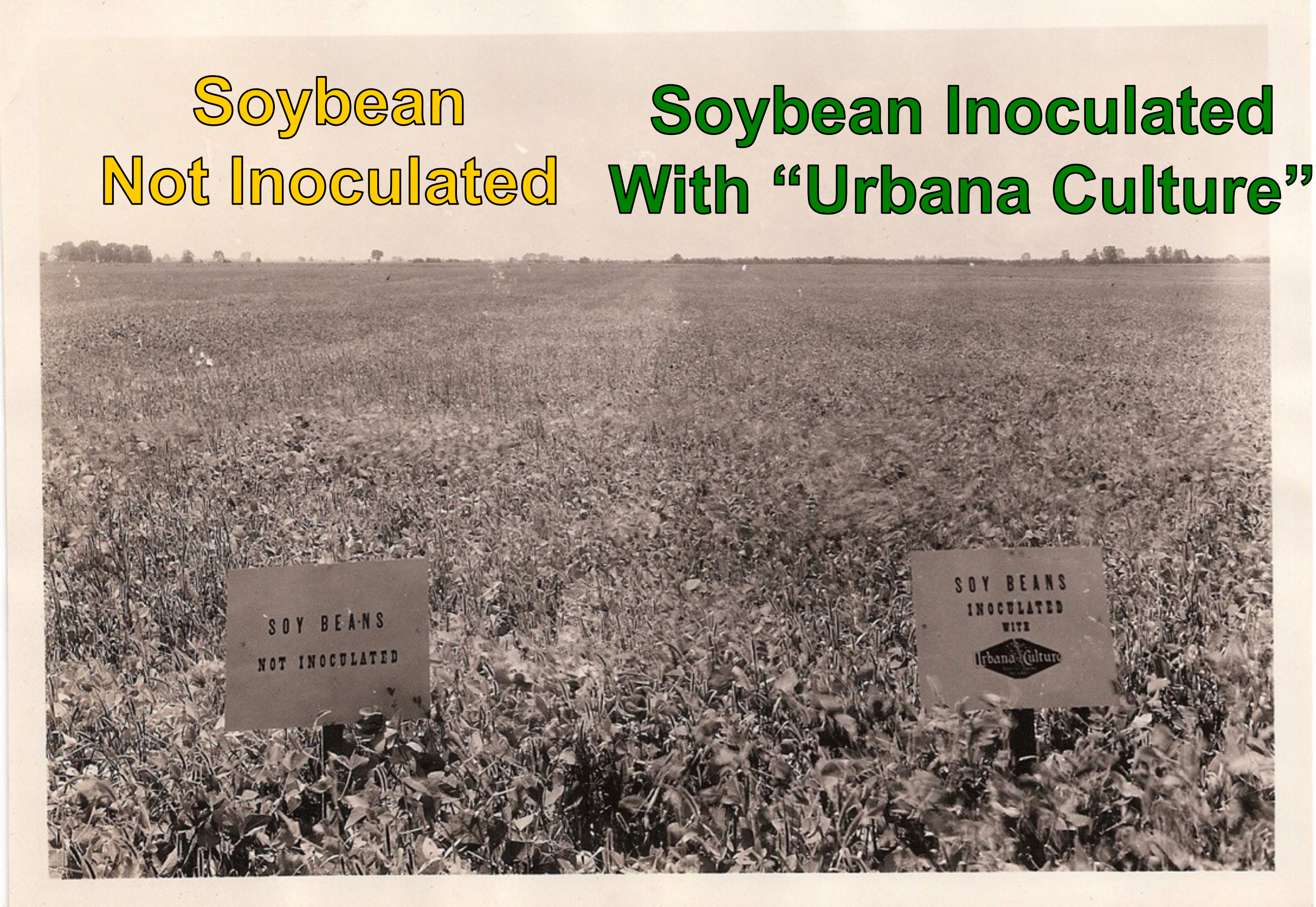
BioControl

Crop & Soil Health



- 400 companies
- ½ in more than one segment
- 2/3 in biocontrol
- 2/3 in crop health
- 1/3 in biocontrol + crop health

https://mixingbowlhub.com/ag-biologicals-landscape-2023/


Soybean
Not Inoculated
Soybean Inoculated
With "Urbana Culture"
SOY BEANS
NOT INOCULATED
SOY BEANS
INOCULATED
WITH
Urbana Culture

Soybean Inoculants

- *Bradyrhizobium japonicum*
- At least 100,000 colony forming units/seed
- Soils with very low pH – correct pH first

When to Inoculate For Nitrogen Management?

- No history of soybean being grown in last 3 to 5 yrs
  - Continuous corn
  - CRP land
  - Newly cleared land
- Sandy soils in northern and southern Indiana
- Soils that have been flooded for extended periods
- What about extremely drought-stressed fields?
- Double inoculant rate and/or two different method of application
- Add sulfur?

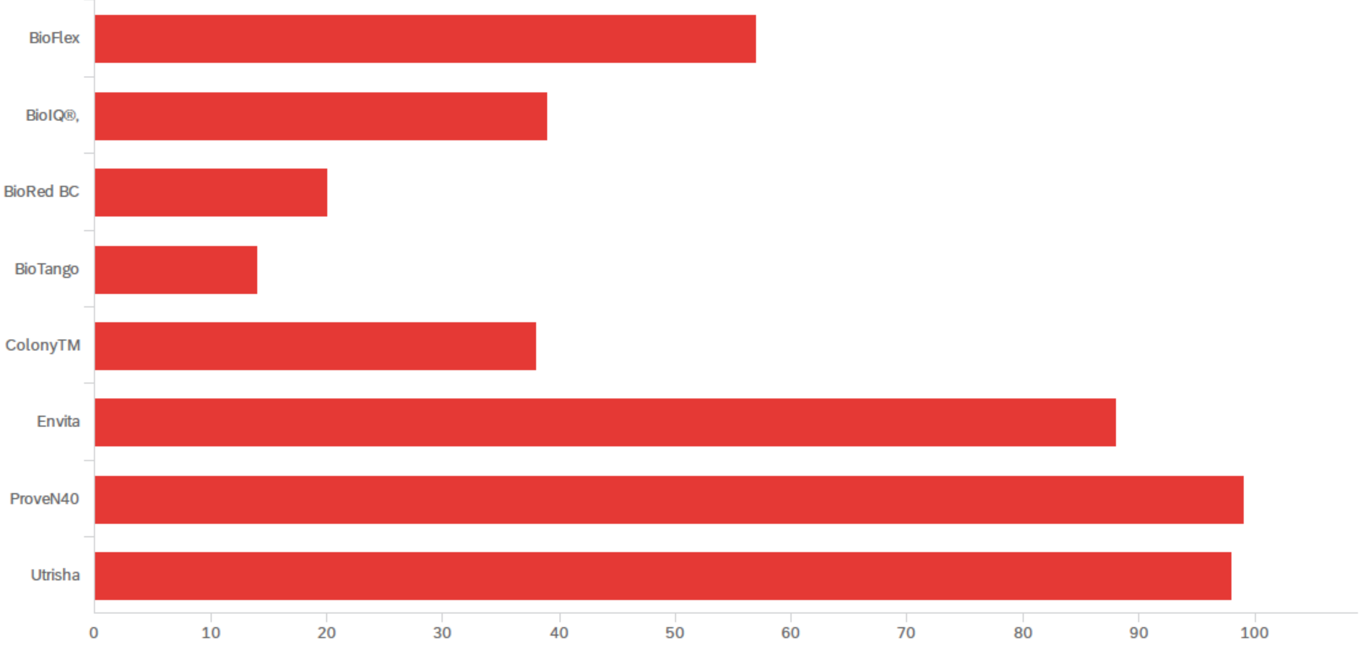
2011 Soybean Inoculants: "EXTRA! EXTRA!"

