Fertilizer Facts and Myths

Brady Goettl
Lindsay Pease
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UNIVERSITY OF MINNESOTA Driven to Discover®

What We'll Cover

- Nitrogen cycling and "Green Lightning"
- Phosphorous sources and best management
- Sulfur management—"building a better mousetrap"

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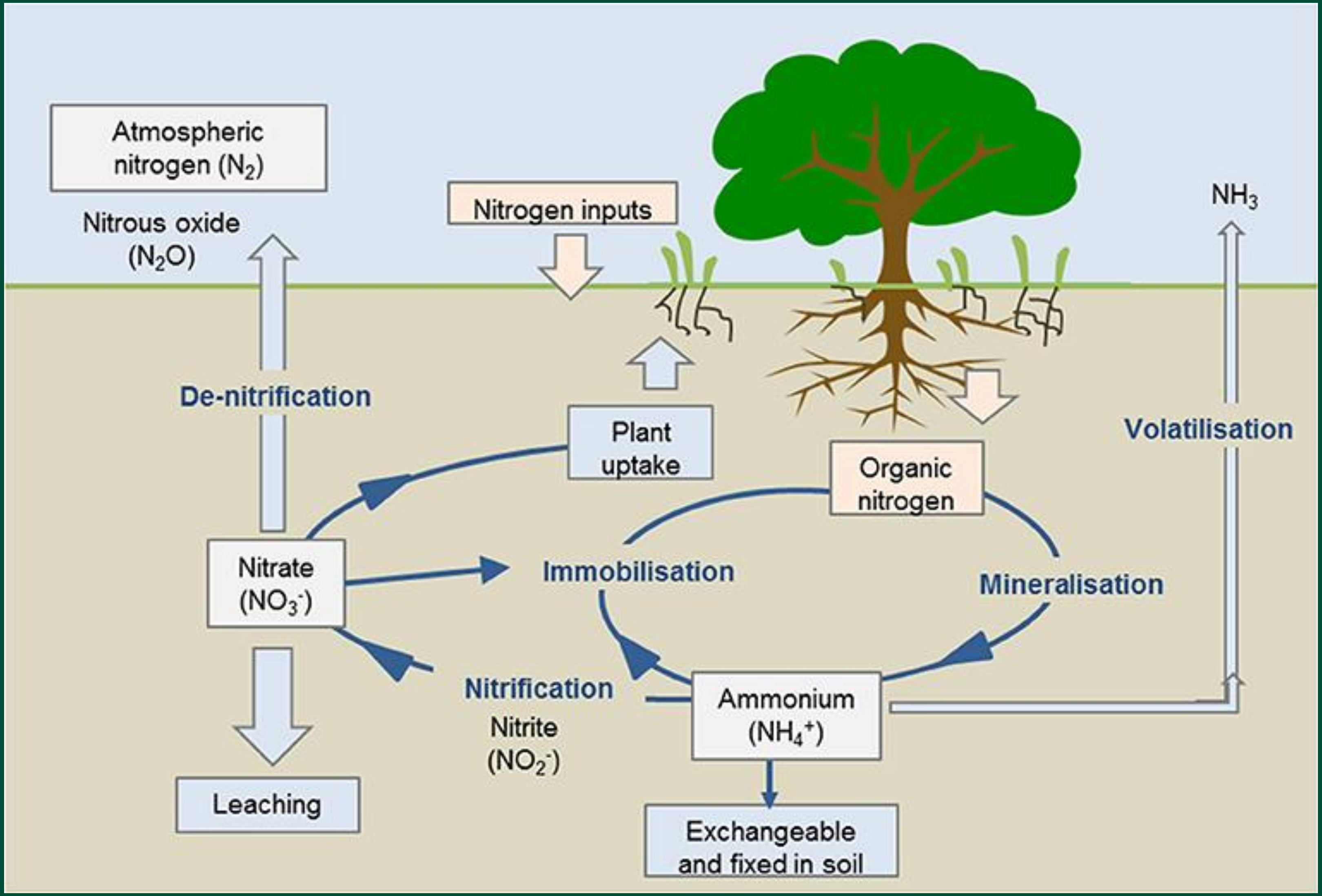
New nitrogen sources: separating fact from fiction

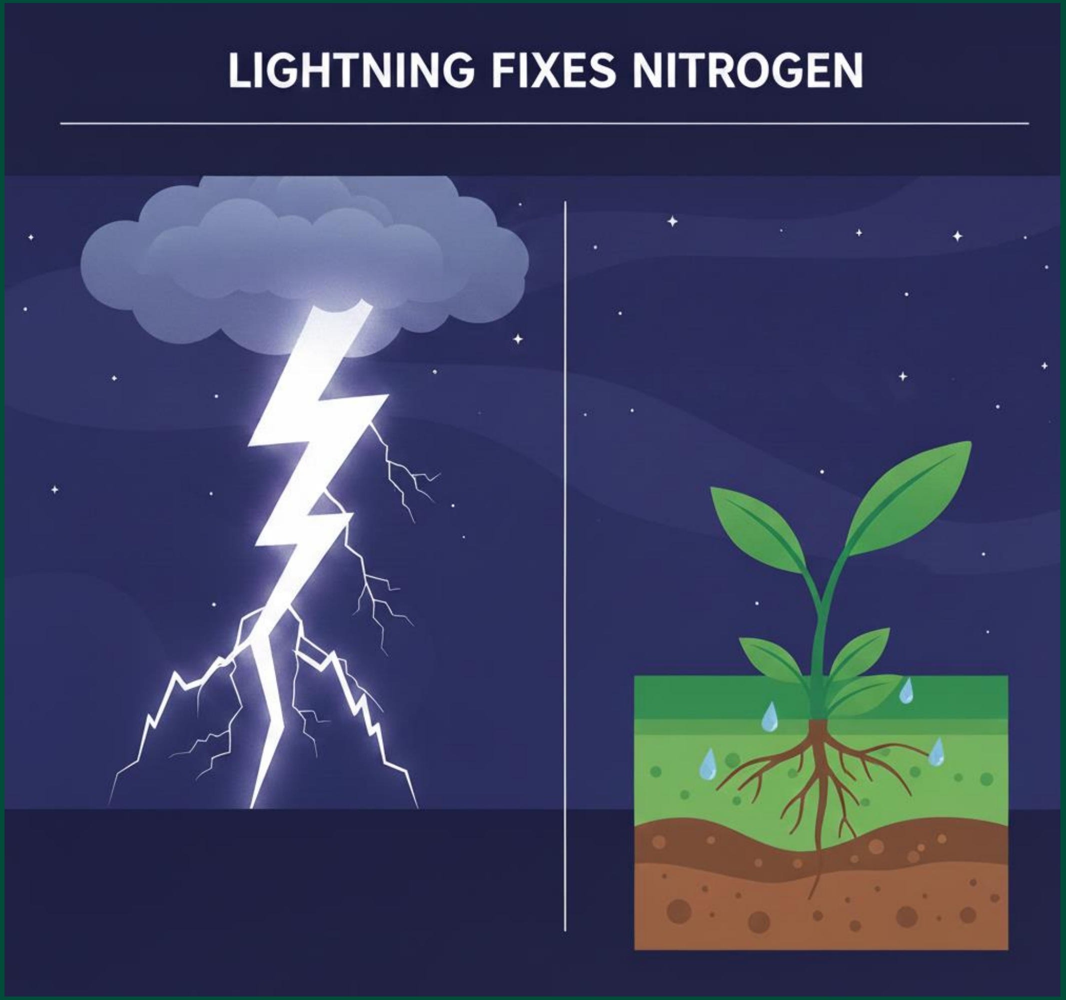
Szilvia Yuja – NDSU, Carrington REC

The nitrogen cycle



Source: Aczel, M. R. (2019). *Frontiers for Young Minds*

Green lightning technology



Our Technology.

A new solution for agricultural Nitrogen applications.

Green Lightning is a mechanism to replicate a naturally occurring process that leads to nitrogen. During a lightning storm, static electricity rearranges the nitrogen molecule in the air, and this modified molecule is contained within the rain wetting the soil.

Our Green Lightning machine creates lightning in a controlled environment under the same premise. We send air and water into a static electric field for the nitrogen molecule to go through the rearrangement process. It attaches itself to the water present, flowing through the machine, and drips out the bottom of this same machine as NO2 NO3.

Source: www.greenlightning.ag

Green lightning technology contd.

Product questions

How much actual nitrogen is in the product?

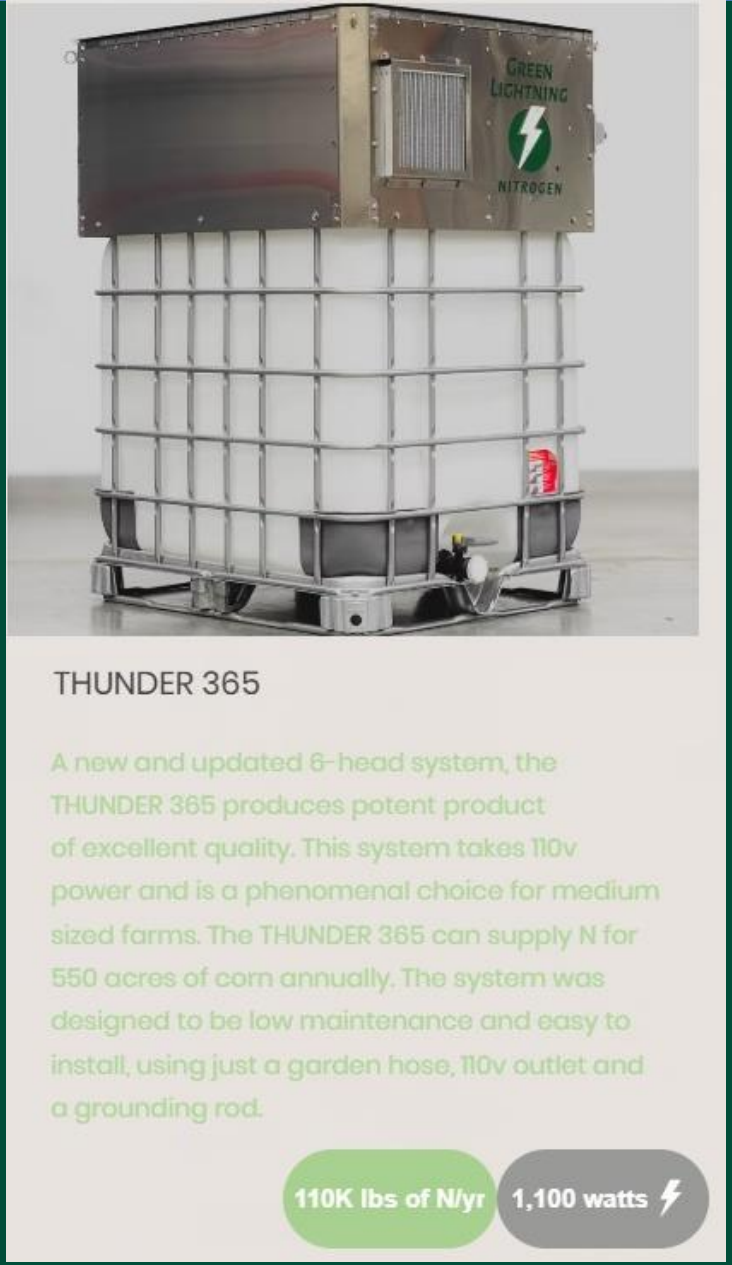
The product from our machines is high in NO3 which is what the plant consumes directly, allowing the plant to need less. One gallon of our product will equate to 2-3 pounds (units) of traditional N.

Source: www.greenlightning.ag

Claim: **1 gallon** of product will <u>equate</u> to **2-3 pounds** of traditional N

Comparison: 28% UAN has 3 pounds of N per gallon ~ 280 000 ppm

Green lightning technology contd.



Source: www.greenlightning.ag

Claim:

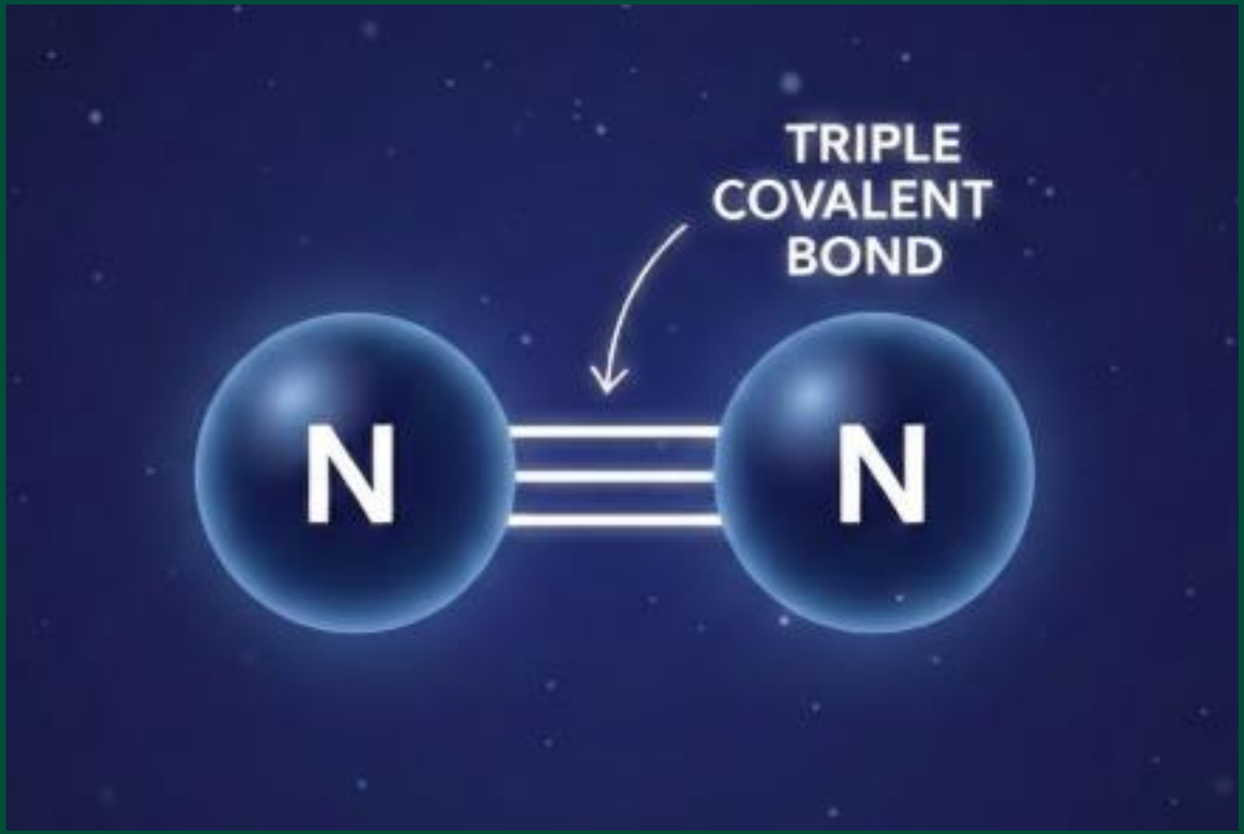
110,000 lbs of N per year at a power use rate of

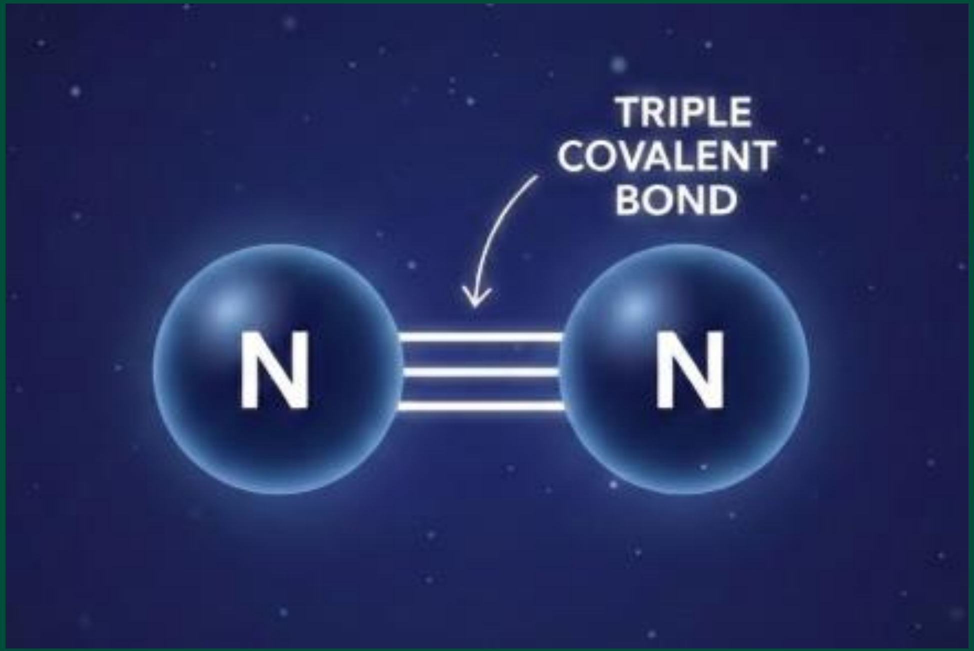
1100 watts rate → ~**10,000 kwh**

Comparison to Haber-Bosch process:

400 000 kwh

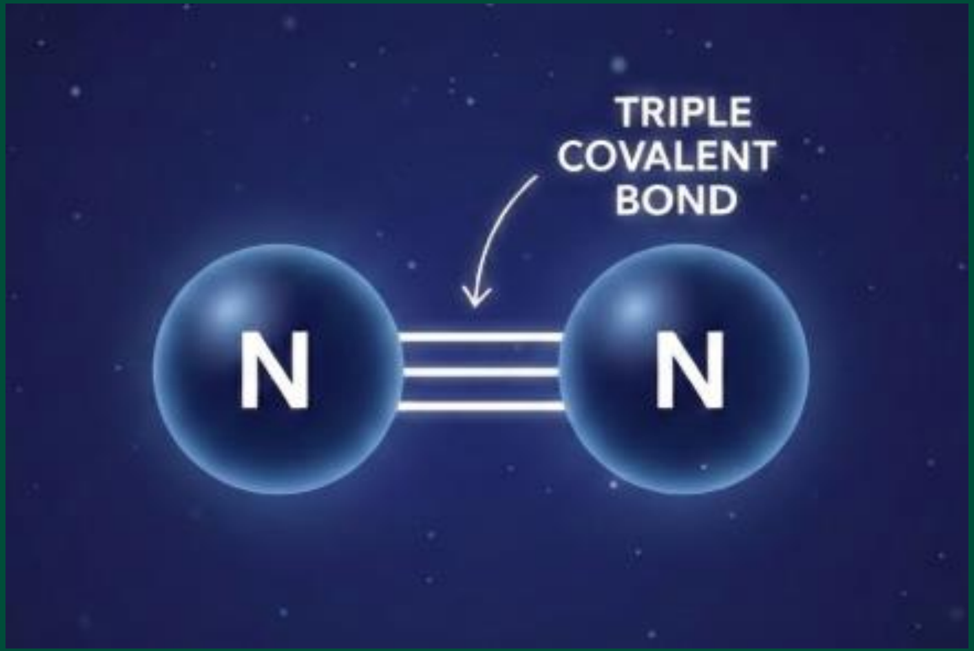
Nitrogen molecule





Hydrogenation:

Creates ammonia → NH_3



Hydrogenation:

Creates ammonia → NH_3

Oxygenation:

Creates nitrogen oxides → NO_x

Pathways of atmospheric nitrogen fixation

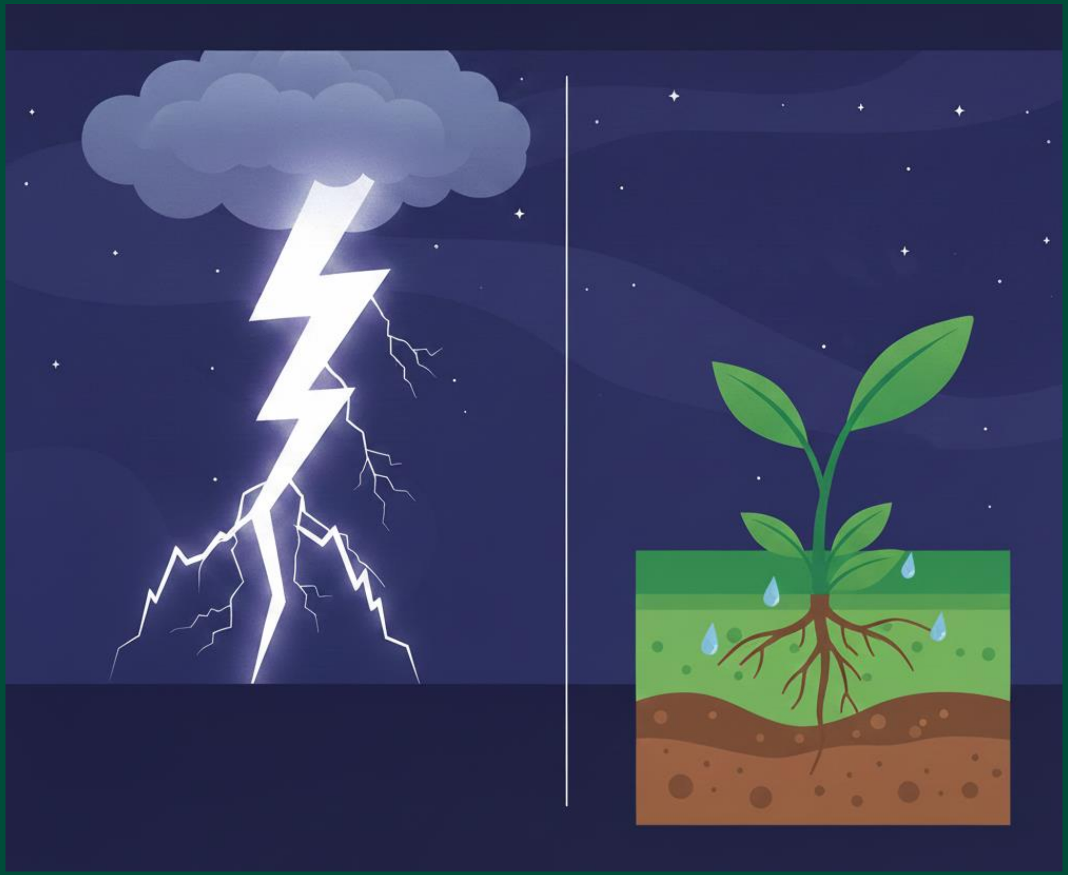
- Biological
- Lightning strikes
- Haber-Bosch process
- Birkeland-Eyde process

Biological

- Symbiotic and free-living microorganisms
- Terrestrial : 40-60 mill tons/year
- Marine ecosystems: 100 mills +

Image source: Charlie Lai, 2022. Earth.org

Lightning strike



- Creates plasma (ionized gas)
- Produces NOx species
- 5-10 mill tons/year

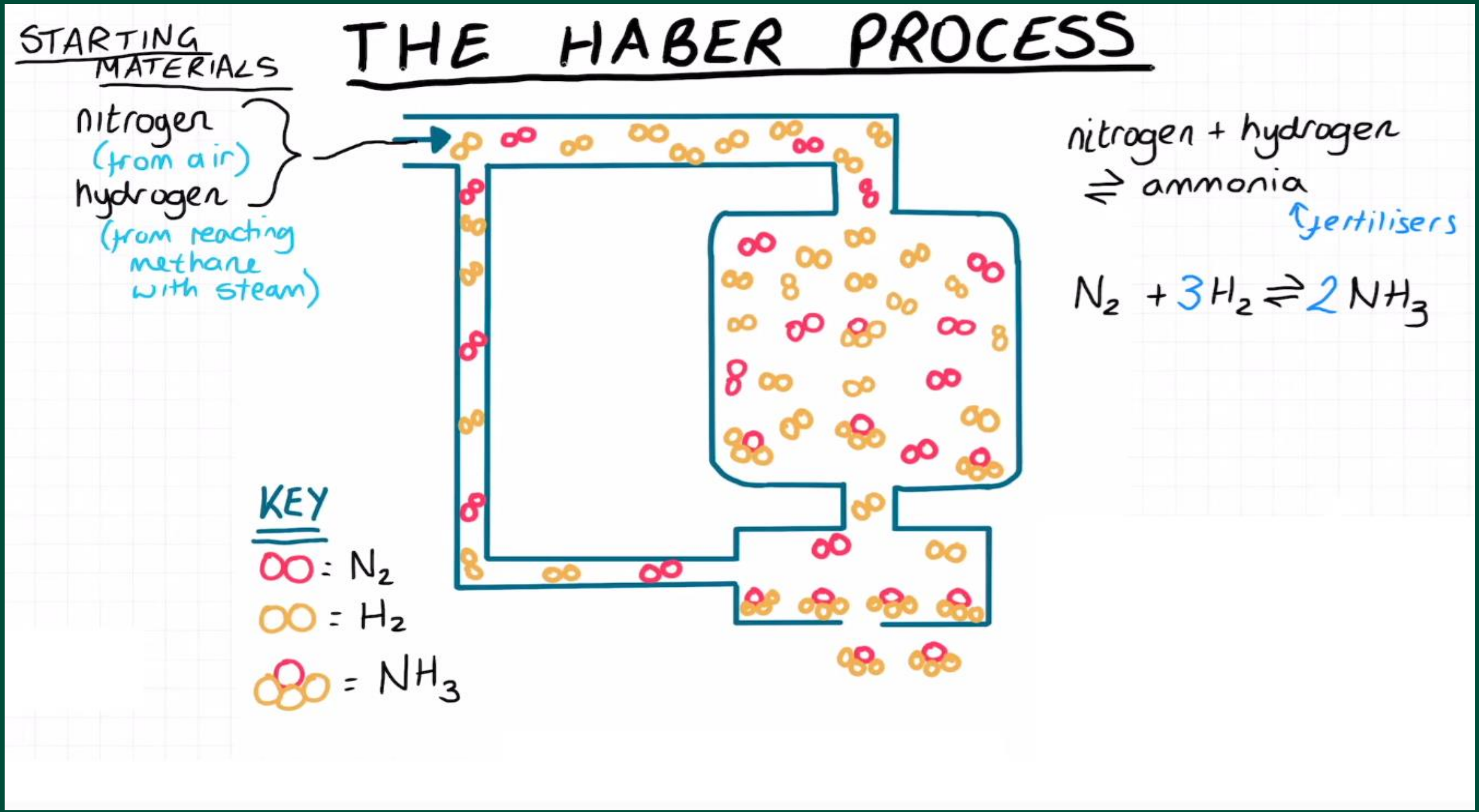


Image source: The Haber Process Summary Explanation (making ammonia)." *YouTube*, uploaded by ChemJungle, 22 Sept. 2021

100 million tons/year

Birkeland-Eyde process

- Lightning (thermal plasma) in a controlled environment
- The first industrial process for producing synthetic nitrogen fertilizer
- Fertilizer product: Calcium nitrate
- No longer in use, lost against the Haber-Bosch process

Theoretical energy minimums

- To break triple bond of N_2 in a vacuum:

  945 kJ/mol

- To create ammonia:

  485 kJ/mol

- To create nitrogen oxide species:

  ~ 200 kJ/mol

Energy estimates

- Biological:
- symbiotic ~ 1200 kJ/mol, free living ~ 2500 – 5000 kJ/mol
- Lightning strikes:
- Energy efficiency: 1700 to 60000 kJ/mol
- Haber-Bosch process:
- Energy efficiency: 800 - 1100 kJ/mol
- Birkeland-Eyde process:
- Energy efficiency: 2500 to 3000 kJ/mol

Energy estimates

- Biological:
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- Haber-Bosch process:
- Energy efficiency: 800 - 1100 kJ/mol
- Birkeland-Eyde process:
- Energy efficiency: 2500 to 3000 kJ/mol

- If 1100 watts produced 100 k N/year

  19.47 kJ/mol ⟵ below theoretical limit of 200 kJ/mol

AGVISE Water Characterization Report

Submitting Account	=	FR0802
Submitting Firm	=	NDSU-BRADY GOETTL
Grower Name	=	GREEN LIGHTNING
Sample ID	=	PRODUCE #1
Date Received	=	04-21-2025
Date Reported	=	05-06-2025

AGVISE Lab No. 268

pH	2.9
Conductivity	0.78 mmhos/cm
Nitrogen (Total Analyzer)	38.0 ppm
Nitrogen Analyzer (Nitrate+Nitrite)	38.0 ppm

Non-thermal plasma

- Only the electrons heat up
- Does not require high temperatures and high pressure
- NOx gases are formed
- Nitrogen oxides need to be captured in water

Capturing NOx gases

- Increasing gas to liquid contact
  - atomizer

- Overcoming acidity by using an alkaline scrubber
  - Calcium hydroxide
  - Potassium hydroxide

Because this is a salt free product it is very good for your soil and safe to apply on your crop. You can apply it to the soil, in furrow, side by side, side dress, as well as foliar application which is where we have seen some of our best responses. The finished product is fairly acidic with a pH of around 3-4. If you use Green Lightning as a carrying agent for your herbicide or fungicide applications you will see increased efficacy of those products as most prefer lower pH environments.

Source: https://1agsource.com/Green-Lightning

The promise of new technologies

- Reduced need for fossil fuels
- Lower theoretical energy minimums
- Small units, decentralized production

The promise of new technologies

- Non-thermal plasma
- Electrochemical nitrogen oxidation

Technologies and their limitations

Non-thermal plasma issues:

- Electron scattering
- NOx capture efficiency
- Vibrational inefficiency

- Currently 5 to 10 times less efficient than Haber-Bosch

Technologies and their limitations

<u>Electrochemical nitrogen oxidation:</u>

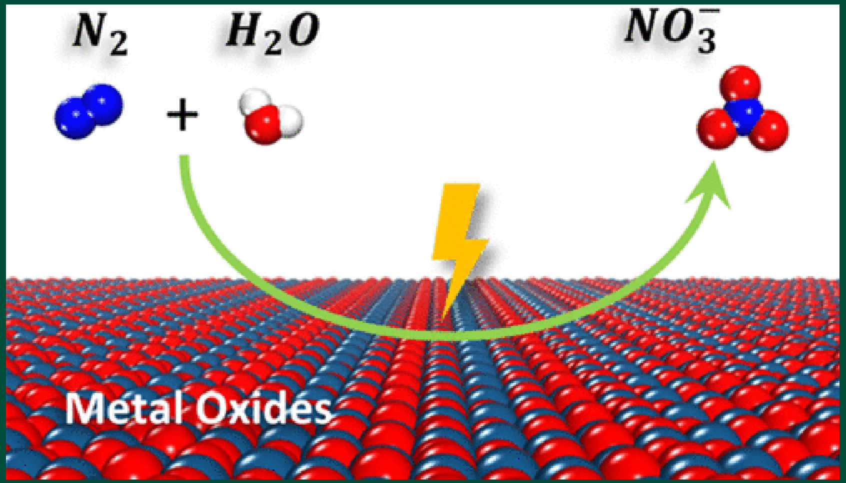
- Splits and oxidizes the nitrogen molecules using electrodes

Efficiency issues:
It's hard to get N_2 to dissolve in water

The electrodes just end up splitting a lot of water

~ currently about 30x less efficient than Haber-Bosch

Waiting for the right catalyst!



Source: Long, Jun, et al. (2024) Fundamental Insights on the Electrochemical Nitrogen Oxidation over Metal Oxides

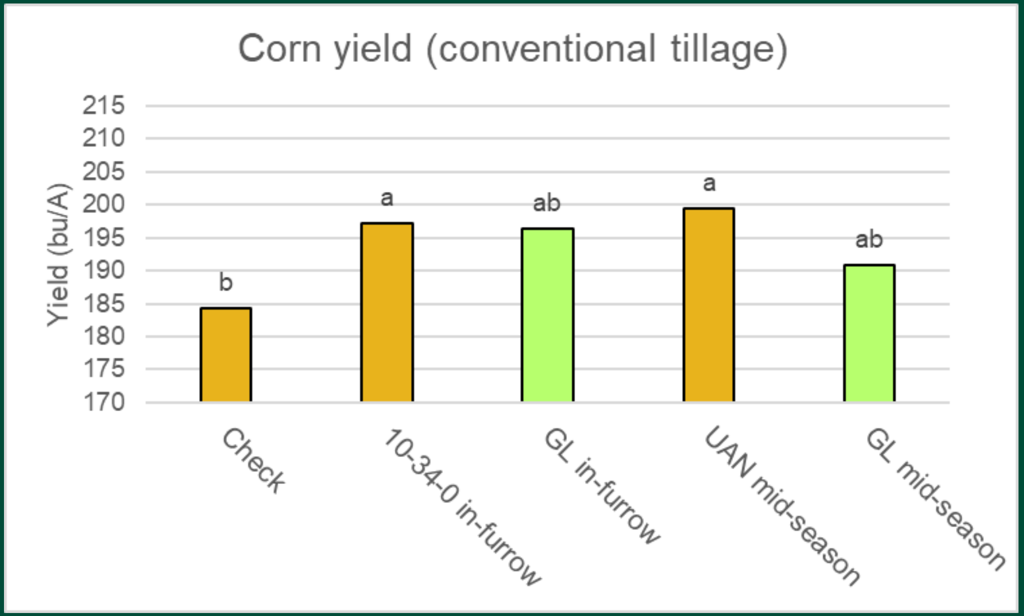
Plasma activated water benefits

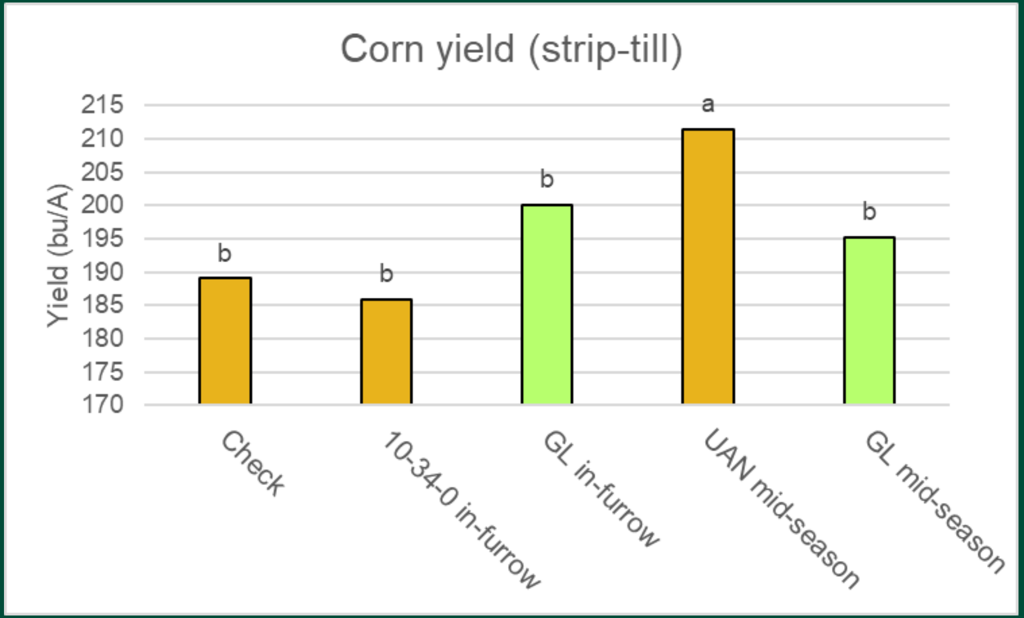
- Biostimulant
- Disinfectant
- Germination stimulant
- Spray efficacy boosting
- Can be integrated with waste treatment

Green Lightning trial at Carrington

2025 Carrington Research Extension Center
Dr. Mike Ostlie

Check
10-34-0 in-furrow
GL in-furrow
UAN mid-season
GL mid-season





Future trials at Carrington and Oakes

- Testing the Green Lightning product as a nitrogen fertilizer in corn
- Testing the product with fungicide application in spring wheat
- Researchers: Dr. Thomas Miorini and Szilvia Yuja

Thank you!
Question?

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Fertilizer Facts and Myths: Phosphorus Sources

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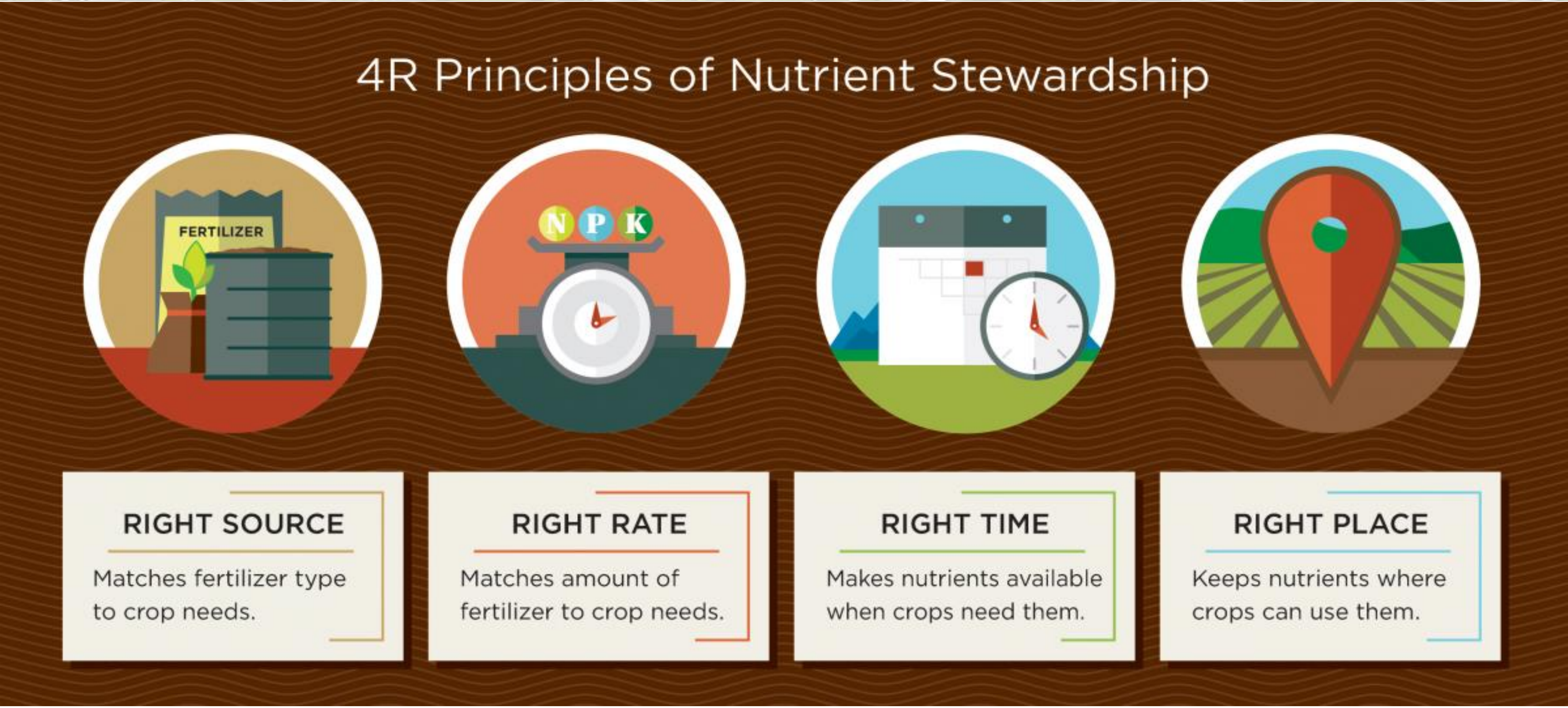


Image from: nutrientstewardship.org

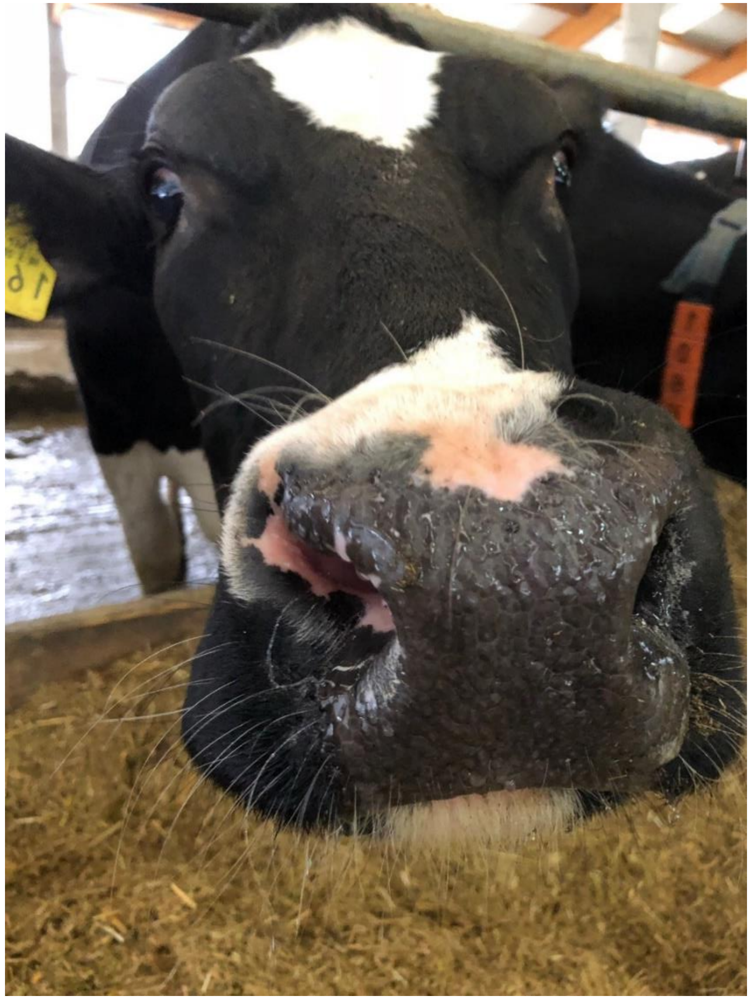
Source: What are you using?