- **Integral® bio-fungicide in Vault LVL and Vault HP:**
  - *Bacillus subtilis* = ubiquitous bacterium that contributes to nutrient cycling when biologically active by producing various enzymes
- **LCO Promoter Technology in Optimize and Optimize 400:**
  - Isoflavinoid is the soybean's signal to rhizobia for N
  - LCO (Lipo-chitooligosaccharide), "I heard you – please send food"
- ***Azosperillium brasilense* in Primo:**
  - Produces Indole Acetic Acid (IAA) = plant hormone that initiates primary and secondary root development as well as root hair formation

Nutrient Influencing Biologicals

- **Nitrogen-Supplying Biologicals (non-rhizobial)** may fix or generate N.
- **Phosphorus Supply:** Biostimulants may provide enzymes (e.g., phosphatase that break and release phosphorus bound to organic matter). Solubilizers may solubilize P from soil minerals.
- **Humic/Fulvic Acids:** may chelate (acquire) cations in the soil to increase P and Zn availability. A general effect on soil and nutrient availability/access. Some may influence plants.
- **Marine Extracts:** may stimulate microbes, roots, and shoots (in general a plant effect).
- **Combinations:** may provide any of the previously mentioned effects depending on microbes in the mix.

Nitrogen-Supplying Biologicals (non-rhizobial)



Treatment	ACRE	Pinney	Average
UTC	74.2	80.9	77.6
Utrisha	71.7	83.8	77.8
Envita	70.9	84.3 x	77.6
Optimize	70.1	84.1 x	77.1
MegaPhos	74.2	81.4	77.8
Phosgard	75.7	82.0	78.9
Rootella	72.3	82.9	77.6
MegaFol	79.6	83.7	81.7 x
Maritime	72.7	80.3	76.5
QuickRoots	74.6	83.2	78.9
Accomp_Max	76.2	82.2	79.2
PhosN	73.8	81.5	77.6
Env_401	77.3	79.0	78.2
Ferti_Fulvic	73.1	79.7	76.4
Nutra	73.3	79.8	76.5
Hydra	70.3	79.3	74.8

2023 Bio Shotgun

- ACRE: NS, CV 8.8%
- Pinney Sand: NS, CV 4.5%

Nitrogen Supply: -4.1 to 3.4 bu

Phosphorus Supply: -1.9 to 2.0 bu

Humic/Fulvic Acids: -3.9 to -1.1 bu

Marine Extracts: -1.5 to 5.4 bu

Combinations: -0.4 to 2.3 bu

x = UTC Contrasts at $p \leq 0.10$

Bio N Supplier x Fertility

- **Three non-rhizobial N supplying biologicals:**
  - Untreated
  - Envita (Azotic): *Gluconacetobacter diazotrophicus*
  - Utrisha (Corteva): *Methylobacterium symbioticum*
- **Four fertility regimes:**
  - Unfertilized
  - N → 40 lb N/ac from Urea (46-0-0)
  - S → 20 lb S/ac from pelletized gypsum (0-0-0-17S)
  - N+S → 40 lb N/ac + 20 lb S/ac (urea + pelletized gypsum)

23 Bio N Supplier x Fertility: W. Laf

Bio N: none to ~4 bu

Fertility	No Bio		Envita		Utrisha	
None	75.0	c	74.1	c	80.5	b
Nitrogen	77.4	bc	81.2	b	78.2	bc
Sulfur	88.0	a	88.7	a	87.7	a
Nitrogen + Sulfur	90.4	a	91.0	a	89.7	a

Sulfur: +13 bu

23 Bio N Supplier x Fertility: Wanatah

Fertility	No Bio	Envita	Utrisha
None	82.5	82.7	81.6
Nitrogen	79.5	79.5	82.6
Sulfur	82.7	76.1	78.0
Nitrogen + Sulfur	81.2	79.7	80.0

23 Bio N Supplier x Fertility: LaCrosse

Fertility	No Bio		Envita		Utrisha	
None	49.3	c	53.2	bc	53.0	bc
Nitrogen	53.7	bc	48.8	c	49.5	c
Sulfur	$\boxed{58.4}$	ab	57.5	ab	51.3	c
Nitrogen + Sulfur	58.5	ab	59.5	a	61.9	a

Sulfur: +9 bu

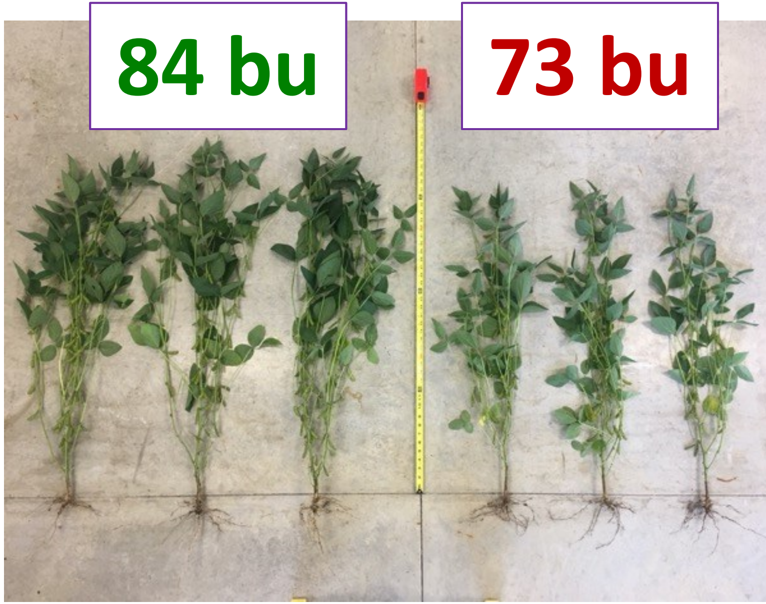
LSD0.05, CV(%) 8.3

Concluding Thoughts

- **Apply the lessons learned from Bradyrhizobium**
  - Soil fertility, field condition, crop rotation, CFUs, etc.
- **Identify the potential benefit** of the biological
- **Evaluate it in the field(s) in need** of this effect
- Test over multiple seasons to determine **repeatability of response or no response**
- **Purdue On The Farm: Non-rhizobial N Suppliers**

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

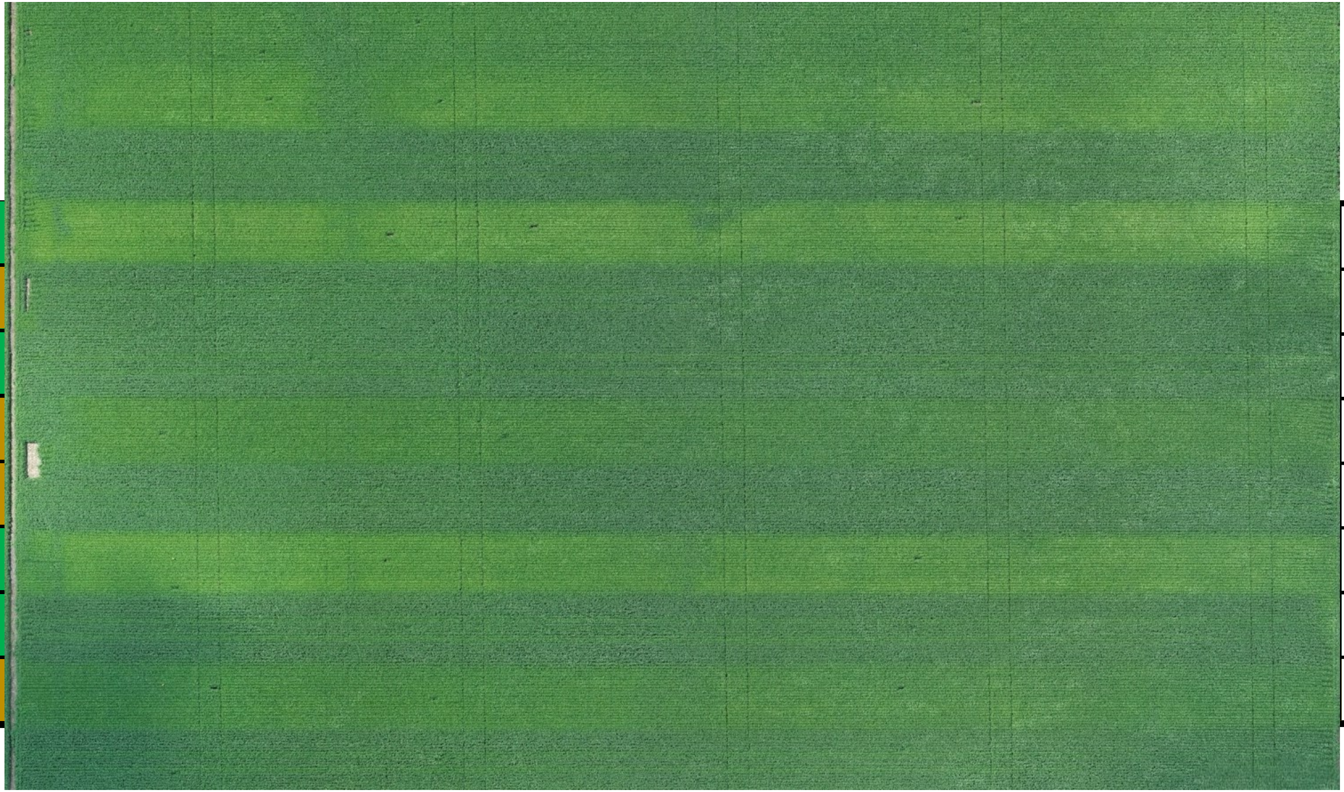
23 Cereal Rye x NS: West Lafayette

April 18th
Terminate Cereal Rye

May 6th
Apply Fertilizer, Plant Soy

Sept 1st
Response of Soybean

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

W. Lafayette, Aug. 10, 2023

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

BONUS BENEFITS?

Sudden Death Syndrome

Fertilizer	Severity		Incidence	Disease Index	
None	2.3	a	48%	12.6	a
Urea	2.0	a	48%	10.7	a
Gypsum	1.0	b	39%	3.6	b
Urea + Gypsum	1.1	b	33%	4.8	b

Pooled over cereal rye + no cover, West Lafayette, 2023

Sudden Death Syndrome

PRE-applied Sulfur

No Sulfur

Phytophthora


AMS 20 lb S/ac
Untreated

Thanks for the support!

INDIANA SOYBEAN ALLIANCE

USB
UNITED SOYBEAN BOARD
Making Your Checkoff Pay Off.

@PurdueSoybean | Purdue Crop Chat podcast | scasteel@purdue.edu

QUESTIONS?

Shaun Casteel, scasteel@purdue.edu

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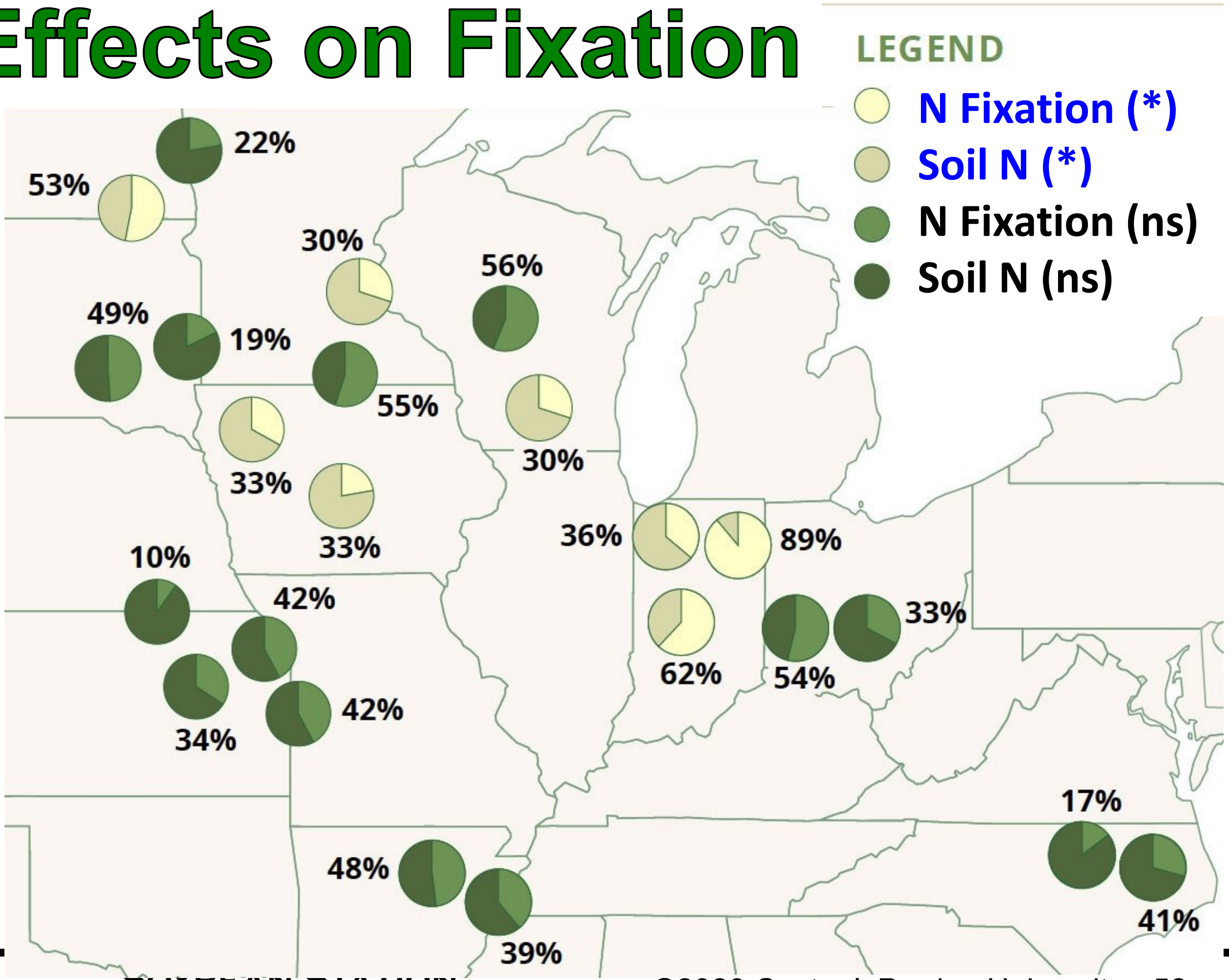
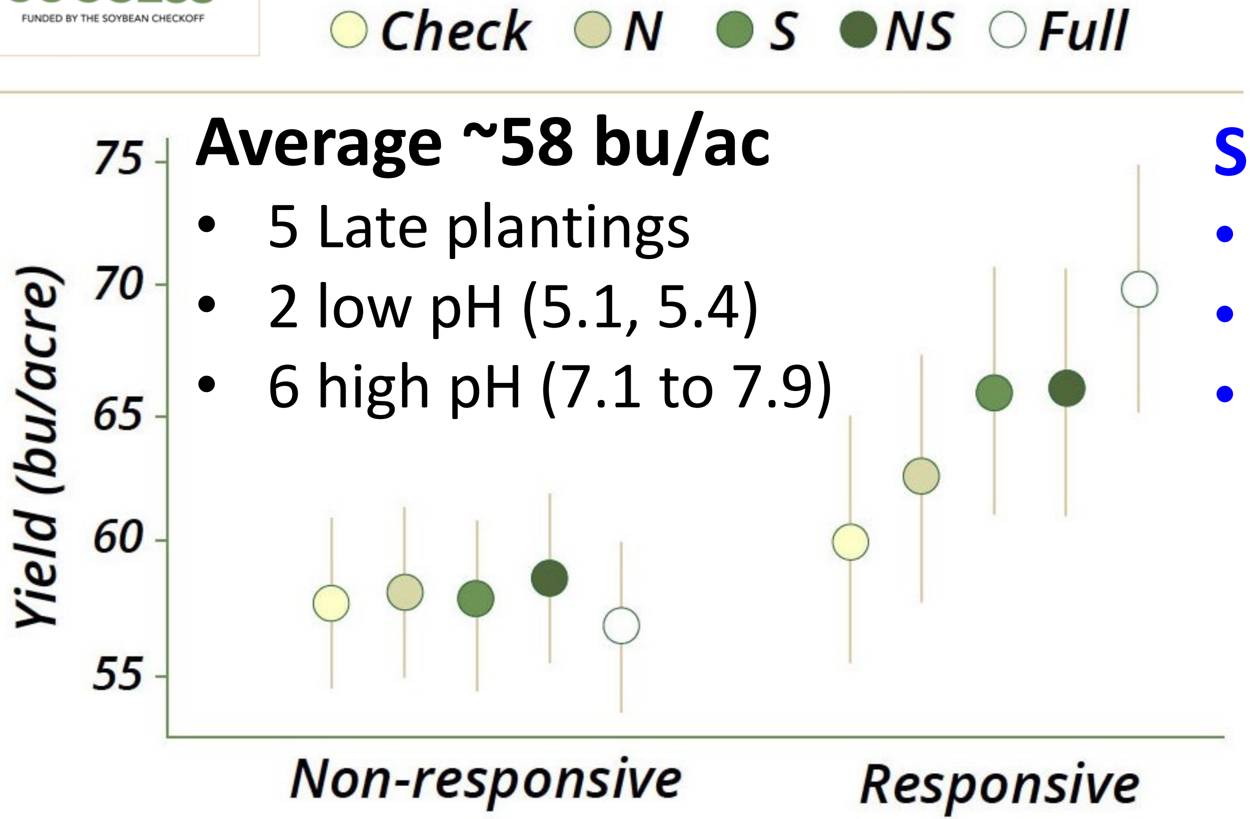
Sulfur Effects on Fixation