- Manure or commercial fertilizer?
- What else is in your fertilizer?
- What can your soil supply?
- Is your fertilizer a salt that can cause damage to sensitive crops?

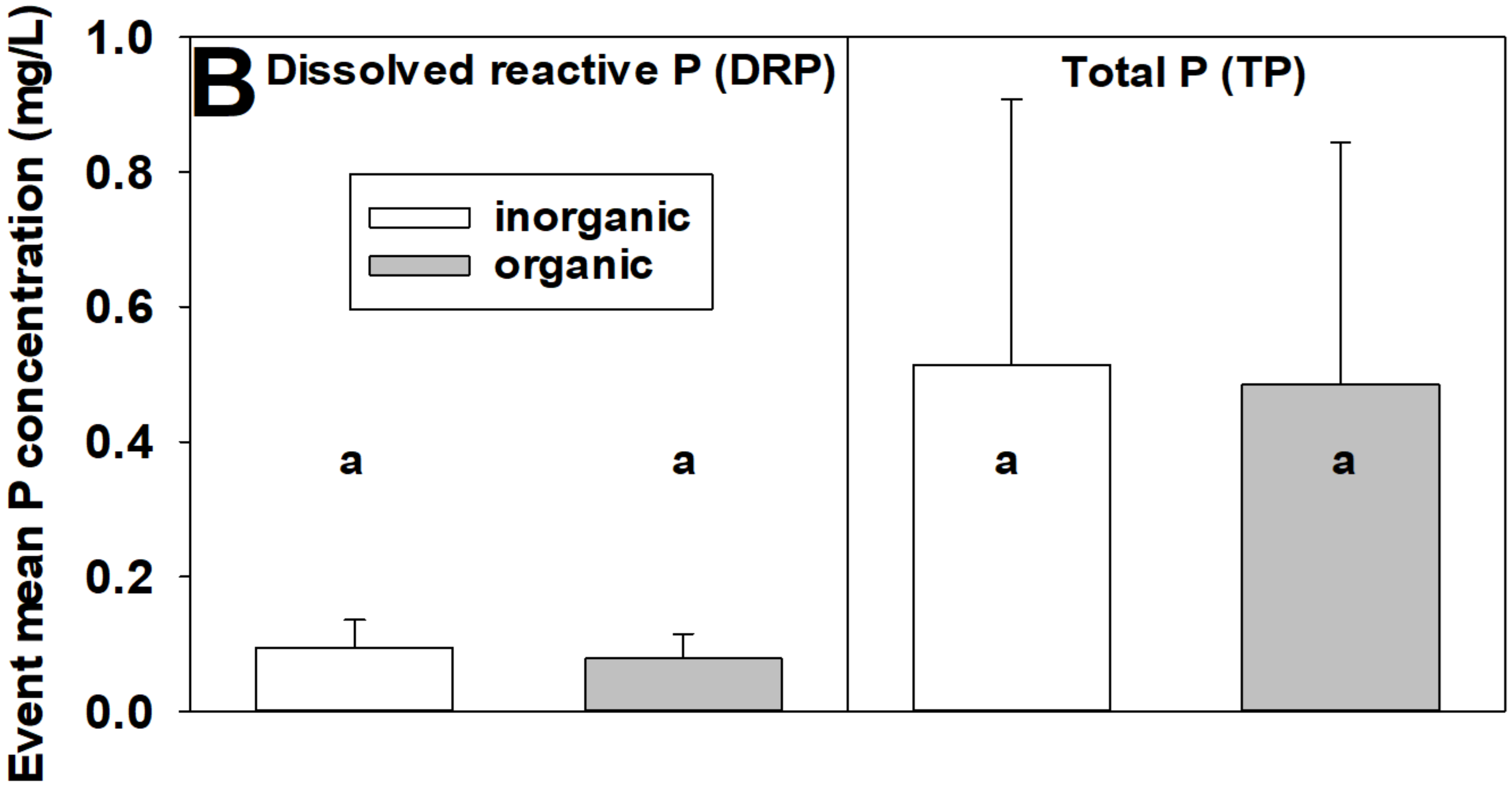
Fertilizer Facts and Myths: P Source

- Does manure pose a greater water quality risk than commercial fertilizer?
- Does P source or P timing matter more?
- Can my soil even provide P?
- Is starter a good P source?

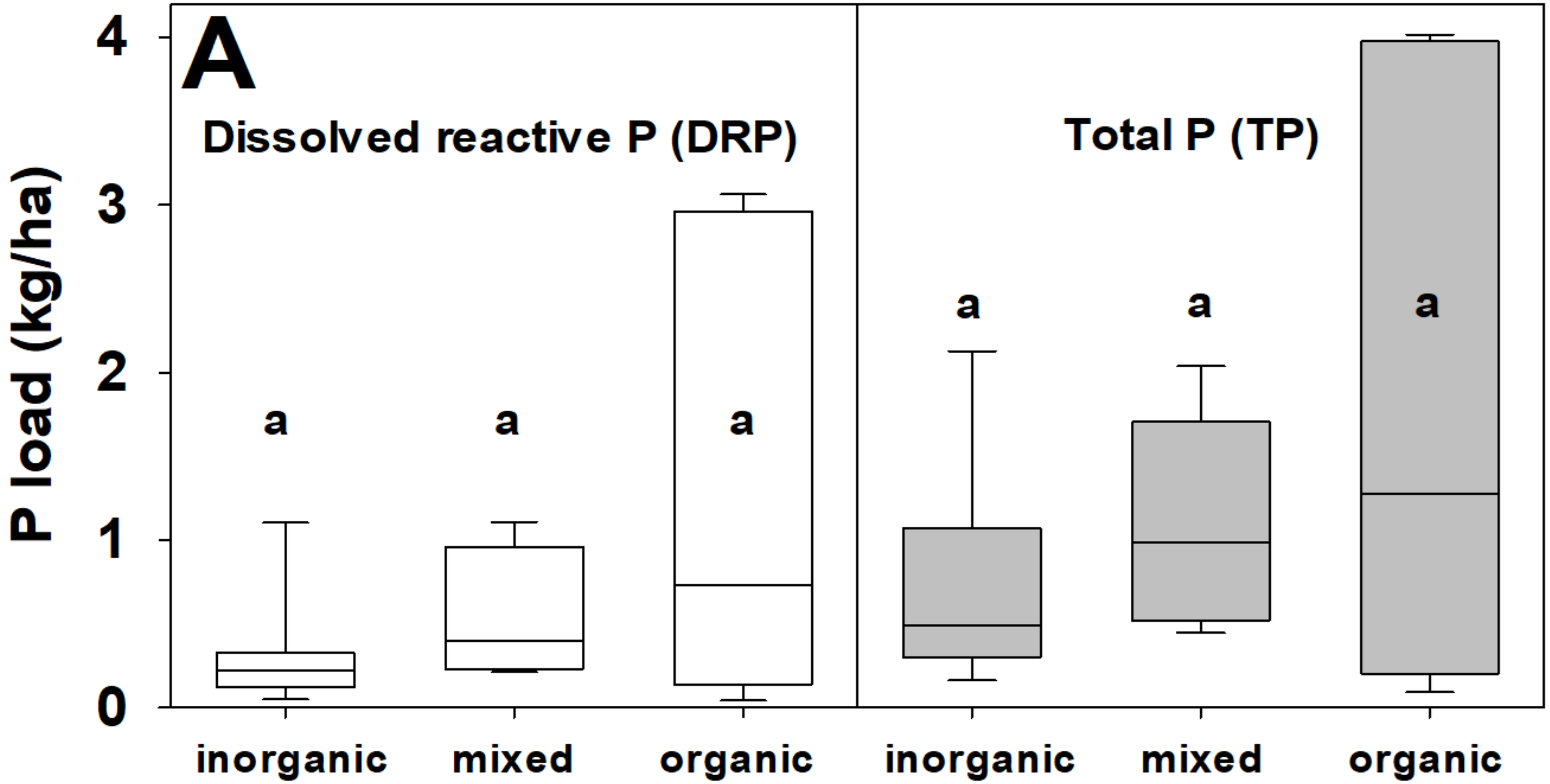
Does manure pose a greater water quality risk than commercial fertilizer?



At the same rates, we see the same losses



It's a rate x time issue, not a source issue



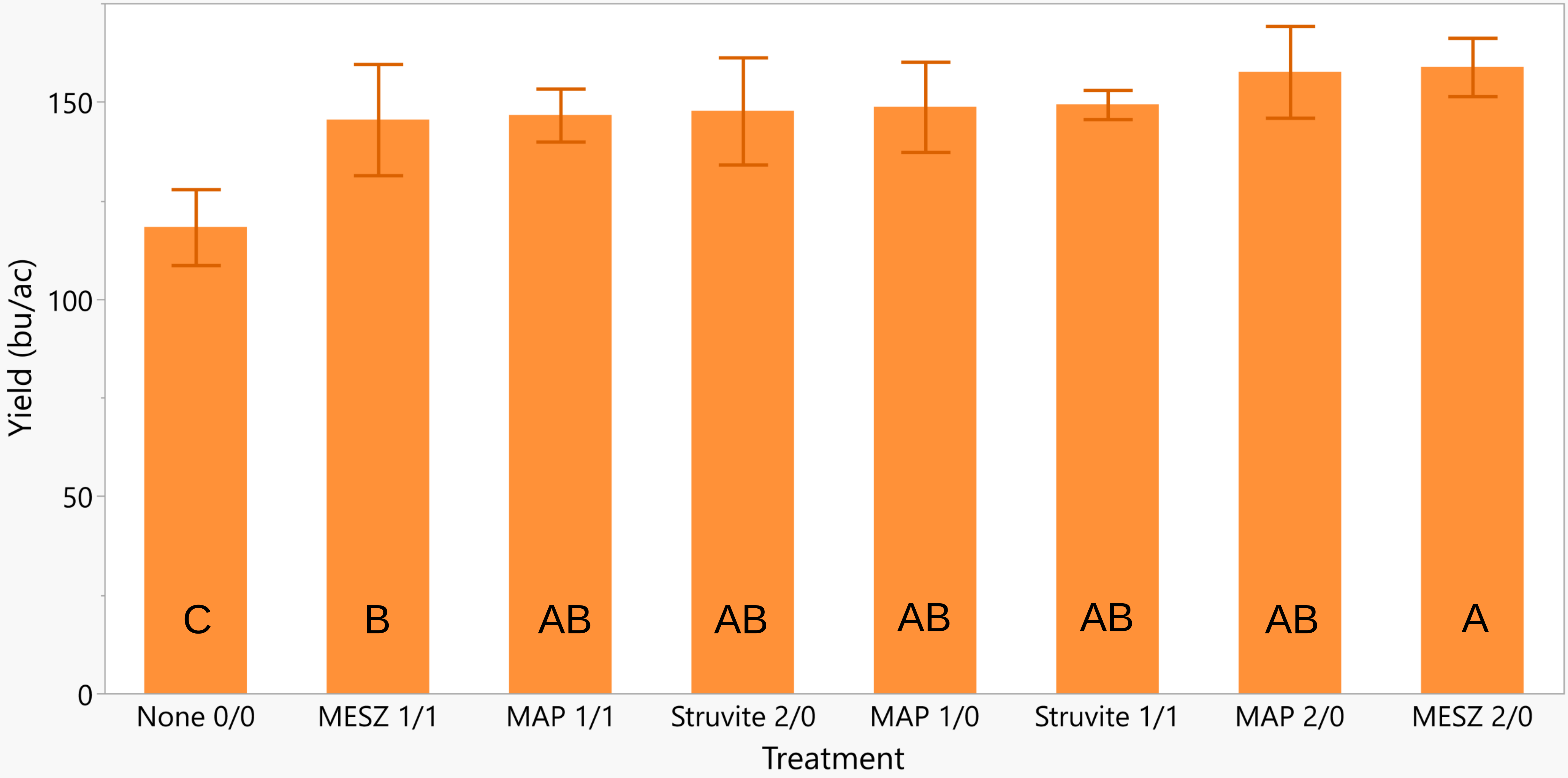
King et al. (2018)

Does **P source** or **P timing** matter more?

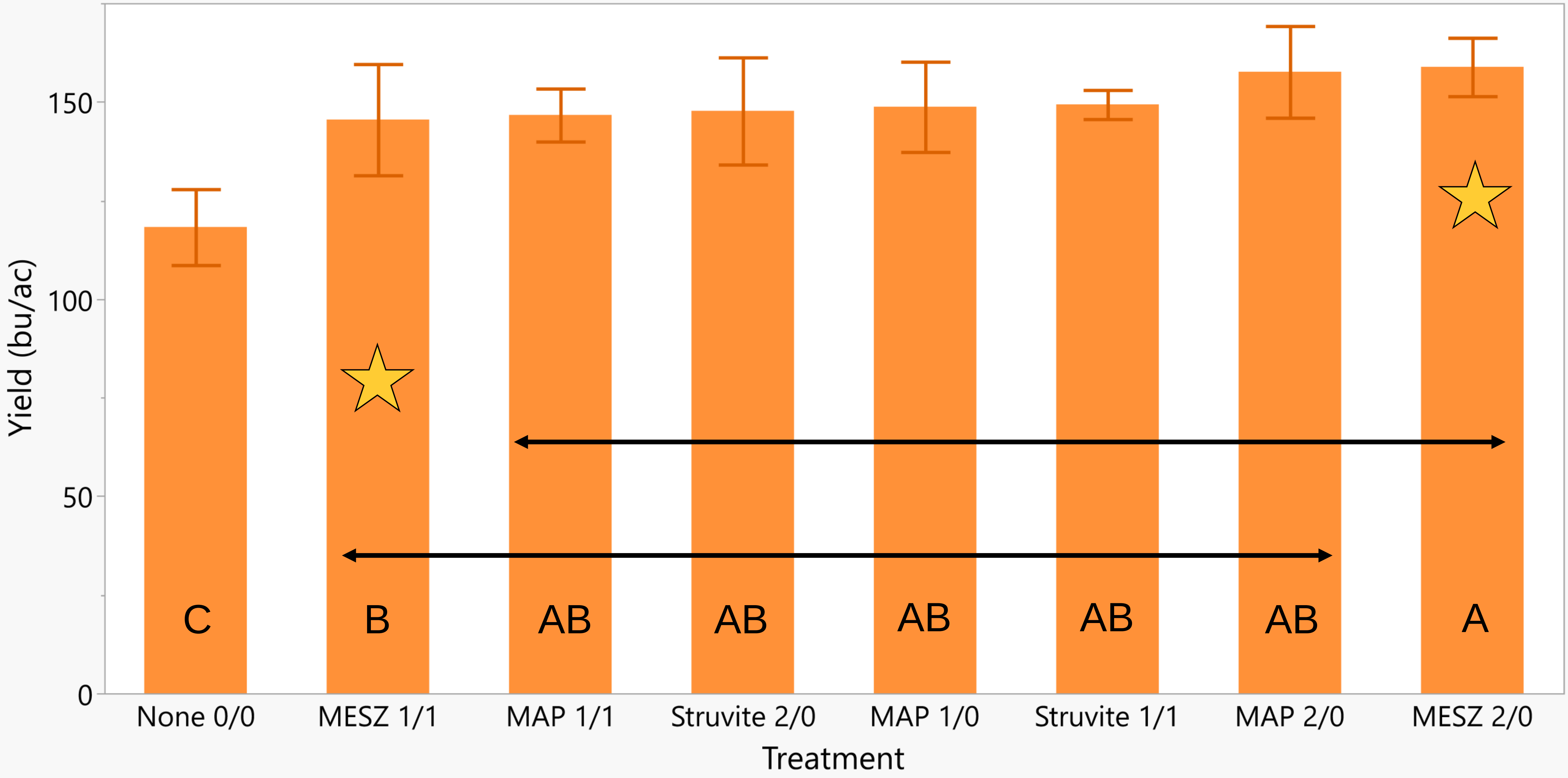
1. Can you apply two years of P before corn in a corn-soybean rotation?
2. Do any P sources perform better than others when making annual vs two-year applications in corn-soybean rotations?