- 12 States
- 25 Trials
- **8 Responsive**
  - 30 to 89% N Fix'n
- **18 No Response**
  - 10 to 56% N Fix'n



Sulfur Effects on Fixation

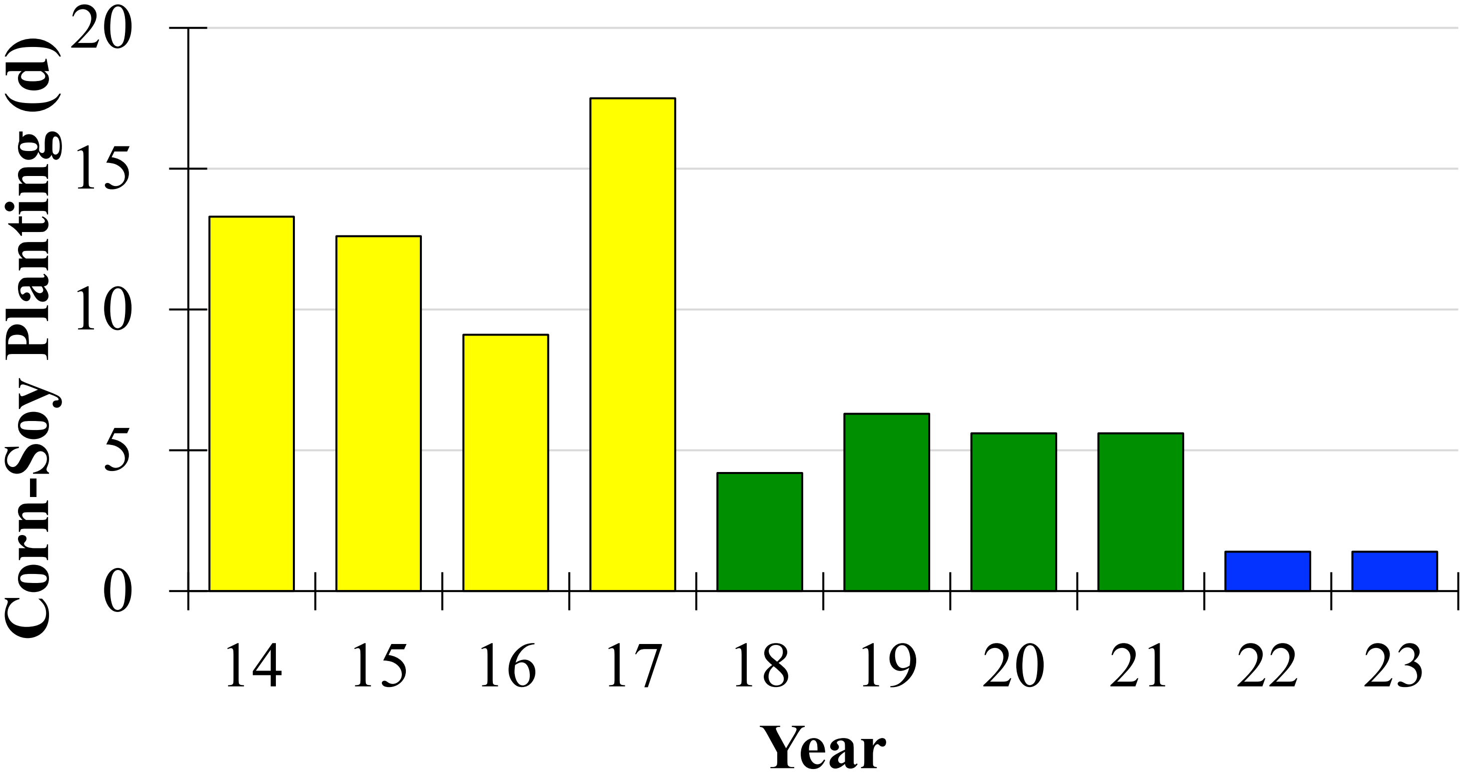


Average ~58 bu/ac
- 5 Late plantings
- 2 low pH (5.1, 5.4)
- 6 high pH (7.1 to 7.9)

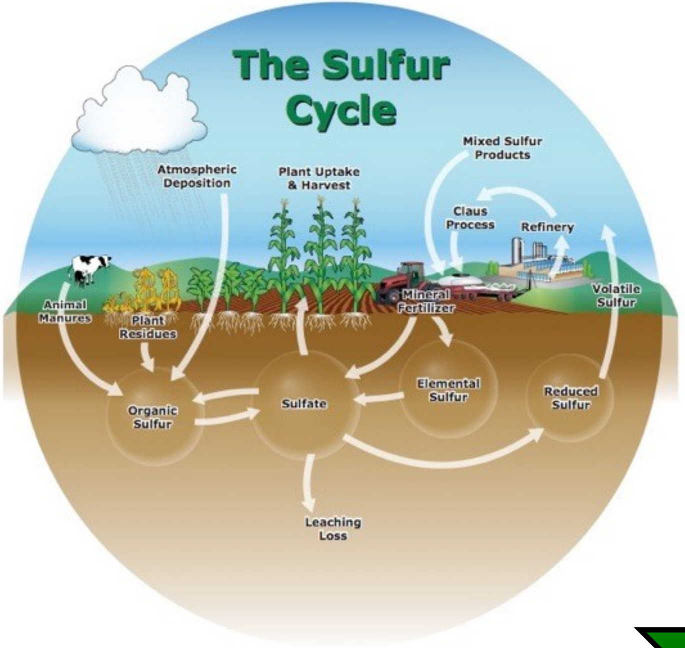
Sulfur Responsive
- **+ 6 bu/ac**
- Midwest to North
- Pdate: 4/29 to 5/25

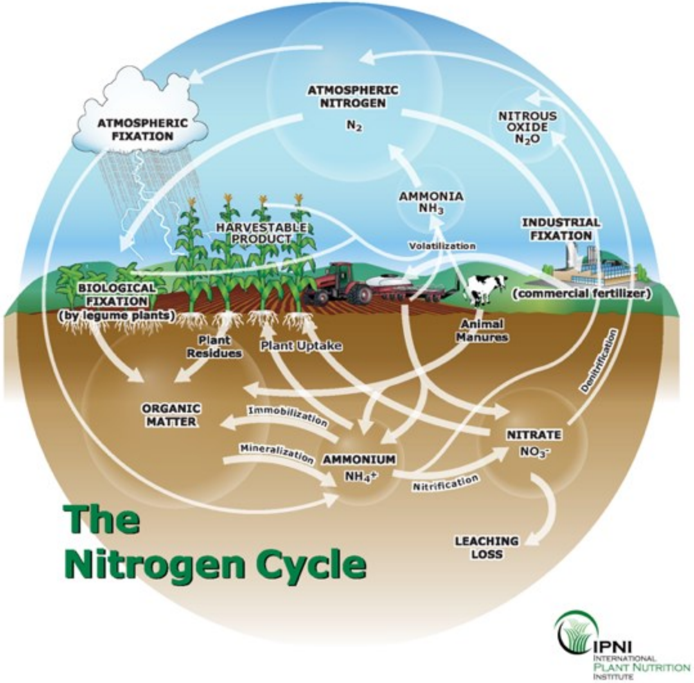
*** Responsive +2 to 13 bu/ac**

Indiana Soybean Planting Relative to Corn



Adapted from USDA-NASS, 2023





High Yielding Soybeans!

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

8 to 11 bu in EARLY Planting

No Effect in LATE Planting

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

		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**	
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Urea	.		.	.

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Early Planting	**11-May**		**12-May**		**14-May**	
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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

8 to 11 bu in EARLY Planting

No Effect in LATE Planting

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

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

Sulfur x Planting Interaction

- **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).

Thanks for the support!

INDIANA SOYBEAN ALLIANCE

UNITED SOYBEAN BOARD
Making Your Checkoff Pay Off.

@PurdueSoybean | **Purdue Crop Chat podcast** | scasteel@purdue.edu

QUESTIONS?

Shaun Casteel, scasteel@purdue.edu

@PurdueSoybean and **Purdue Crop Chat podcast**

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**

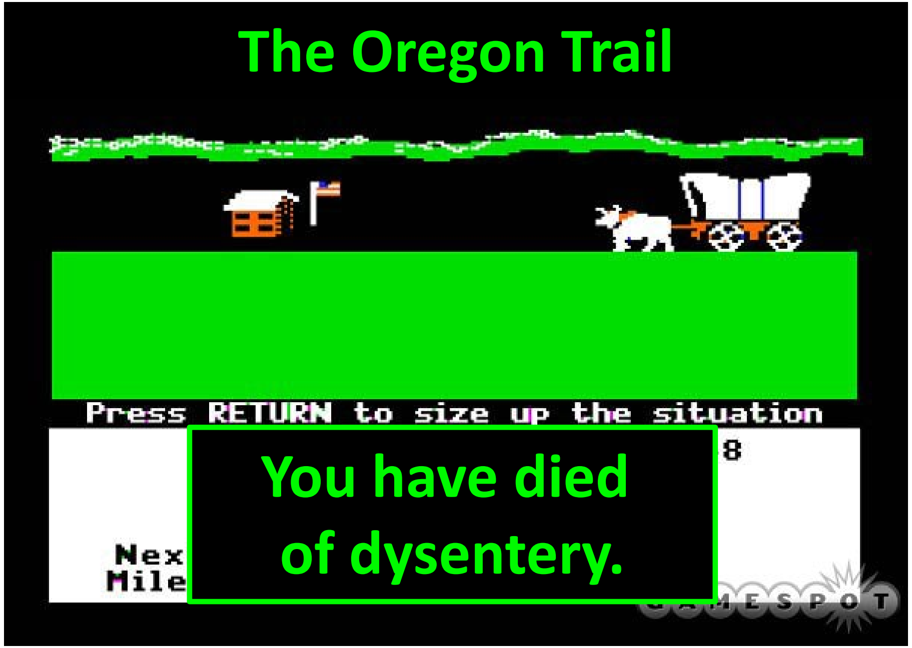
Doing the Math: Sulfur Needs (lb S/ac)

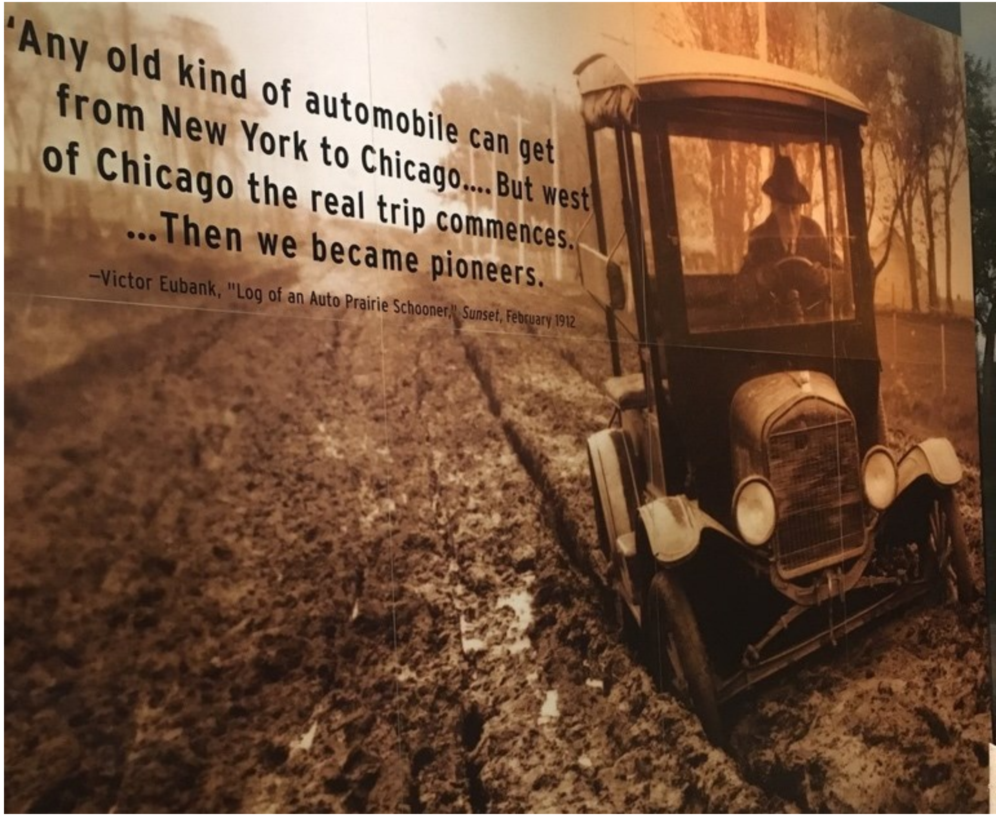
(Rough Mass Balance)

			Soil Organic Matter			
Yield	Need	Sky	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

IPNI, 2014

Expanding Across The Frontier





Azospirillum

- **Proposed benefits:** increased root growth and improved mineral and water uptake
- **Co-inoculated with *Bradyrhizobium japonicum***
  – Increased plant growth and nodules (Cassan et al., 2009)
  – Brazil: increased nodulation in early stages, N accumulation, plant growth and yield (especially under drought) (Chibeba et al., 2015; Hungria et al., 2015; Cerezini et al.,2016)
  – US: Co-inoculation of *Azospirillum brasilense* and *Bradyrhizobium japonicum* resulted in a ***soybean yield increase in only 2 out of 25 site-years*** (de Borja Reis et al., 2022).