Phosphorus Fertilizer Treatment		Rate (lb P_2O_5 / ac) Year 1 (corn)	Year 2 (soybean)
MAP	Annual	100	80
	2x before corn	180	0
	1x before corn	100	0
Struvite (Crystal Green)	Annual	100	80
	2x before corn	180	0
MESZ	Annual	100	80
	2x before corn	180	0
Control	None	0	0

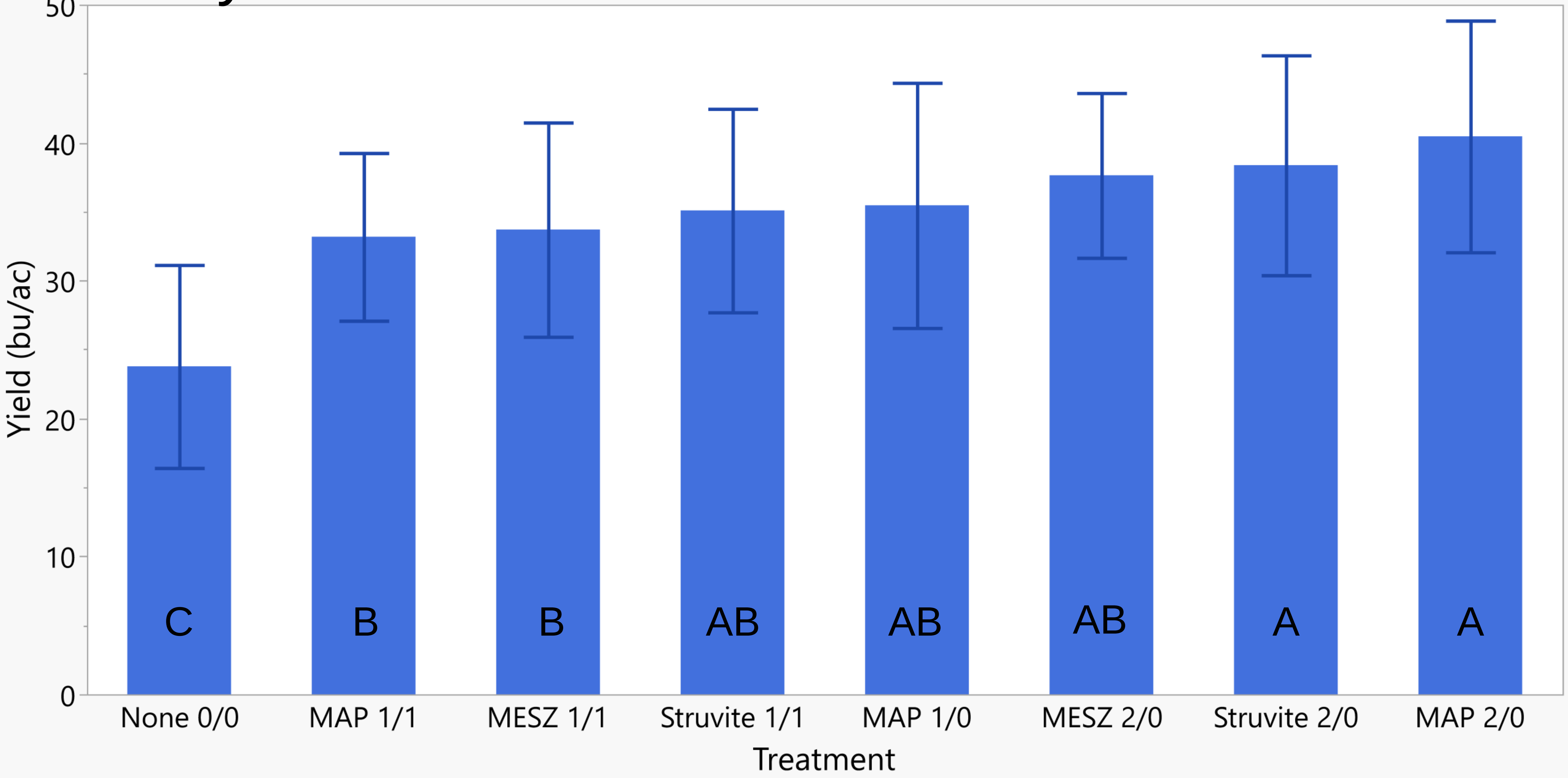
2022 Corn: Any rate/source better than 0 P control



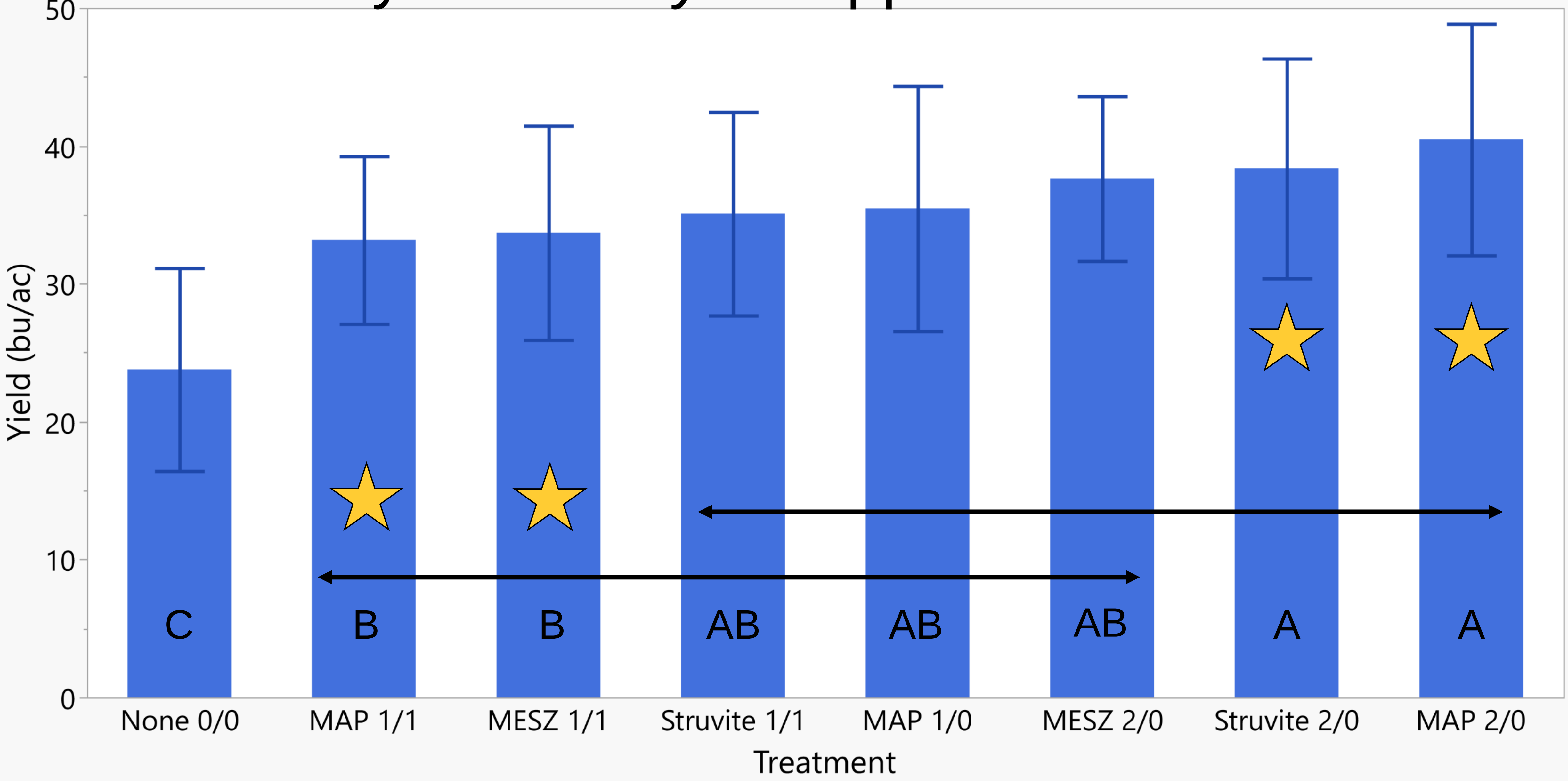
2022 Corn: 2x MESZ > 1x MESZ



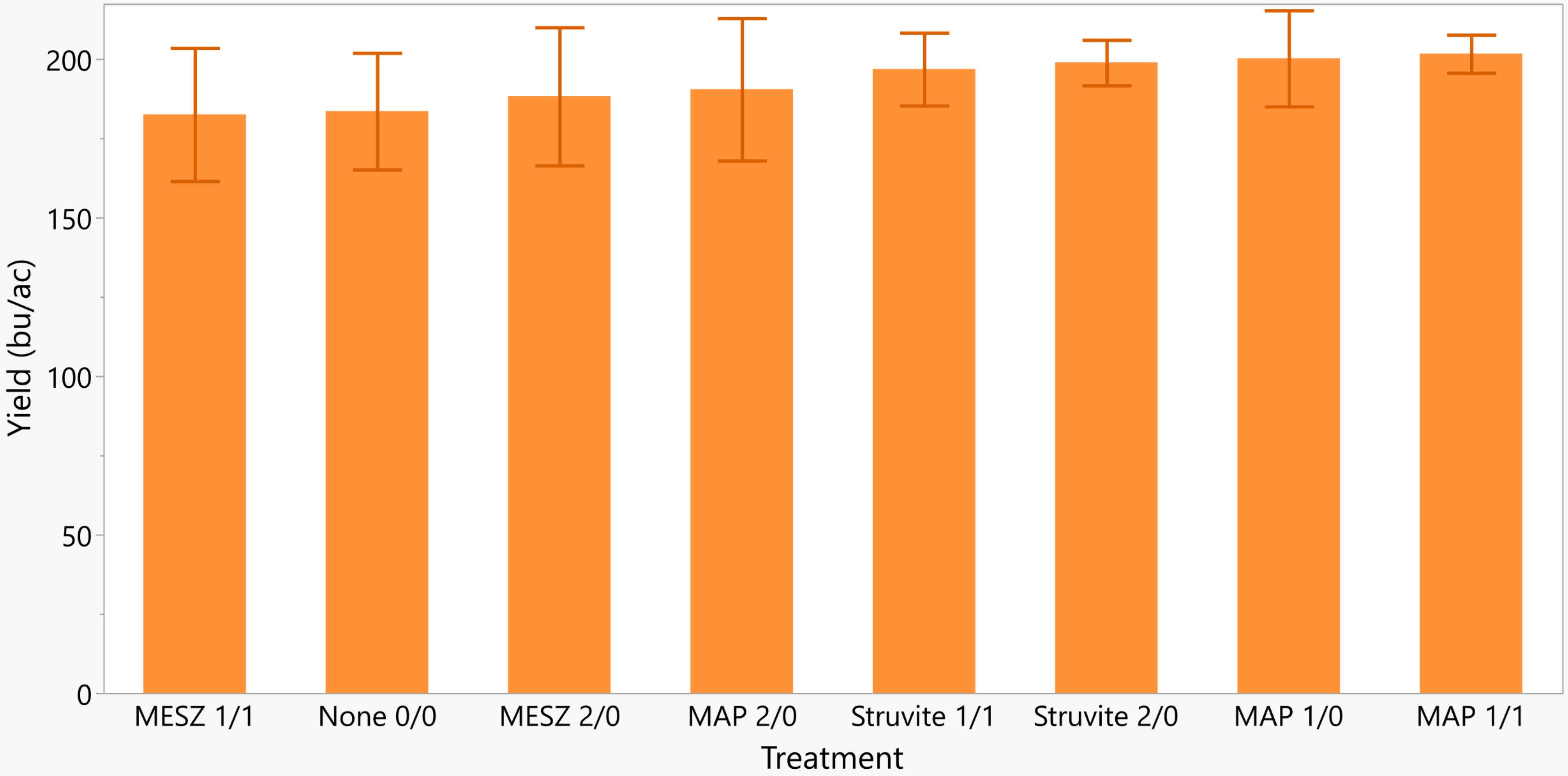
2023 soybeans: All rates/sources better than 0 P control



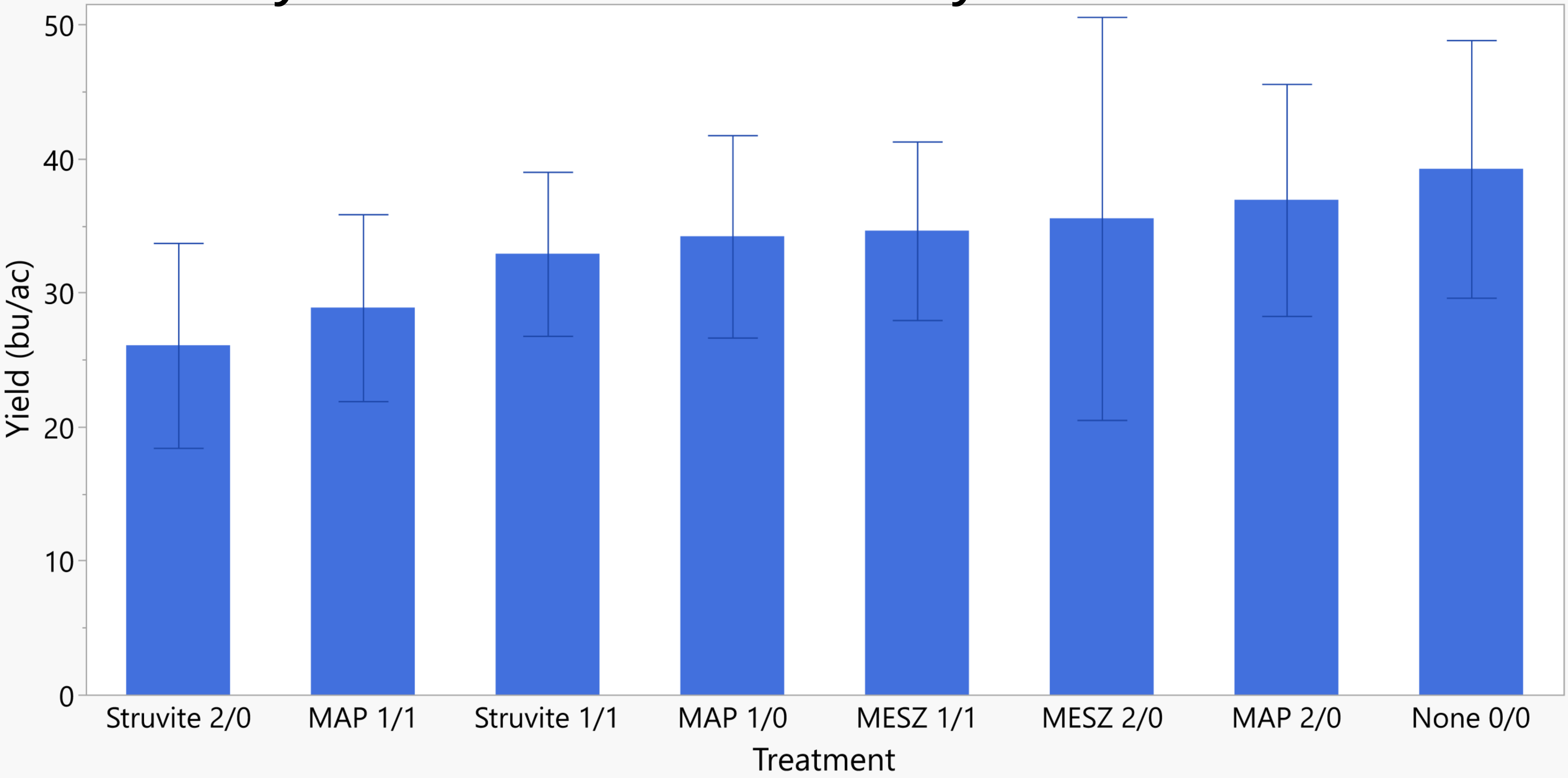
2023 soybeans: 2-year applications > Annual



2023 Corn: No difference by P rate or P source



2024 soybeans: No difference by P rate or P source



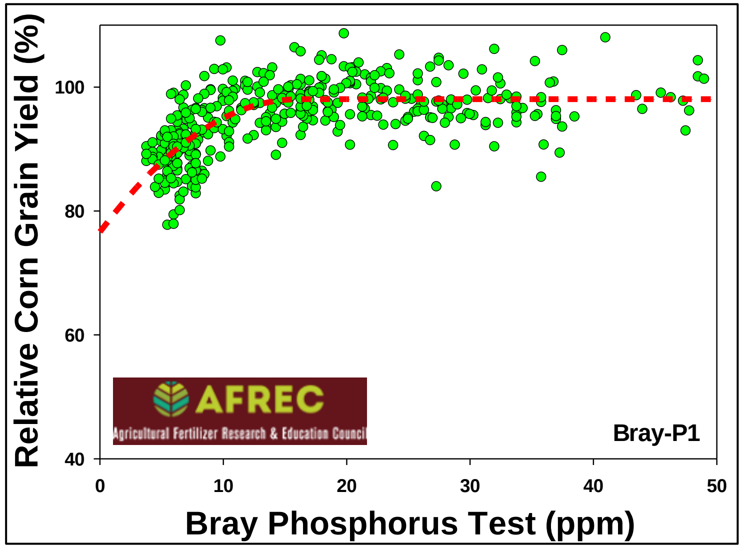
We saw a response to P timing in one location but not the other

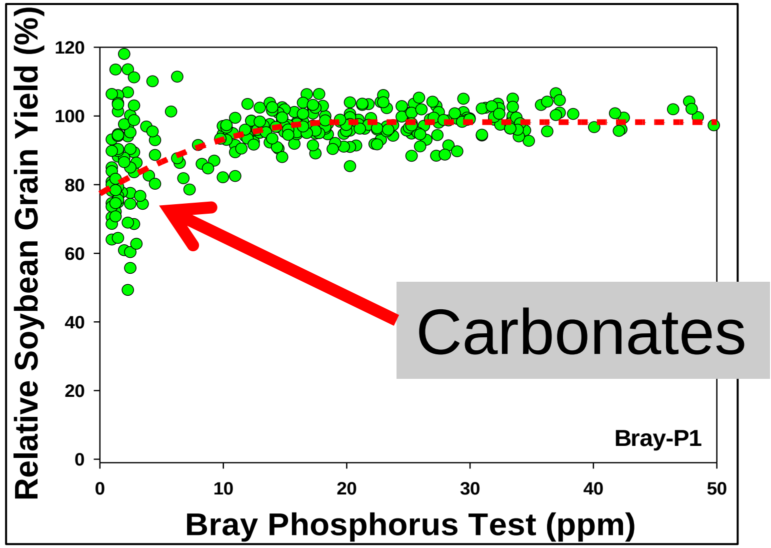
- Similar locations, same soils, very low to medium P fertility level
  - Location 1: 3 ppm Olsen-P
  - Location 2: 6 ppm Olsen-P
- Other factors besides P fertility played a role

Can my soil even provide P?