Bacillus

- Considered a ***plant growth-promoting bacteria***
  - Improve nutrient supply
  - Modulate plant phytohormones
  - Induce plant resistance with antagonistic substances (Radhakrishnan et al., 2017)
- **Greenhouse**: Improvements in shoot and root weight of soybean treated on the seed (Akinrinlola et al., 2018)
- **Field**
  - ***Quebec***: improve nodule number, nodule weight, shoot weight, root weight, total N, and grain yield (Bai et al., 2003)
  - ***India***: increase Zn solubilization in the rhizosphere → higher Zn in plant biomass (Sharma et al., 2011).
  - ***Egypt***: enhance drought tolerance and increase yield (Sheteiwy et al., 2021).

Bradyrhizobium

- ***N-fixing bacteria provide 50 to 60% of soybean N requirement***
- *Bradyrhizobium japonicum* and *Bradyrhizobium elkanii*

(Salvagiotti et al., 2008; Pagano and Miransari, 2016).

- Rarely any benefit in fields with a history of soybean production and an established *Bradyrhizobium* population (De Bruin et al., 2010)
- In Wisconsin, there was no positive soybean yield benefit to *Bradyrhizobium elkanii* inoculation in fields with a history of soybean production (Furseth et al., 2012).

Delftia

- Promote N fixation through a symbiotic relationship with plants (Braña et al., 2016).
- In canola, a commercial seed treatment containing *Delftia* increased yield, which was attributed to greater S availability (Banerjee and Yesmin, 2004).

Glomus

- Arbuscular mycorrhizal fungi (AMF) are important for plant nutrition due to mutualistic symbiosis with the roots of about 80% of vascular plants (Smith et al., 2003).
- *Glomus* is an example of AMF, which promote P uptake (Smith and Read, 2008).
- **Greenhouse**: **Greater soybean yield with direct inoculation of *Glomus*** (Koyama et al., 2019) and **reduced disease** (Zambolim and Schenck, 1983).
- **Field**: ***Glomus* and half rate of P fertilizer yielded comparable to a full rate of P fertilizer in Ghana** (Thioub et al., 2019).

Pantoea

- **Potential benefits** (based on lab and greenhouse studies):
  - Combat plant pathogens
  - Promote plant growth
  - (May et al., 1997; Wright et al., 2001; Dutkiewicz et al., 2016).
- *Pantoea agglomerans* is considered a biofertilizer, solubilizing insoluble phosphates in a laboratory study (Son et al., 2006; Chen and Liu, 2019).

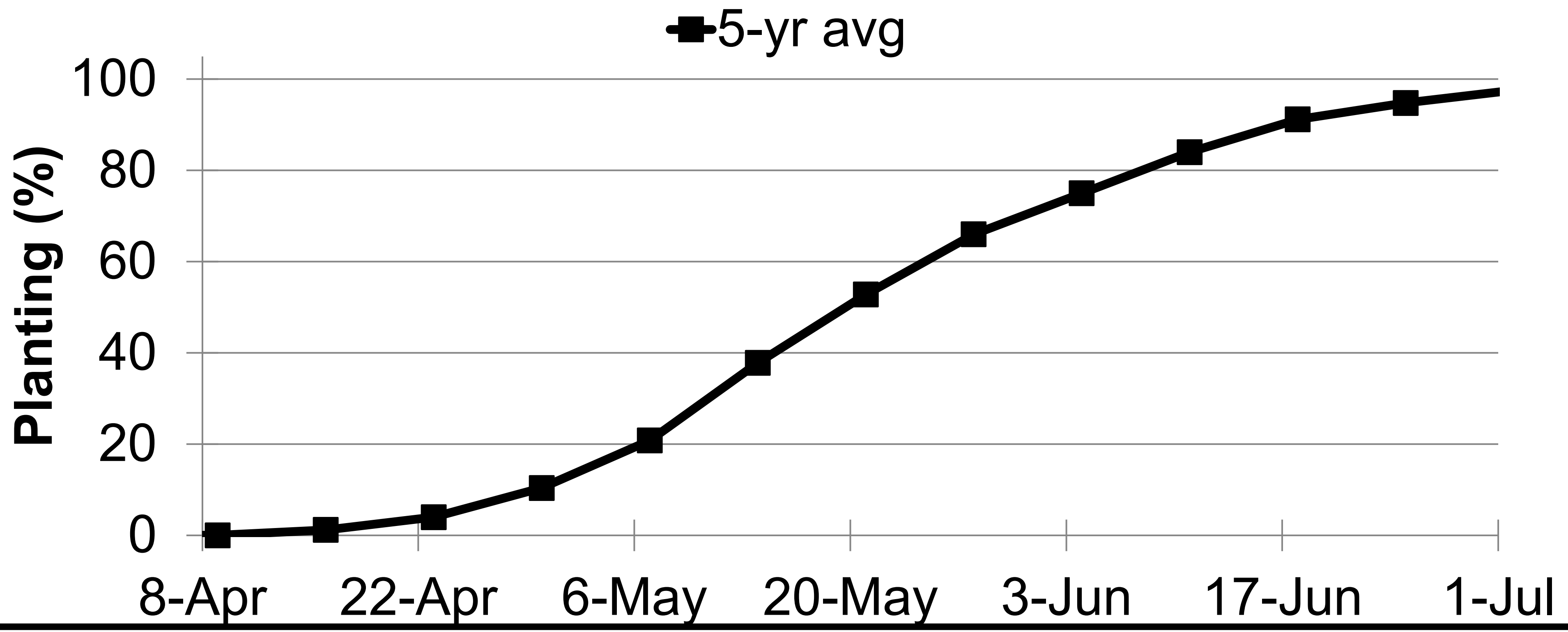
Pseudomonas

- **Potential benefits**
  - Promote plant growth by suppressing pathogenic microorganisms,
  - Synthesize growth-stimulating plant hormones,
  - Promote plant disease resistance (Preston, 2004; Kasotia et al., 2012).
- **Greenhouse or laboratory:**
  - Suppress several fungal root pathogens and plant parasitic nematodes (Timper et al., 2009).
  - Suppress disease and increase nutrient uptake in seeds treated with *Pseudomonas* (Paulitz, 1991)
- **Field**:
  - **Soybean seed treated with *Pseudomonas* yielded comparable to fungicide seed treatment** (Kommedahl et al., 1981). Though more variability.
  - **Did NOT control soybean cyst nematode or impact soybean yield** (Noel, 1990).