	Minnesota STP Category				
Extractant	Very Low	Low	Medium	High	Very High
	---------- ppm P extracted ----------				
Bray-P	0-5	6-11	12-15	16-20	21+
Olsen-P	0-3	4-7	8-11	12-15	16+

Critical Soil Test P Levels

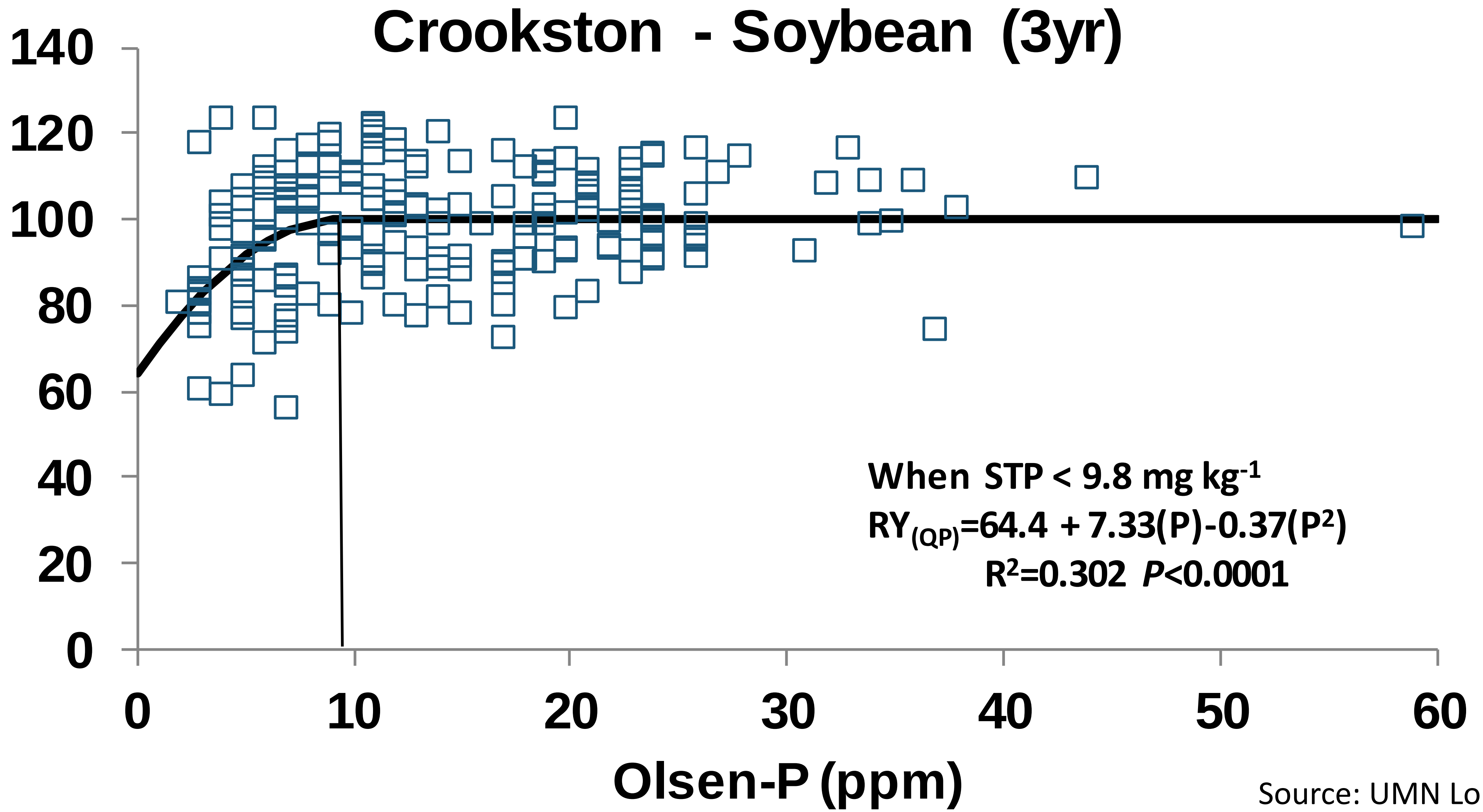




Critical soil test P level at selected relative corn grain yield levels			
Soil Test	95%	98%	100%
	---ppm---		
Bray-P1	10	15	16
Olsen	9	12	13
Mehlich-3	14	19	19

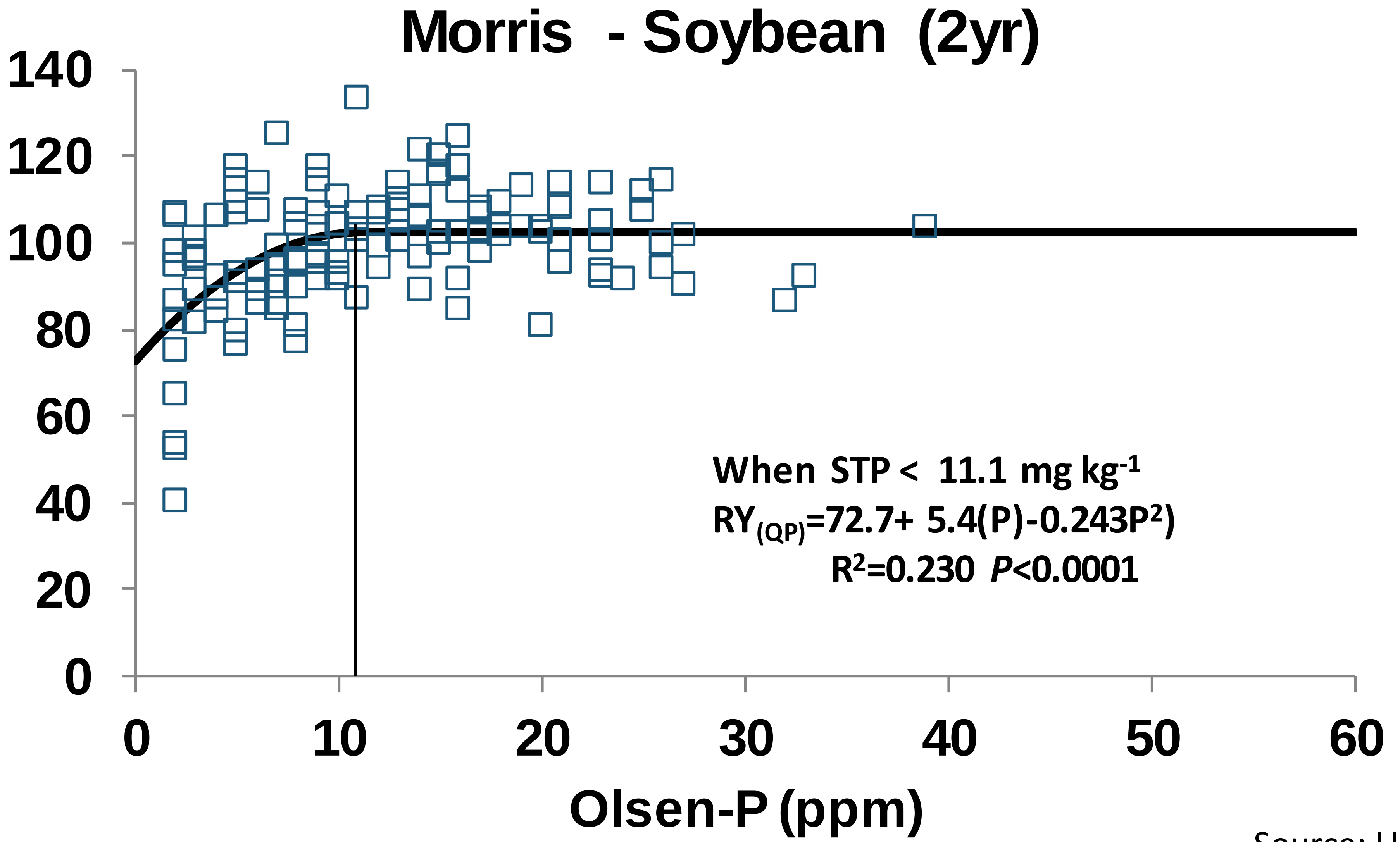
Critical soil test P level at selected relative soybean grain yield levels			
Soil Test	95%	98%	100%
	---ppm---		
Bray-P1	12	17	18
Olsen	8	10	11

Relative Soybean Yield × STP



Source: UMN Long-Term P Trial

Relative Soybean Yield × STP



Source: UMN Long-Term P Trial

Can my soil even provide P?
Yes, but you may still need to add more

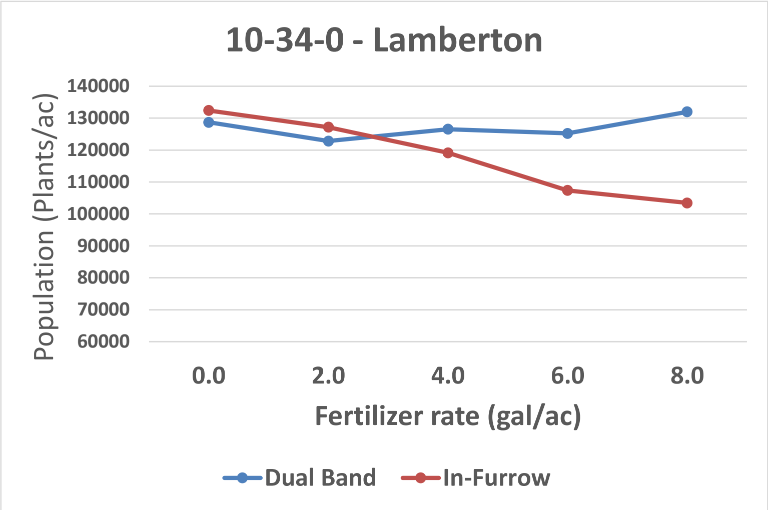
	Minnesota STP Category				
	Very Low	Low	Medium	High	Very High
Chance P fertilizer increases soybean yield	40%	49%	23%	23%	15%
Expected yield without P	90%	91%	98%	99%	99%

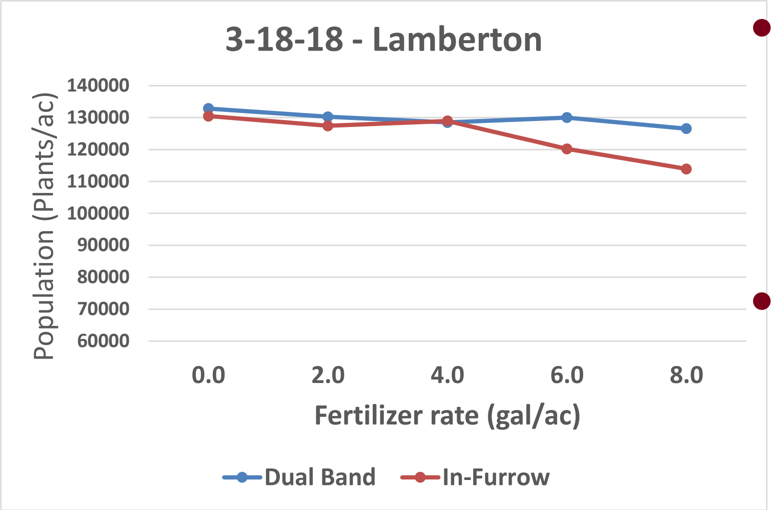
Kasier, 2024

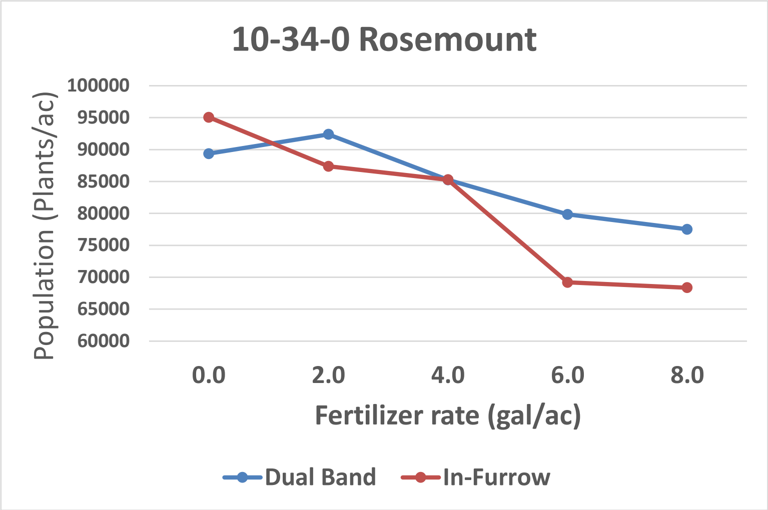
Is starter a good P source?

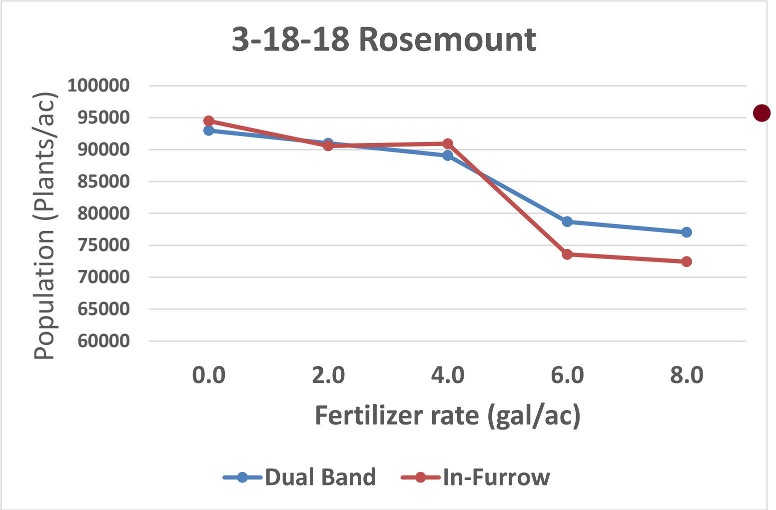
- Salts are an issue as all fertilizers contain salts
- Starter P can reduce or limits or prevents root growth/germination
- Nitrogen, specifically ammonia in the root zone are also a major issue
- No N-P-K fertilizer sources are 100% safe for placement on the seed
- Leaving ¾" of soil between the fertilizer band and seed reduces risk

Starter P can hurt soybean emergence





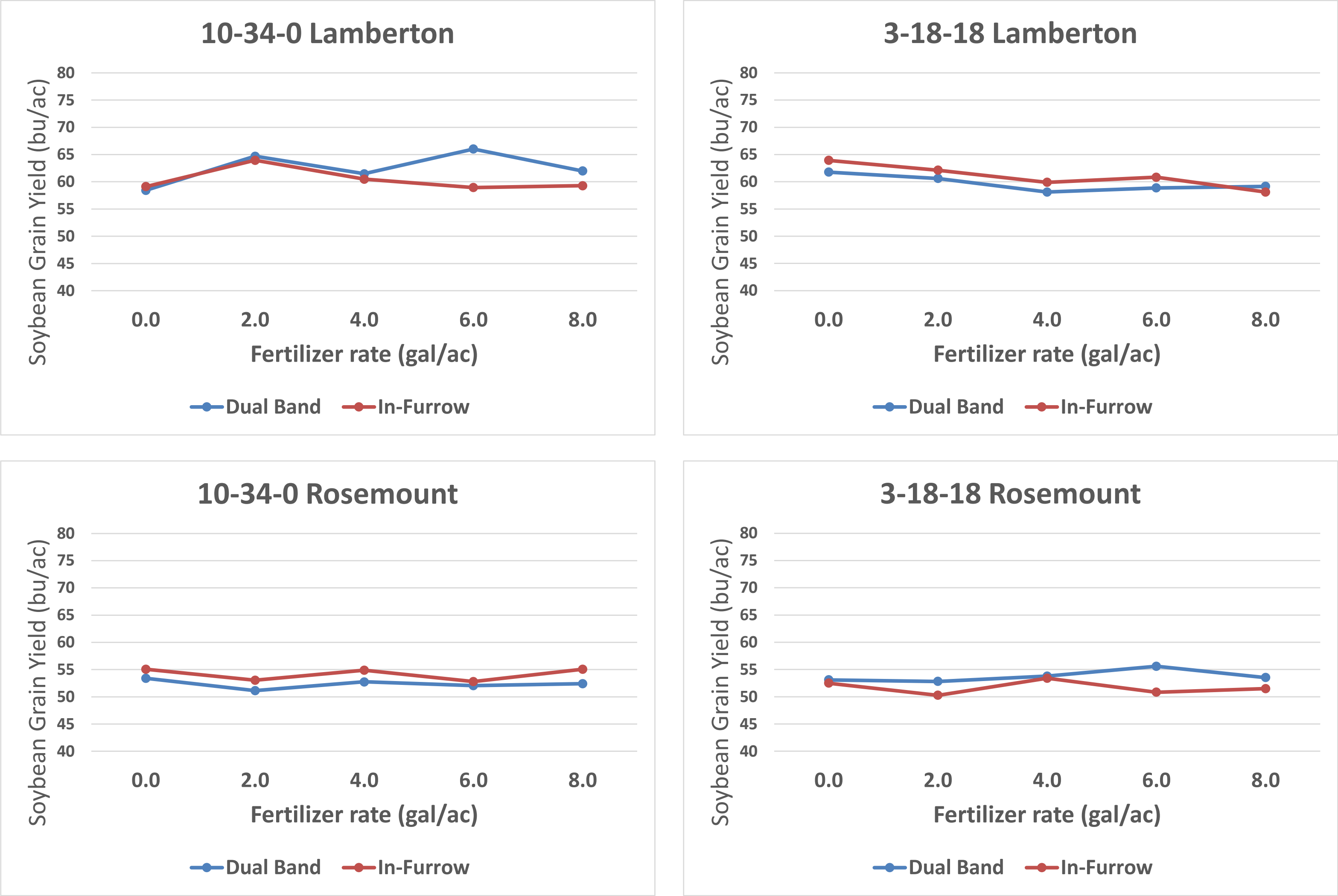




- 2023 data at Rosemount resembles data at Lamberton from 2024
- Damage was more pronounced with 10-34-0 at Lamberton 2024 and Rosemount 2023
- Rosemount 2023 both placement and starter options reduced emergence

Kasier, 2024

Impact of starter P on soybean yield



- Grain yield was not impacted by reduced emergence
  - No impact of starter (positive or negative) on grain yield
- Placement also did not impact yield
- Equal yield means an economic loss from applying starter

Kasier, 2024

Starter P for soybean?

- It’s extremely risky
- Grain yield increase (none) does not justify the cost
- Extra cost for liquids do not pay
- Furrow Jet units not ideal for high clay soil
  - The fertilizer openings are small and plug easy
- Iron products like Soygreen are safe and are effective

Kasier, 2024

Conclusion

- **Fact:** Manure and commercial fertilizer have equal P loss potential
- **Fact:** P rate and timing matter more than P source
- **Fact:** Your soil will provide P if the soil test is high enough even if you have high pH, calcareous soils
- **Fact:** Starter P is a good P source, but you need to watch for salt injury in certain crops

Fertilizer Facts and Myths: Phosphorus Sources

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All About Sulfur in One Easy Lesson

2026 Soil Water Workshop

Dr. Brady Goettl
Assistant Professor of Extension Soil Science

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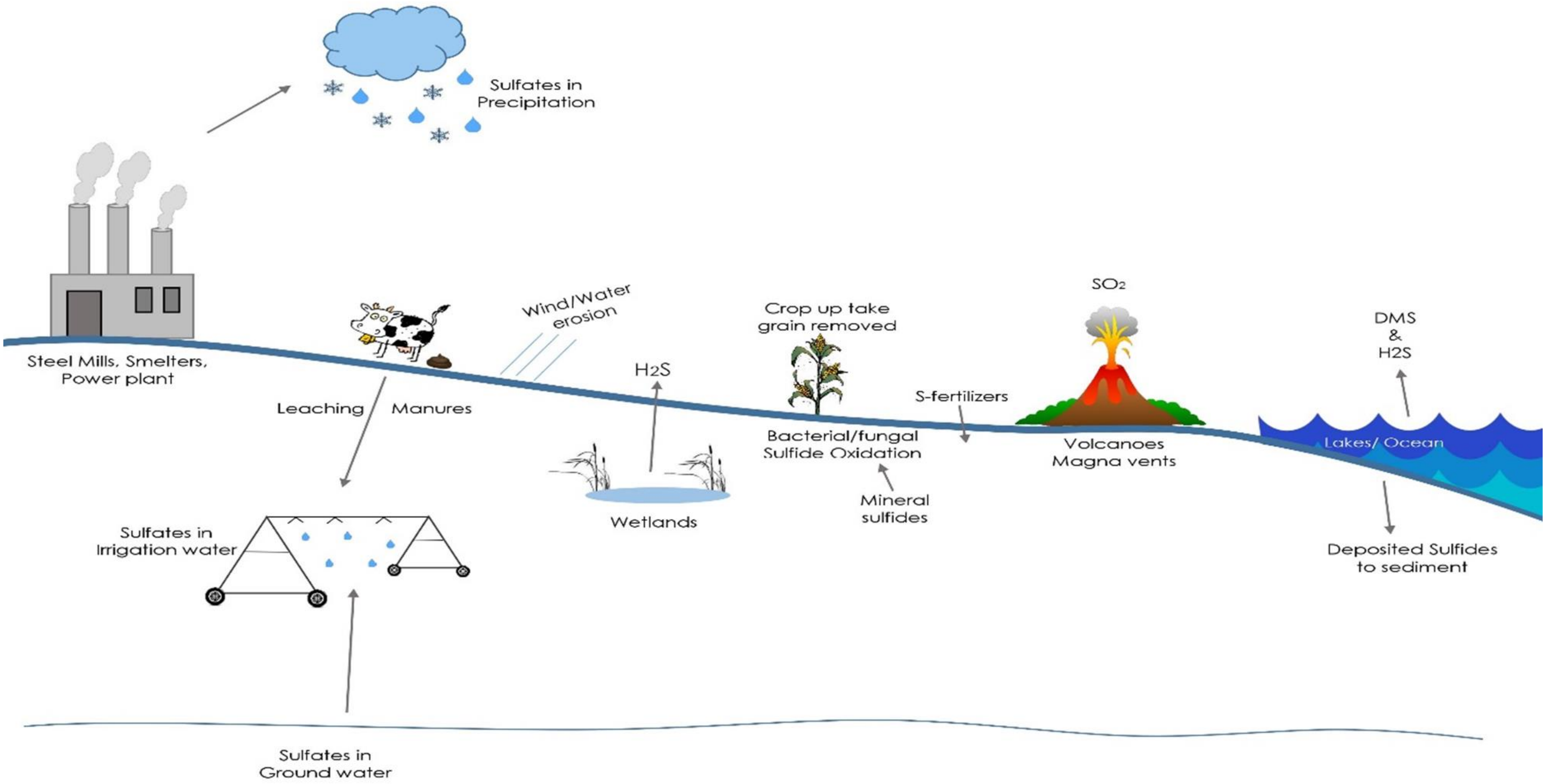
Topic to Cover