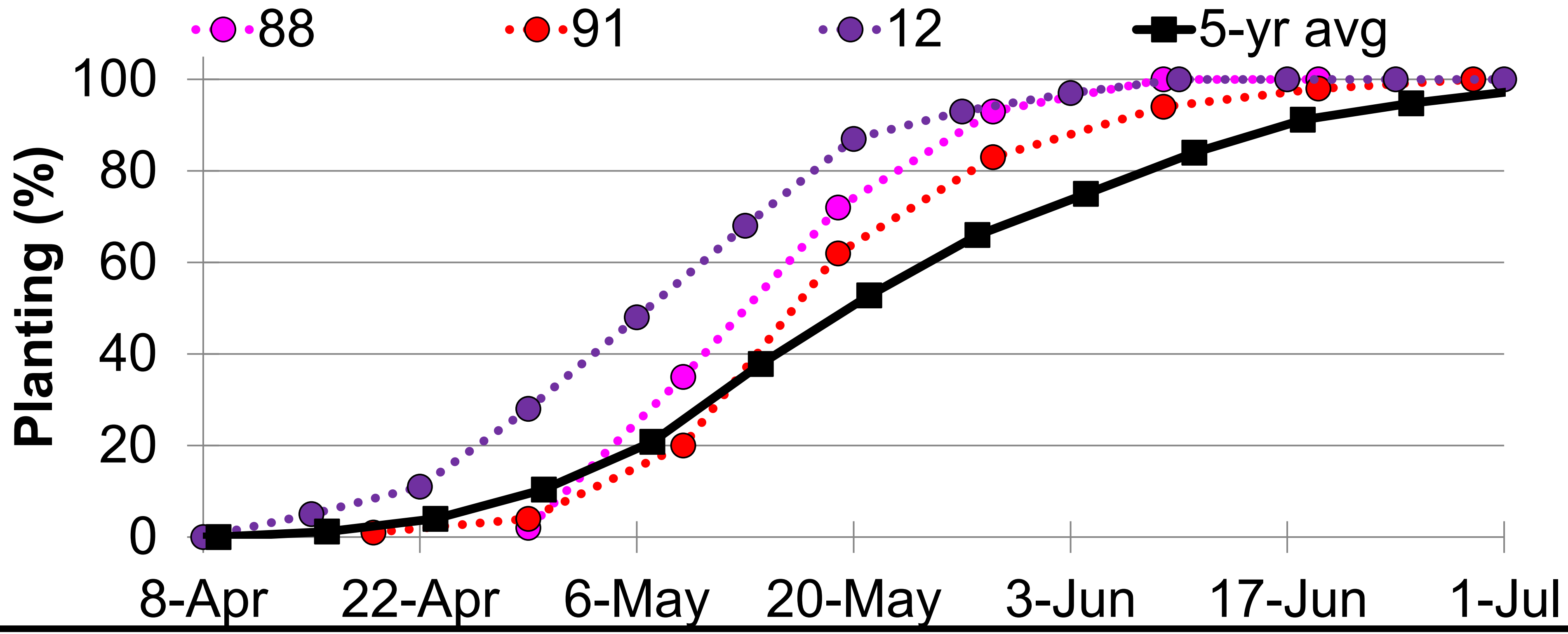
Trichoderma

- **Greenhouse**:
  - *Trichoderma harzianum* showed biocontrol effects against **soybean charcoal rot** caused by *Macrophomina phaseolina* (Khaledi and Taheri, 2016), **white mold** caused by *Sclerotinia sclerotiorum* (Macena et al., 2020), and **root lesion nematode** (Kath et al., 2017).
  - Increased root length and shoot biomass (Entesari et al., 2013; Yusnawan et al., 2019).
  - Little effect on soybean seedling performance if plants were not exposed to biotic or abiotic stress (salinity, chilling, heat) (Mastouri et al., 2010).
- **Field in Brazil**:
  - **4 to 13% increase in soybean yield** (Freitas Chagas Jr. et al., 2021)
  - Increase in height and # of pods per plant in isolated application, and **increase in grain yield when combined with fungicide seed treatment** (Zandona et al., 2019);
  - **53% increase in soybean grain yield when grown on soil infected with root lesion nematode** (*Pratylenchus brachyurus*) (de Oliveira et al., 2019).

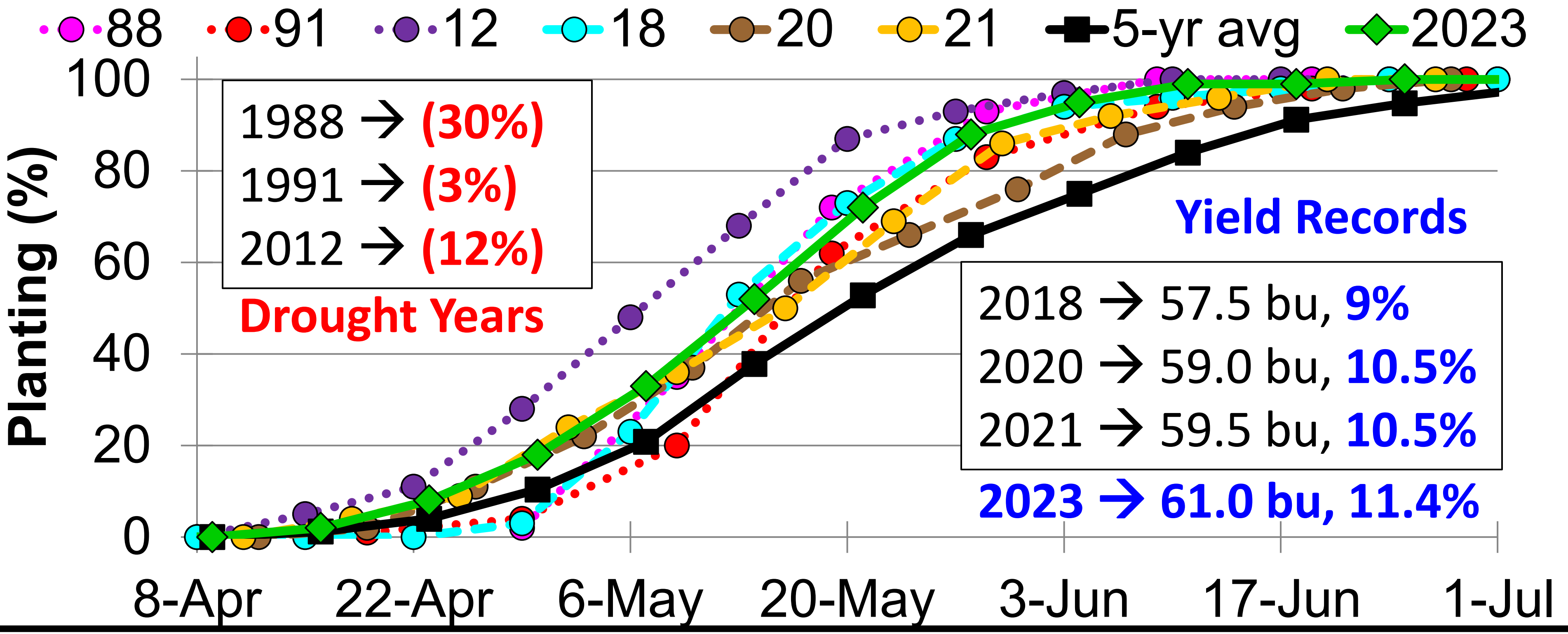
Indiana Soybean Planting: Earliest Years



Indiana Soybean Planting: Earliest Years



Indiana Soybean Planting: Earliest Years



Indiana Yields

Year	Planting (50%)	Yield	Changes from Trend	
	d after corn	bu/ac	Percent	bu/ac
2010	29.4	48.5	**-0.8%**	(0.4)
2011	13.3	45.5	**-7.8%**	(3.9)
2012	12.6	44.0	**-11.7%**	(5.8)
2013	7.0	51.5	**2.5%**	1.2
2014	13.3	55.5	**9.4%**	4.8
2015	12.6	50.0	**-2.3%**	(1.2)
2016	9.1	57.5	**11.4%**	5.9
2017	17.5	54.0	**3.7%**	1.9
2018	4.2	**57.5**	**9.5%**	5.0
2019*	6.3	51.0	**-3.7%**	(2.0)
2020	5.6	**59.0**	**10.5%**	5.6
2021	5.6	**59.5**	**10.5%**	5.6
2022	1.4	57.5	**5.9%**	3.2
2023	1.4	**61.0**	**11.4%**	**6.2**

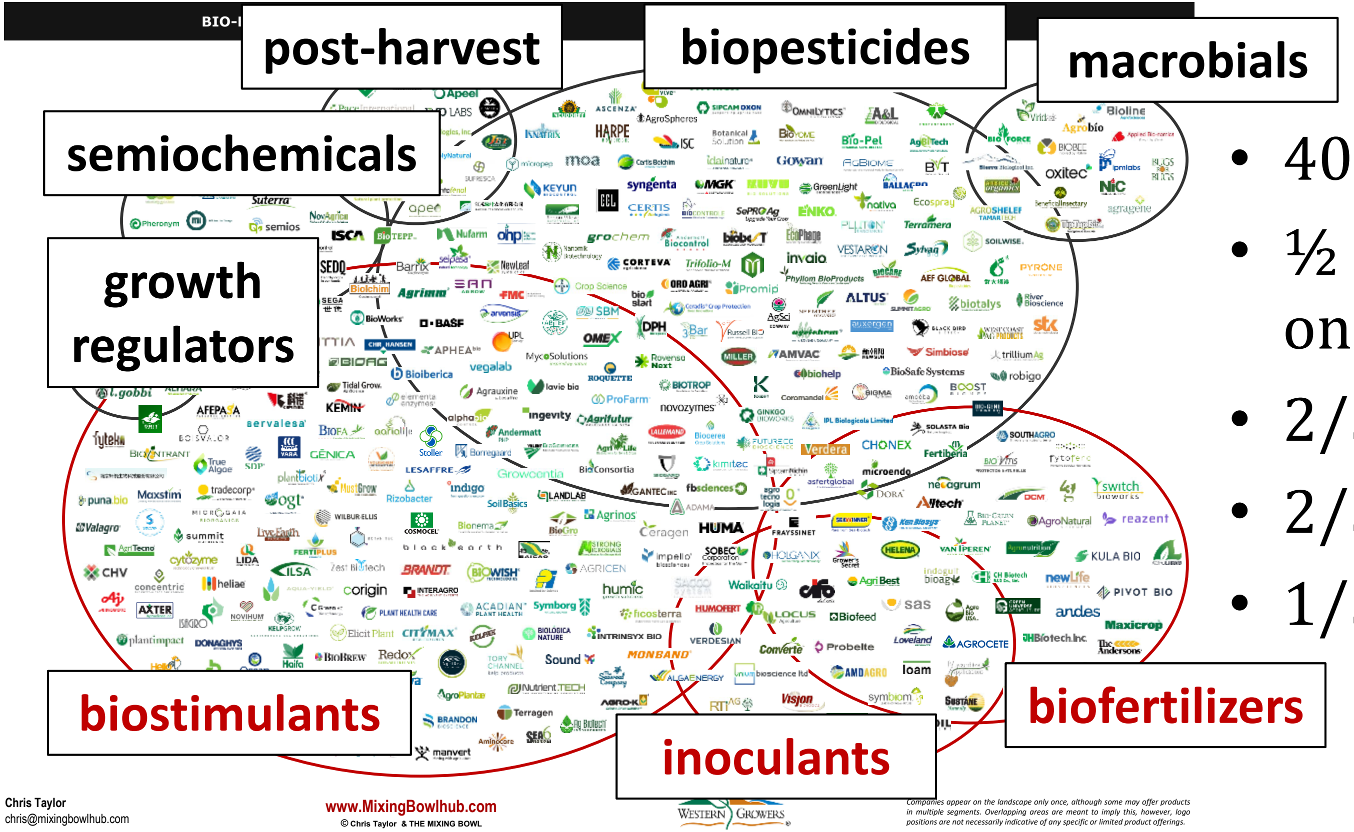
Soybean
Not Inoculated

Soybean Inoculated
With “Urbana Culture”

Bio-Based Substances | Living Organisms

BioControl

Crop & Soil Health



- 400 companies
- ½ in more than one segment
- 2/3 in biocontrol
- 2/3 in crop health
- 1/3 in biocontrol + crop health

https://mixingbowlhub.com/ag-biologicals-landscape-2023/

National Screen of Commercially Available Biological Seed Treatment for Soybean

SCIENCE FOR SUCCESS
FUNDED BY THE SOYBEAN CHECKOFF

Results – Grain Yield

Analysis of variance (ANOVA) for treatment, location, and treatment x location interaction in 2022.

Source of variation	F-value	Prob > F
Treatment	1.02	0.4229
Location	109.46	<.0001
Treatment x Location	1.10	0.0985

SCIENCE FOR SUCCESS

2022		
Treatment	W. Laf	Wanatah
UTC	64.8	55.3
BioBuild	62.9	56.1
SabrEx	62.0	55.6
GraphEx	64.1	53.9
Vault_IP	63.7	55.4
Bio_Yield_ST	63.9	55.1
Bio_Yield	63.5	54.4
LAL_Fix_Rise	65.1	54.7
Rise_Shine	63.4	54.4
Myco_Endo	65.7	55.6

SCIENCE FOR SUCCESS

2022			2023		
Treatment	**W. Laf**	**Wanatah**	**Treatment**	**W. Laf**	**Wanatah**
UTC	64.8	55.3	UTC	70.3	76.0
BioBuild	62.9	56.1	BioBuild	68.8	76.7
SabrEx	62.0	55.6	SabrEx	73.7	76.9
GraphEx	64.1	53.9	GraphEx	71.0	77.9
Vault_IP	63.7	55.4	Vault_IP	72.1	77.0
Bio_Yield_ST	63.9	55.1	*Aveo*	71.4	79.0
Bio_Yield	63.5	54.4	*BioWake*	71.6	76.4
LAL_Fix_Rise	65.1	54.7	*Pro_Larise*	72.0	75.9
Rise_Shine	63.4	54.4	Rise_Shine	68.4	75.0
Myco_Endo	65.7	55.6	Myco_Endo	71.7	75.6

SCIENCE FOR SUCCESS

2022			2023			2022-23
Treatment	**W. Laf**	**Wanatah**	**Treatment**	**W. Laf**	**Wanatah**	**AVERAGE**
UTC	64.8	55.3	UTC	70.3	76.0	67.5
BioBuild	62.9	56.1	BioBuild	68.8	76.7	65.8
SabrEx	62.0	55.6	SabrEx	73.7	76.9	67.8
GraphEx	64.1	53.9	GraphEx	71.0	77.9	67.5
Vault_IP	63.7	55.4	Vault_IP	72.1	77.0	67.9
Bio_Yield_ST	63.9	55.1	*Aveo*	71.4	79.0	.
Bio_Yield	63.5	54.4	*BioWake*	71.6	76.4	.
LAL_Fix_Rise	65.1	54.7	*Pro_Larise*	72.0	75.9	.
Rise_Shine	63.4	54.4	Rise_Shine	68.4	75.0	65.9
Myco_Endo	65.7	55.6	Myco_Endo	71.7	75.6	68.7

QUESTIONS?

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@PurdueSoybean and Purdue Crop Chat podcast

Classic Sulfur Deficiency

- Coarse-textured: Sand, Loamy Sand, Sandy Loam
- Low Organic Matter < 2%

Bio N Supplier x R4 Protect

- **Three non-rhizobial N supplying biologicals:**
  - Untreated
  - Envita (Azotic): *Gluconacetobacter diazotrophicus*
  - Utrisha (Corteva): *Methylobacterium symbioticum*
- **Two fertility regimes:**
  - Unfertilized
  - S → 20 lb S/ac from pelletized gypsum (0-0-0-17S)
- **Two foliar protection regimes:**
  - None
  - R4 application of fungicide and insecticide (Revytek + Fastac)

23 Bio N Supplier x R4 Protect: W. Laf

	Untreated		R4 Protect	
None	77.4	d	78.3	d
Envita	80.6	cd	82.5	bcd
Utrisha	79.2	d	81.5	cd
Gyp	85.4	abc	88.2	a
Gyp_Envita	85.9	abc	87.5	ab
Gyp_Utrisha	84.7	abc	87.6	ab

- **Bio N: NS**
- **R4 Protect: NS**
- **Gypsum: +8 bu**
- **Gyp + R4 Protect: highest yields**