- S in the natural environment
- Forms of S and S cycle
- Sources of S in agriculture
- Practical S-fertility management



Source: D. Franzen, NDSU

Sulfur in the Atmosphere

- Naturally released from wetlands, waterbodies, volcanic activity
- Product of coal and fossil fuel combustion

$$SO_2 + O_2 + H_2O \rightarrow H_2SO_4$$

Photo source: https://19january2017snapshot.epa.gov/history/epa-history-clean-air-act-amendments-1990_.html

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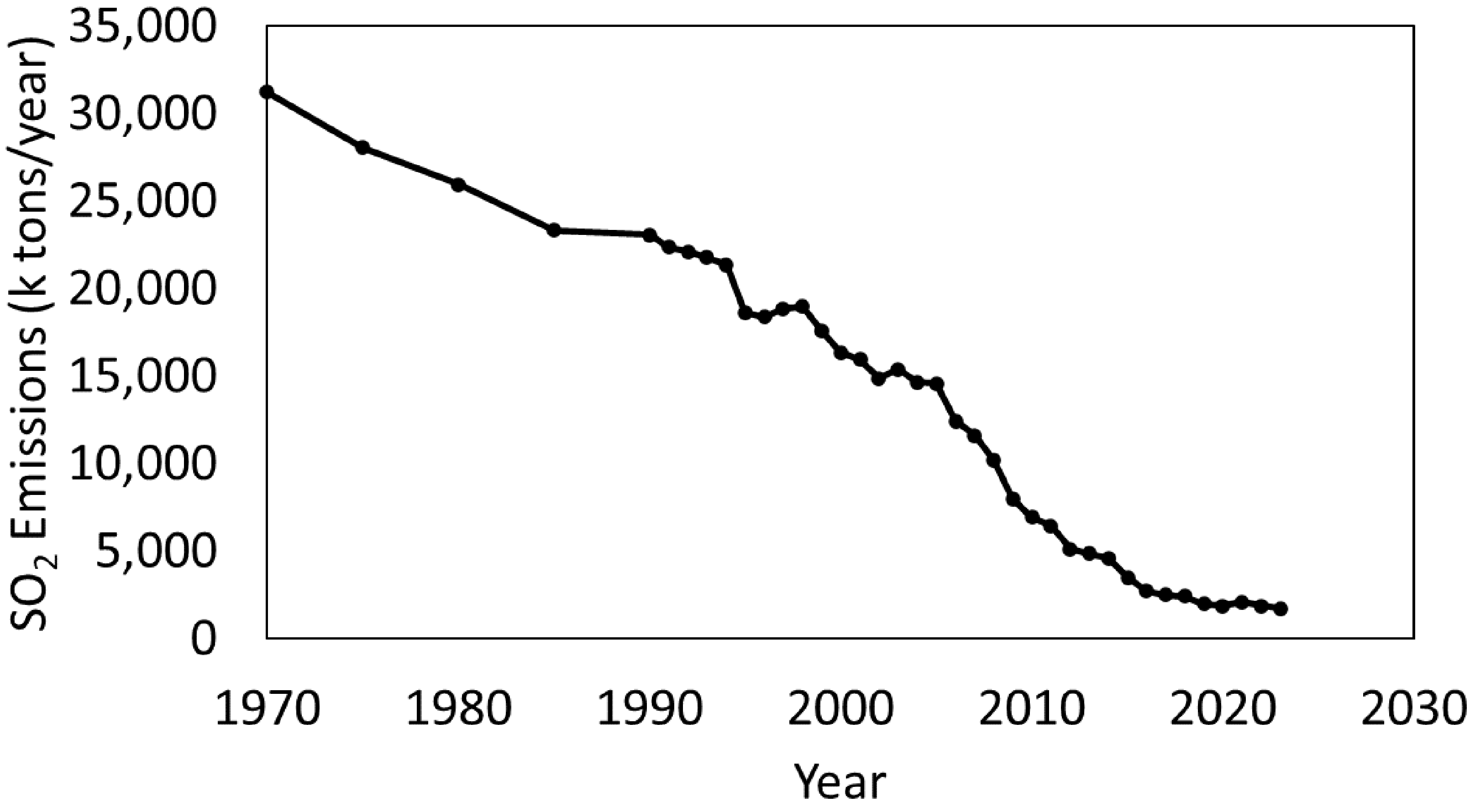
US Anthropogenic SO_2 Emissions



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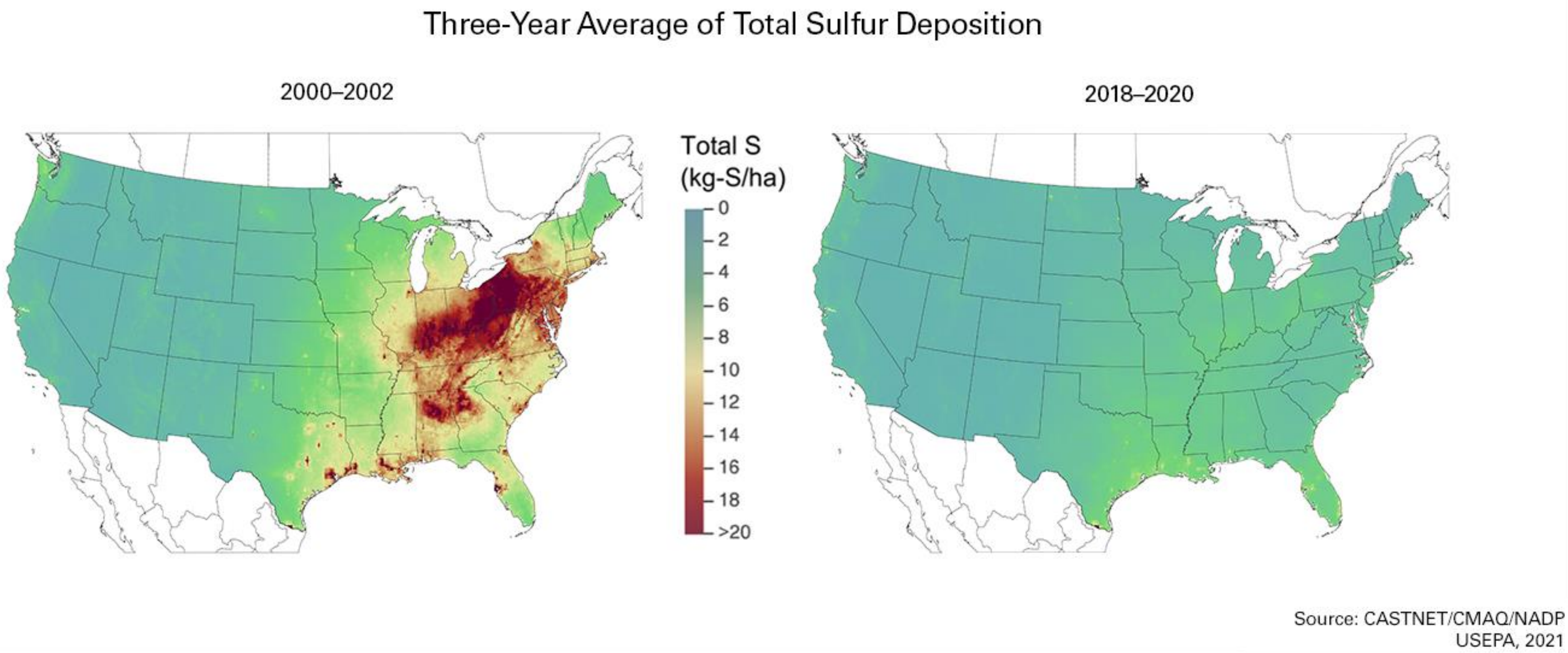
Data Source: https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data



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Source: https://www3.epa.gov/airmarkets/progress/reports_2020/acid_deposition_figures.html

Sulfur in Plants

- Component of amino acids—“the building blocks of protein”
- Component of *nitrate reductase*
  - Converts NO_3 to organic N Deficiency of S interferes with N metabolism
- Deficiency symptoms
  - Light green coloring of the whole plant
  - Interveinal chlorosis—especially evident in corn

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Photo Credit: D. Franzen, NDSU

Sulfur in the Soil

Inorganic

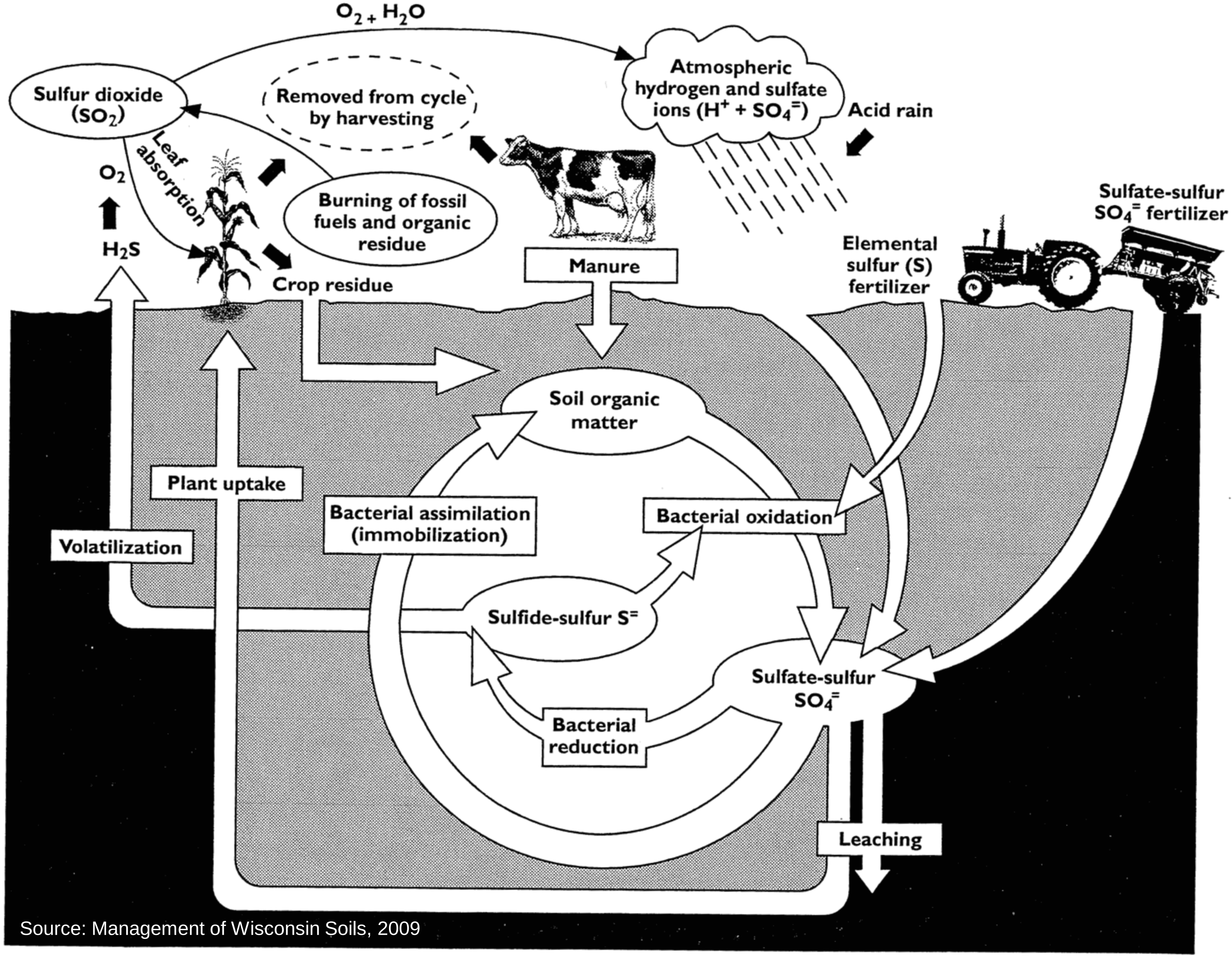
- Sulfate (SO_4^{-2})
- Elemental sulfur (S)
- Hydrogen sulfide (H_2S)
- Salt/Mineral
  - Gypsum ($CaSO_4$)
  - Epsomite ($MgSO_4$)
  - Pyrite (FeS_2)

Organic

- Organic sulfates
- Carbon-bonded sulfur

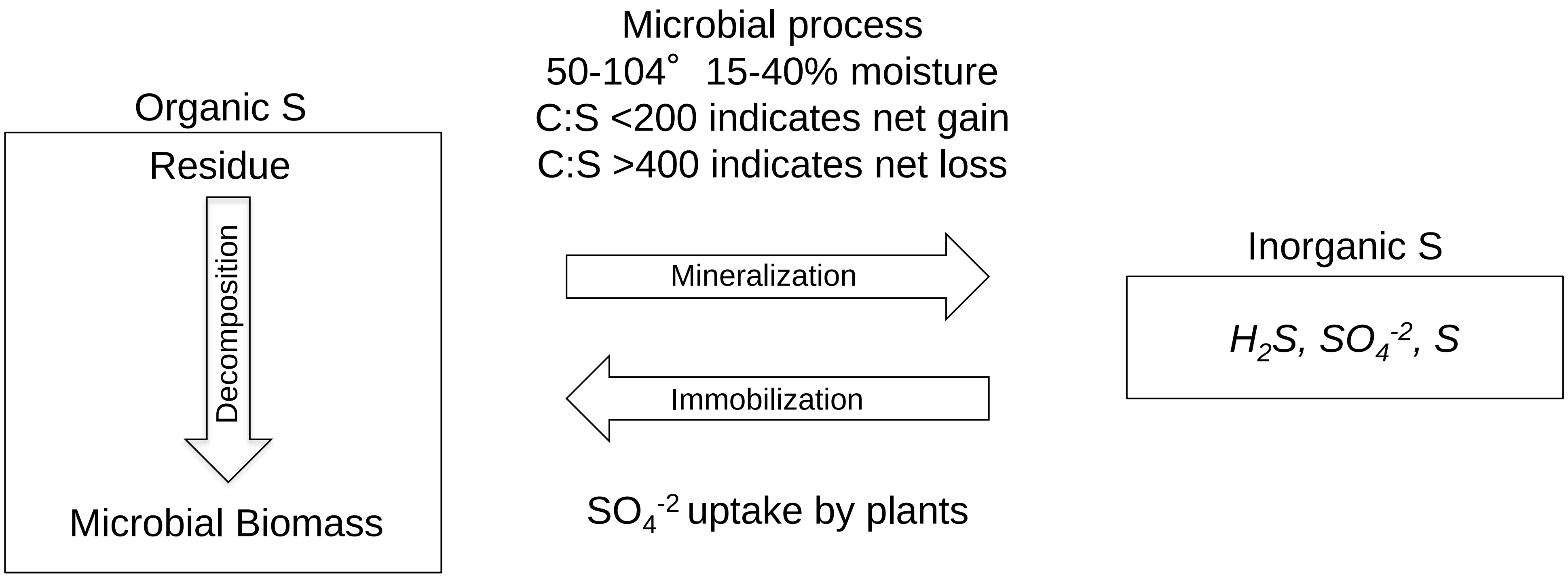
Most soils S is in organic forms, so S is highly correlated to organic matter

Figure 9-6. The sulfur cycle.

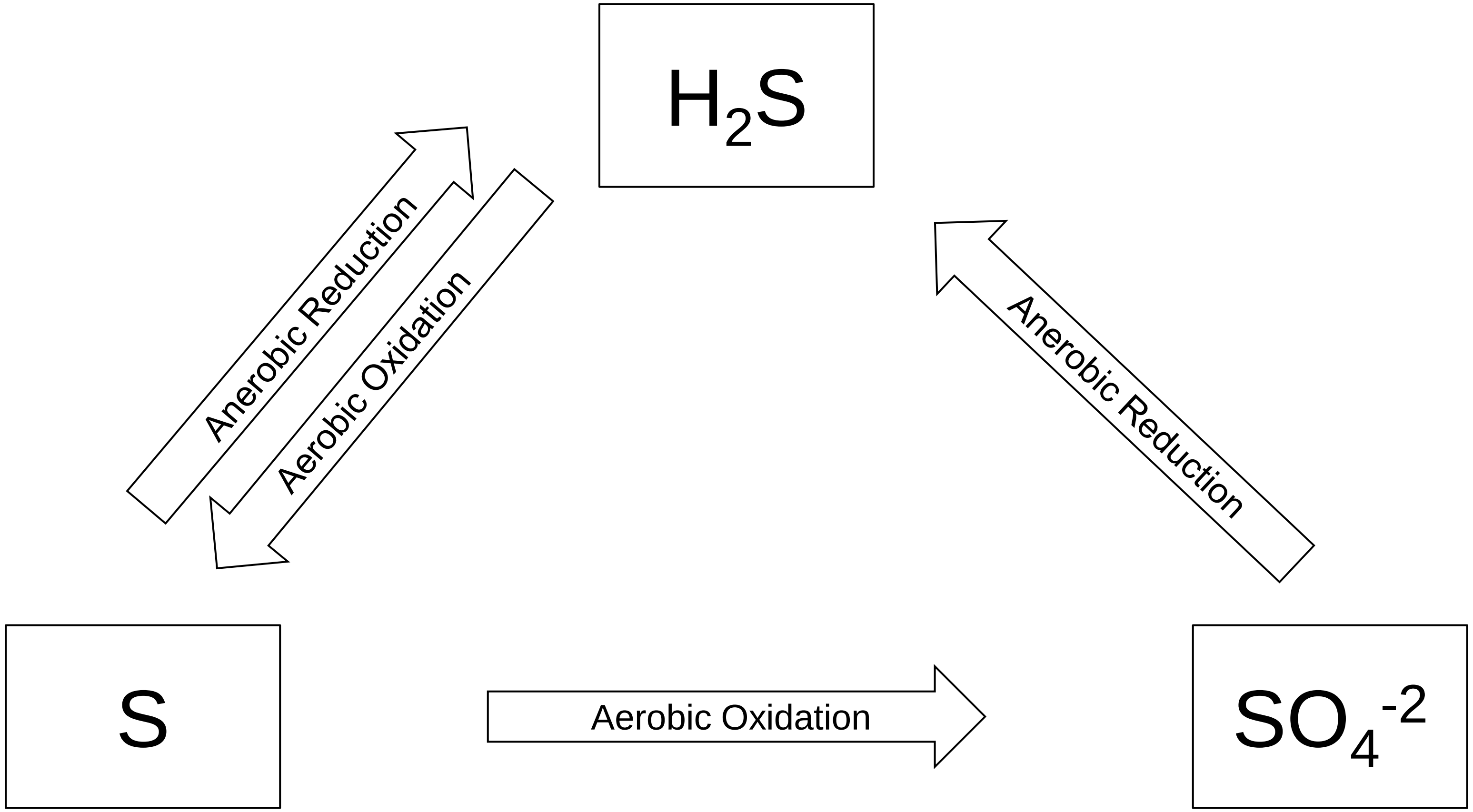


Source: Management of Wisconsin Soils, 2009

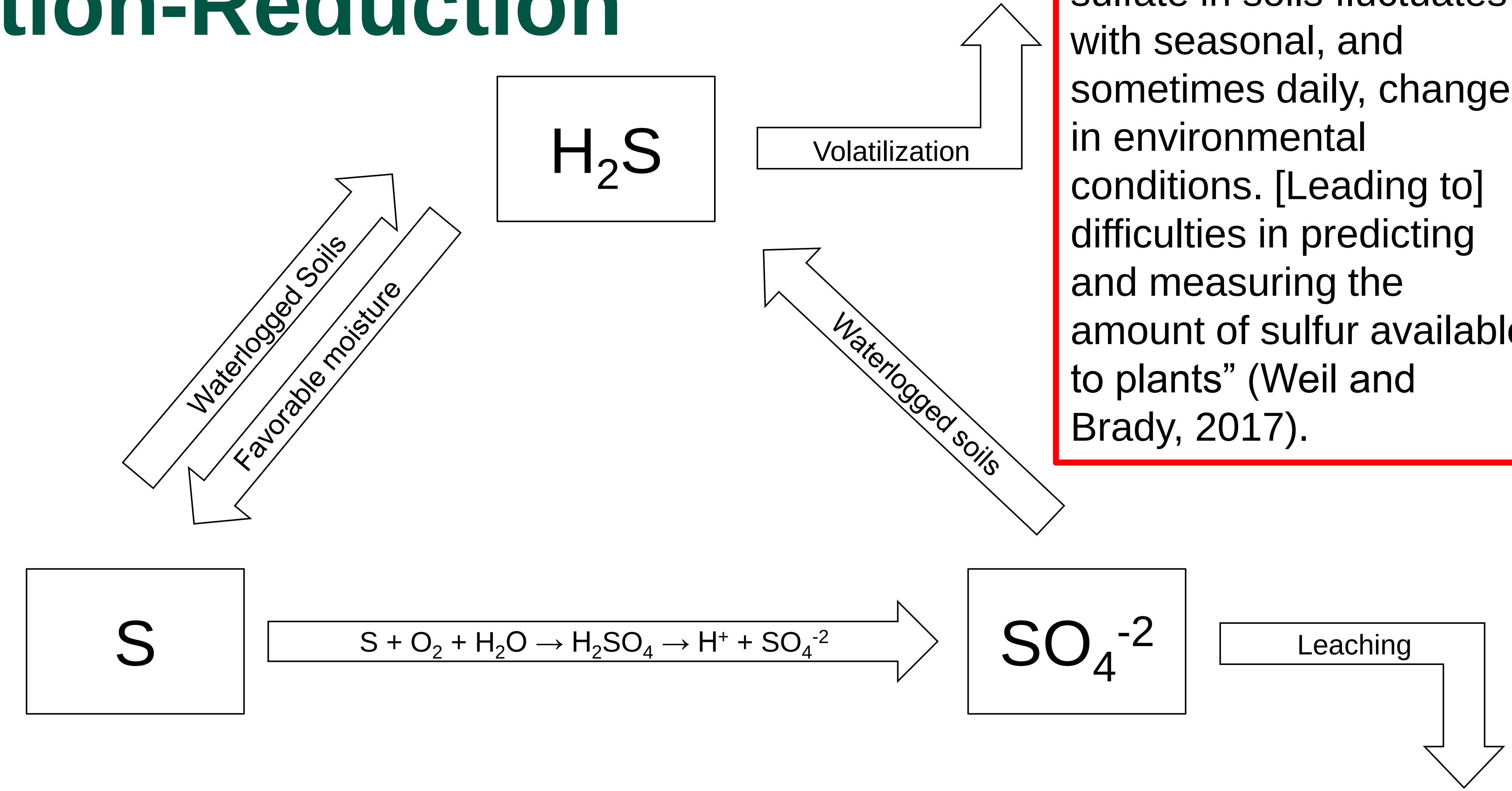
Mineralization-Immobilization



Oxidation-Reduction



Oxidation-Reduction



"The supply of available sulfate in soils fluctuates with seasonal, and sometimes daily, changes in environmental conditions. [Leading to] difficulties in predicting and measuring the amount of sulfur available to plants" (Weil and Brady, 2017).

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Sources of Sulfur

Table 9-12. Sulfur fertilizers.

Material	Chemical formula	Fertilizer analysis $N–P_2O_5–K_2O$	Sulfur content
		— % —	— % —
Very soluble			
Ammonium sulfate	$(NH_4)_2SO_4$	21-0-0	24
Potassium sulfate	K_2SO_4	0-0-50	18
Potassium-magnesium sulfate	$K_2SO_4•2MgSO_4$	0-0-22	23
Ammonium thiosulfate[a]	$(NH_4)_2S_2O_3 + H_2O$	12-0-0	26
Magnesium sulfate (Epsom salts)	$MgSO_4•7H_2O$	0-0-0	14
Ordinary superphosphate	$Ca(H_2PO_4)_2 + CaSO_4$	0-20-0	14
Slightly soluble			
Calcium sulfate (gypsum)	$CaSO_4•2H_2O$	0-0-0	17
Insoluble			
Elemental sulfur	S	0-0-0	88–98

[a]*Ammonium thiosulfate is a 60% aqueous solution.*

Source: Management of Wisconsin Soils, 2009

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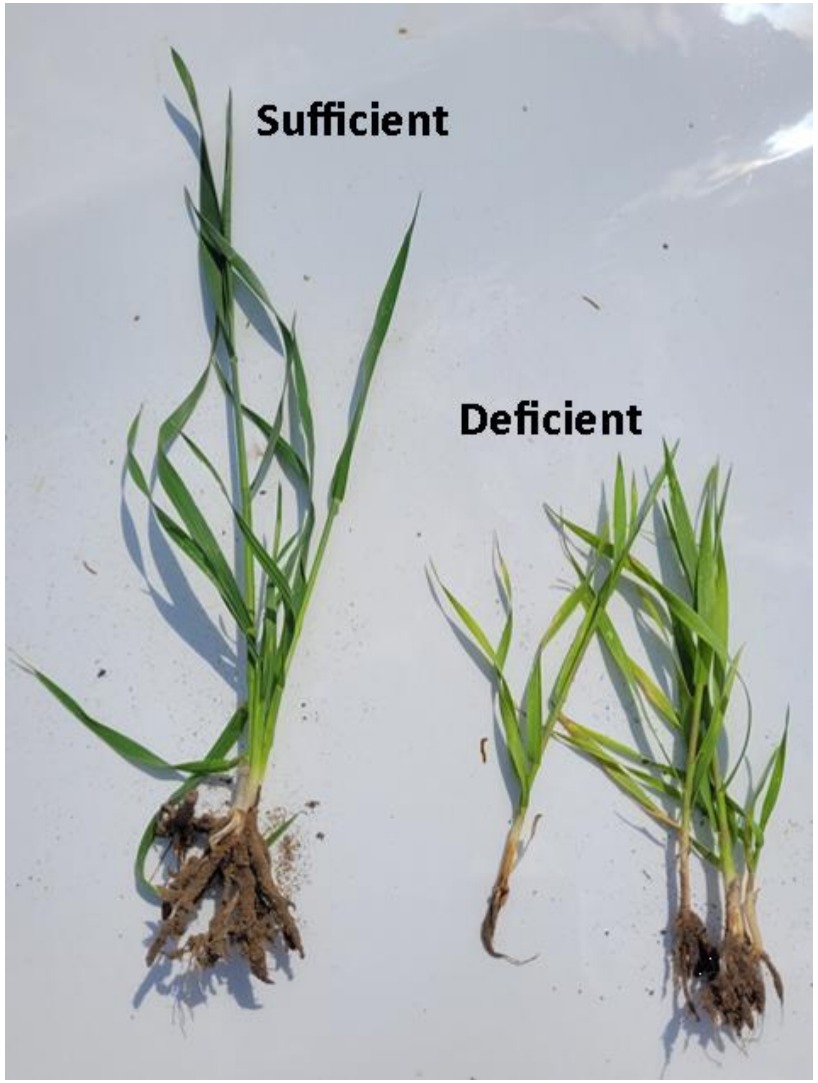
Are all S sources created equal?

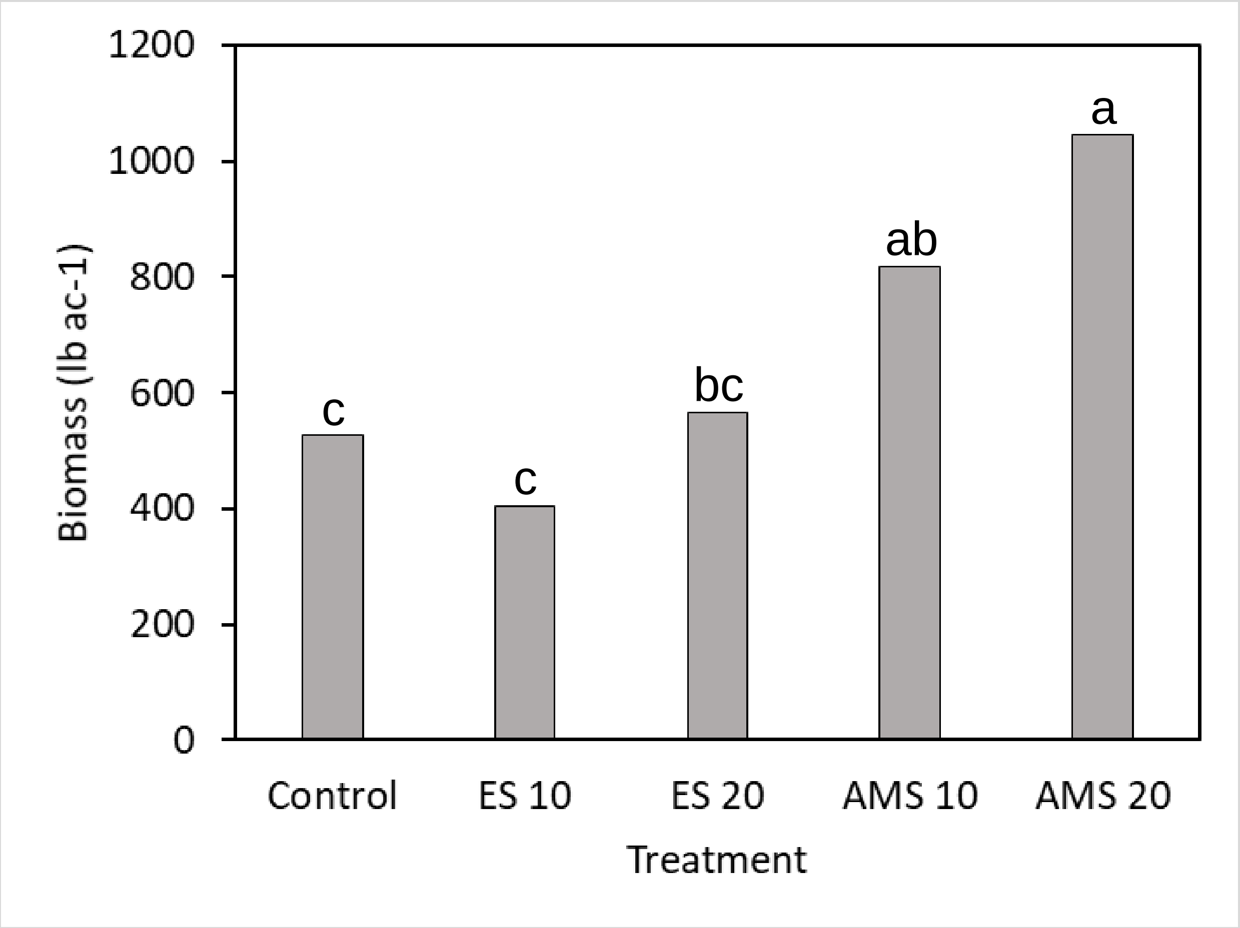
- **No.** This was a perfect year to illustrate this point…

Sulfur Deficiency in Wheat, Griggs County, 2025



Are all S sources created equal?

- **No.** This was a perfect year to illustrate this point…
- Elemental sulfur (ES) and AMS were applied pre-flagleaf to deficient wheat near Carrington at the rates of 10 and 20 lb S/ac



Elemental Sulfur

- Very insoluble
- Requires oxidation before it is plant available
- Oxidation rate depends on:
  - Particle size
  - Soil mixing/incorporation
  - Soil moisture and temperature
  - Microbial activity

Sulfur Response in ND

- Severe S deficiency became evident in early 1990s with the introduction of canola

		Canola Yield (lb/ac)		
S rate (lb/ac)	S source	Hilltop	Slope	Footslope
0		30	240	1460
20	AMS	1650	1670	1720
40	AMS	1800	1860	2170
40	Elemental	620	1060	1630

6,000% Yield Increase!

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Source: Deibert et al., 1996

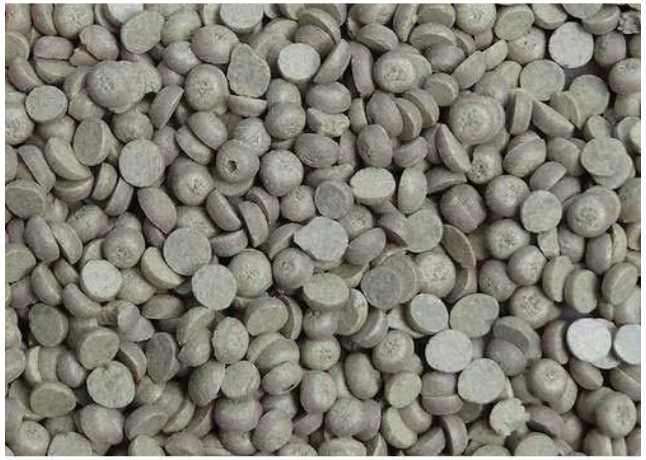
“A Better Mousetrap”

Elemental Sulfur

- Particle size matters
- ~30%/yr plant available
- Apply well in advance of planting

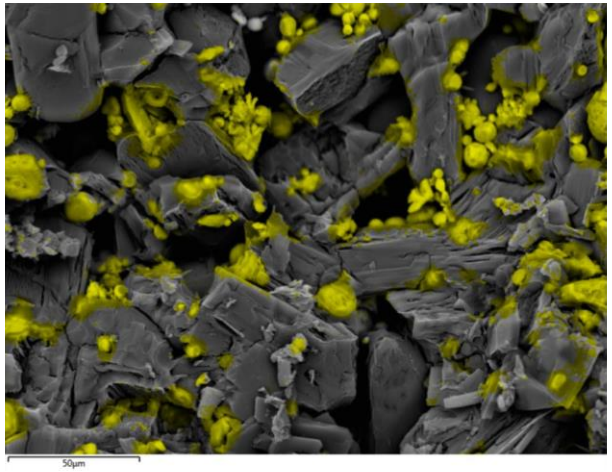
Elemental Sulfur in Bentonite Clay

- Requires multiple wetting and swelling events to disperse prill



Micronized Elemental Sulfur

- Rapid conversion to SO_4
- Often combined with other fertilizers like urea or MAP



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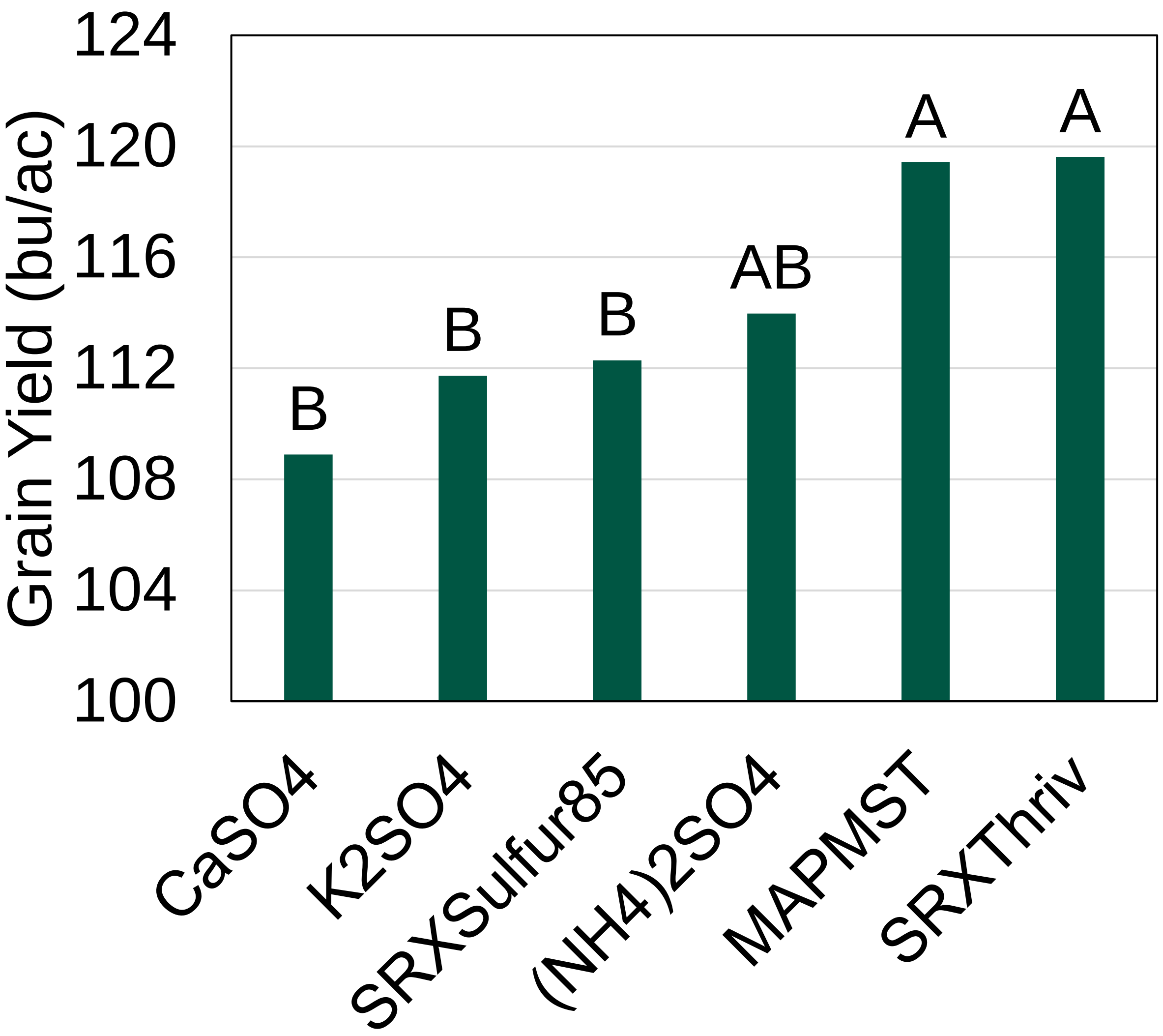
Slide adapted from J. Spackman, Univ of Idaho

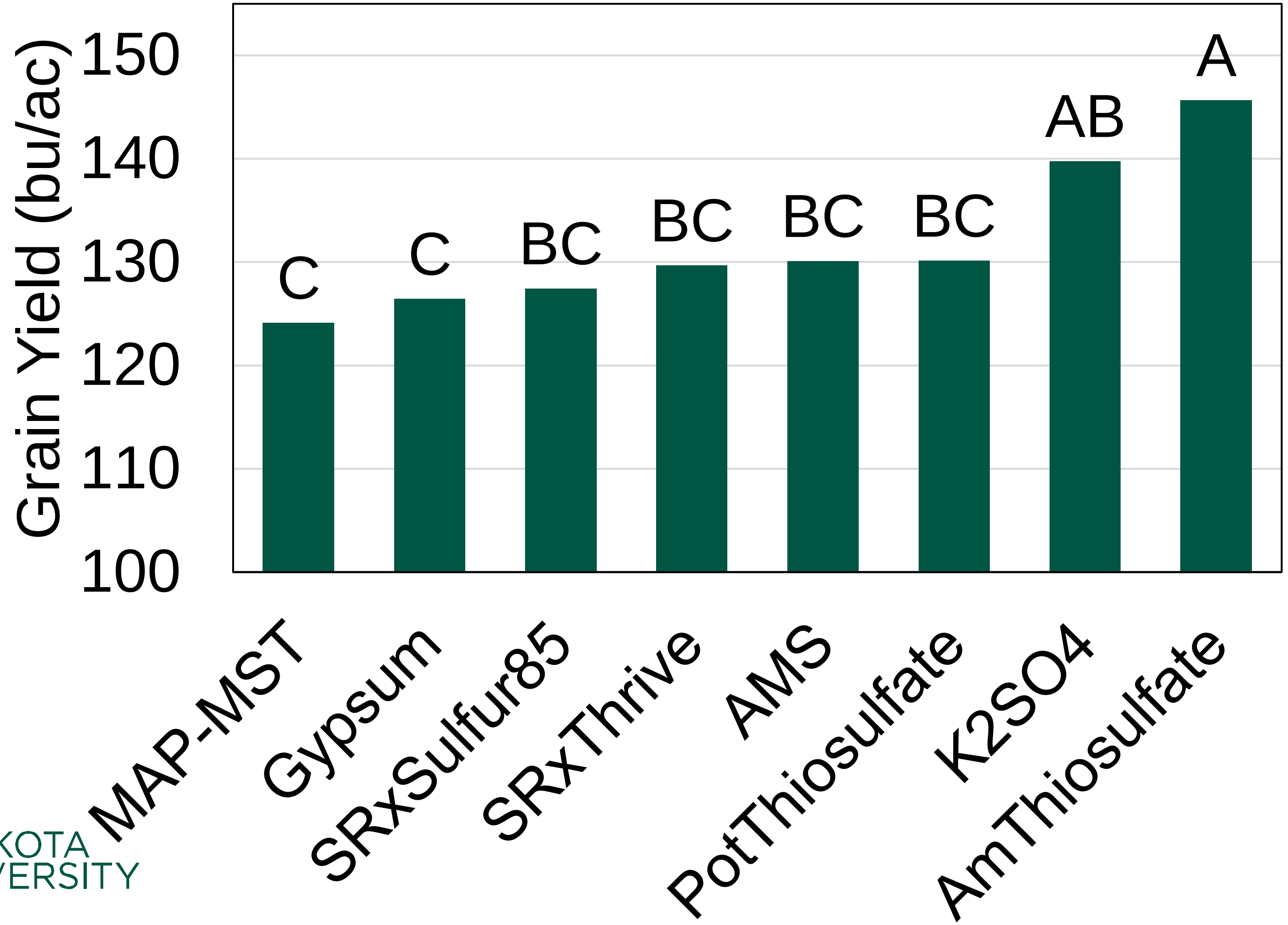
Idaho S Source Study 2023

- Gypsum ($CaSO_4$)
- Potassium sulfate (K_2SO_4)
- SRX Sulfur 85 (bentonite-prilled elemental S)
- Ammonium sulfate $(NH_4)_2SO_4$
- MAP-MST (Nutrien)
- SRX Thrive (micronized elemental S)



Slide adapted from J. Spackman, Univ of Idaho

Idaho S Source Study 2024



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Slide adapted from J. Spackman, Univ of Idaho

S Source in Corn, MN 2019-2022

Table 2. Source and rate main effect means across four years 2019, 2020, 2021, and 2022 at four Minnesota locations. Within each main effect, within rows, numbers followed by the same letter are not significantly different at $P \leq 0.10$.

	Source Rate Effect				Rate Main Effect		
Location	Control	K-Sulfate	K-MST	Tiger 90	5	10	20
	Bushels per acre at 15.5% moisture						
Becker	197	200	196	197	189b	200a	202a
Morris	200	199	199	203	201	200	200
Rosemount	186b	207a	207a	201a	197b	195b	209a
Waseca	119c	177a	174a	153b	147b	158a	162a

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Kaiser, D. (2023) *Is there and optimal source of sulfur for corn?* In Proc. 2023 North Central Soil Fertility Conference.

Ammonium Thiosulfate

- $(NH_4)_2S_2O3$ (12-0-0-26S)
- S is not in plant-available form
  - approximately 50% is available within one week, under moist conditions
- Should NOT seed or foliar applied
- When mixed with UAN, AST may have urease- and nitrification-inhibiting properties

ATS as a Nitrification- and Urease-Inhibitor

- In order to get any potential inhibition from ATS, use at least 8% v/v with UAN
- Banding UAN/ATS mixture concentrates the materials in a smaller volume of soil
- Research has shown inconsistent benefits of ATS as a urease inhibitor, and when it does work, it is not as effective as NBPT.

Source: blog-crop-news.extension.umn.edu/2020/06/should-you-add-inhibitors-to-your.html

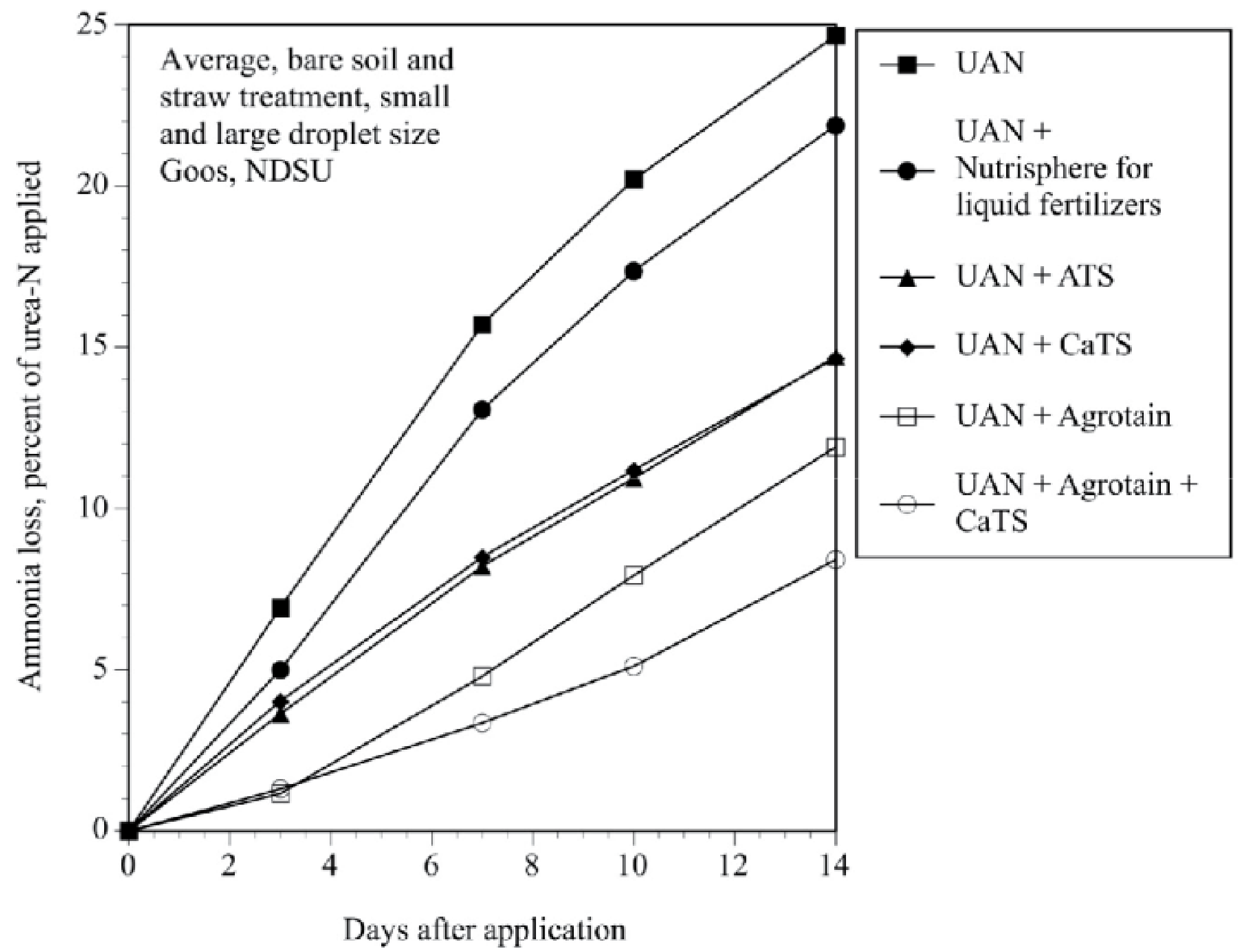

Figure 12. Effect of treatment of UAN with ATS and other amendments on ammonia volatilization through time under greenhouse conditions. (Goos, 2013)

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Source: NDSU Circular SF1581

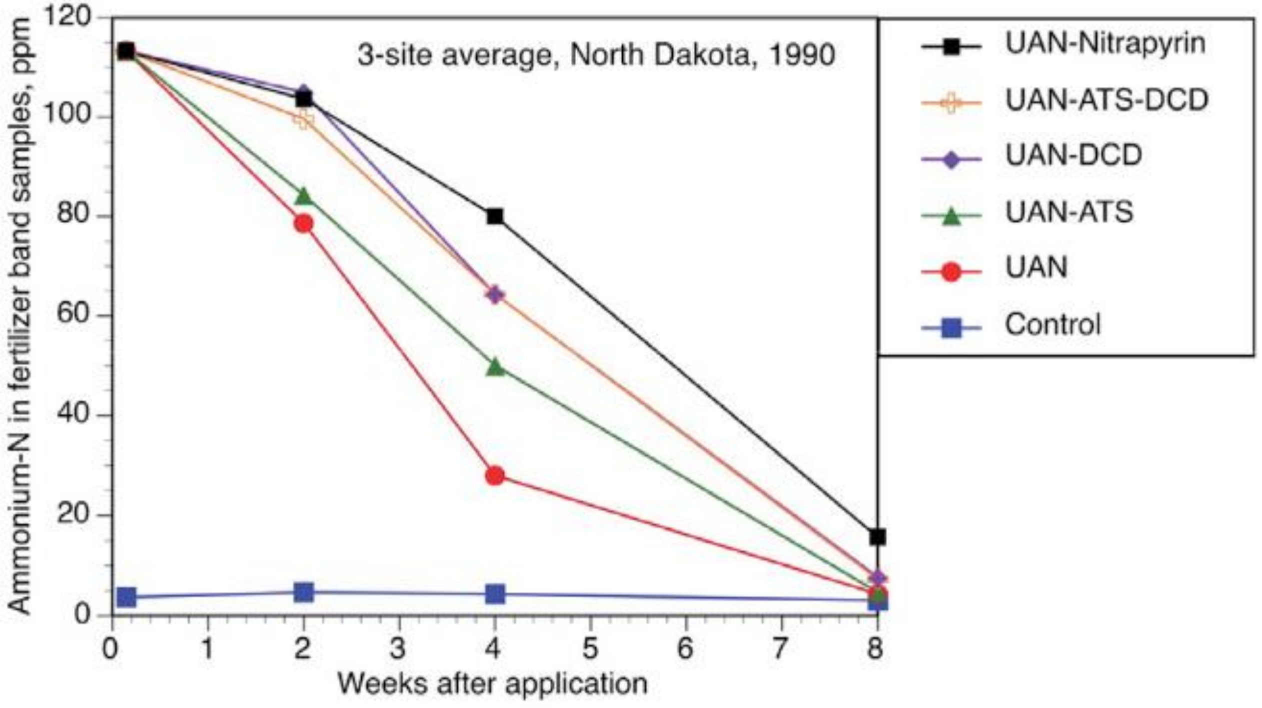

Figure 14. Mean of three field sites, incubation of soil with beginning concentration of 120 ppm ammonium-N as UAN through time. Soil treatments were UAN (urea-ammonium nitrate fertilizer), ATS is ammonium thiosulfate, DCD is dicyandiamide, nitrapyrin is the formulation for anhydrous ammonia. (Goos and Johnson, 1992)

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Source: NDSU Circular SF1581

Sulfur Soil Tests

- No fully satisfactory SO_4^{-2} tests exist
  - S is constantly undergoing transformations
  - Tests do not reflect sources of potentially available S
  - High mobility of SO_4^{-2}
  - Precipitated gypsum in arid/semi-arid environments

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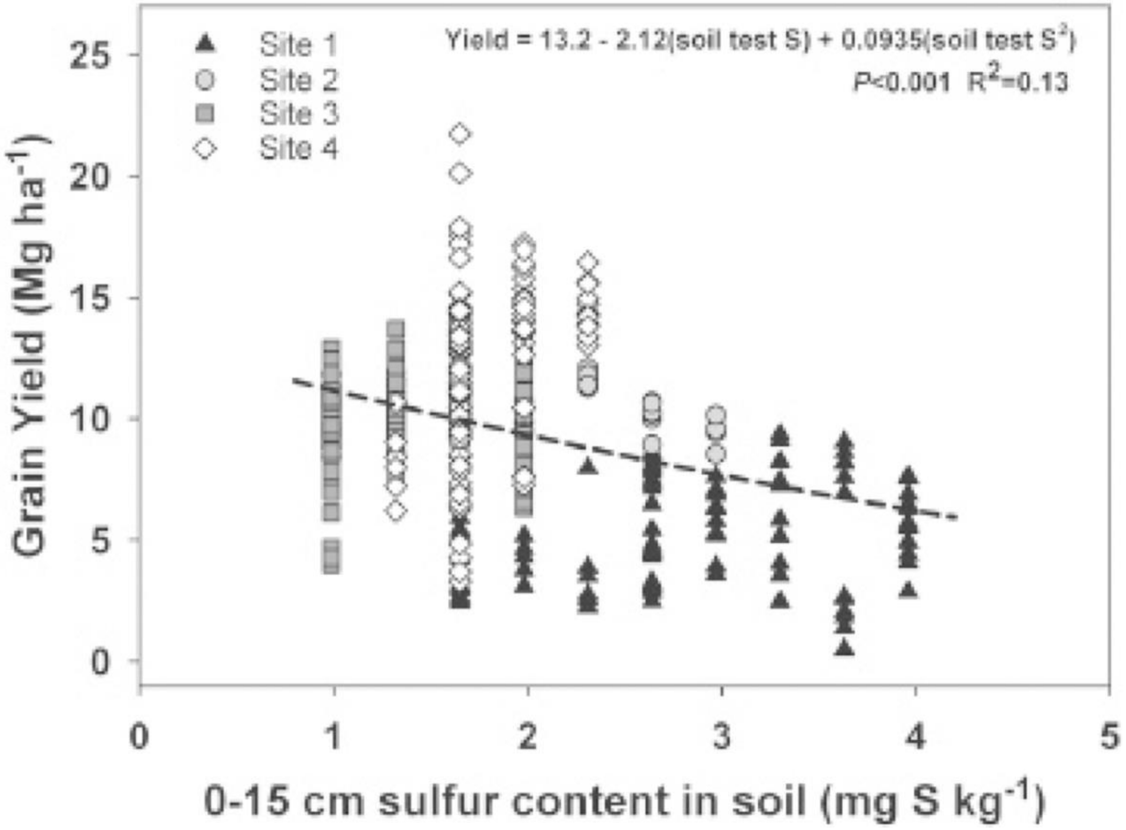
Source: Recommended Chemical Soil Test Procedures for the North Central Region, 2011

Photo Credit: NDSU Soil Testing Lab

Sulfur Soil Test Calibration (or Lack of)

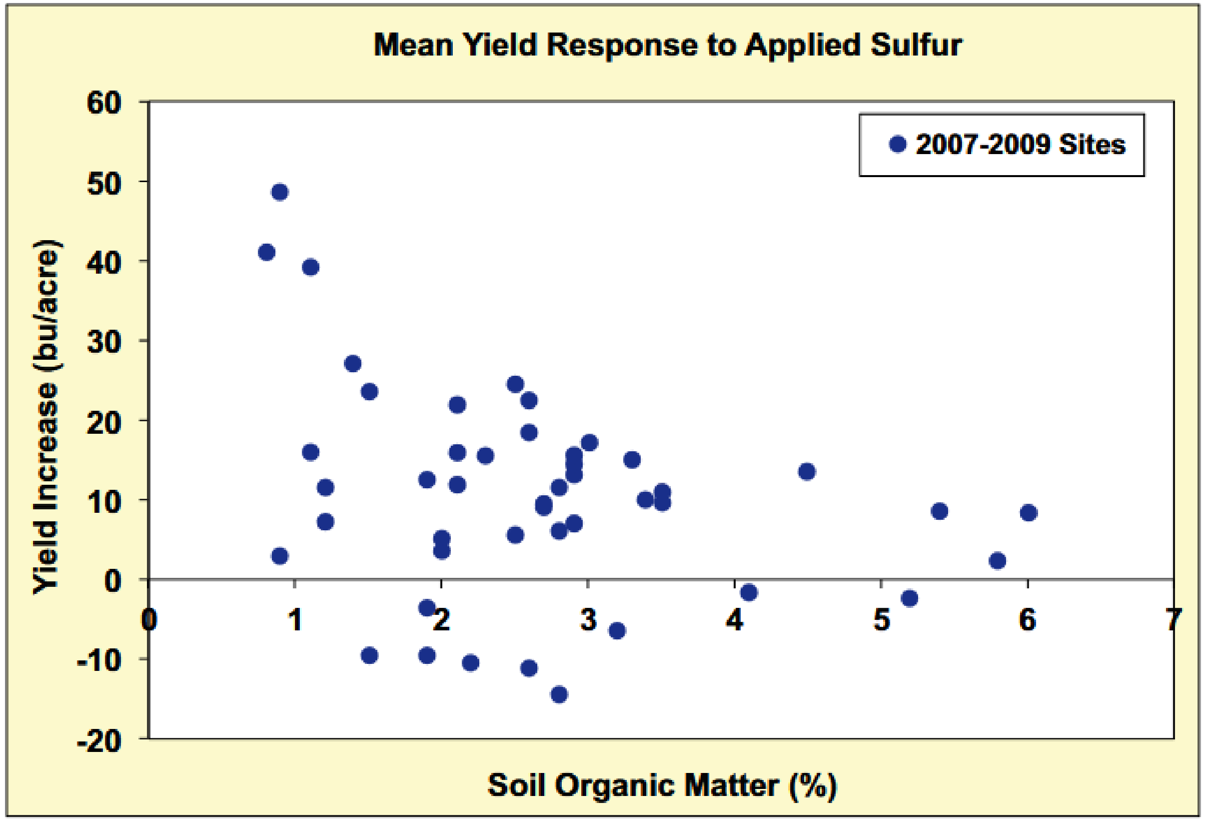
- Minnesota, 2008-09
- S increased corn yield at two of four locations
- Greatest response to S occurred in soils with <2% OM
- Response was not related to SO_4-S soil test



Source: https://doi.org/10.2134/agronj2012.0299

Sulfur Soil Test Calibration (or Lack of)

- Iowa 2007-2009
- S fertilizer increased yield at 28 of 47 sites
- 0-6 in. depth SO_4-S soil tests were not related to yield response
- Response to S was greater in low OM soils



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Source: https://store.extension.iastate.edu/Product/CROP3072-pdf

Practical Sulfur Management

- Do all fields/crops require a sulfur application?
  - Pay particular attention to crops with high S demand
- How do we know when to apply S when the tests are not good predictors?
  - Consider aggravating factors of S deficiency
  - High precipitation, low soil OM, coarse soil textures, high water table, saturated conditions

Sulfur Facts

- Across the US, S demand is increasing
- Not all fields will show a response to S every year
- The S soil test is not diagnostic
- Not all S fertilizers are created equal
- While ATS shows some urease and nitrification inhibiting properties, it is not nearly as effective as NBPT or DCD

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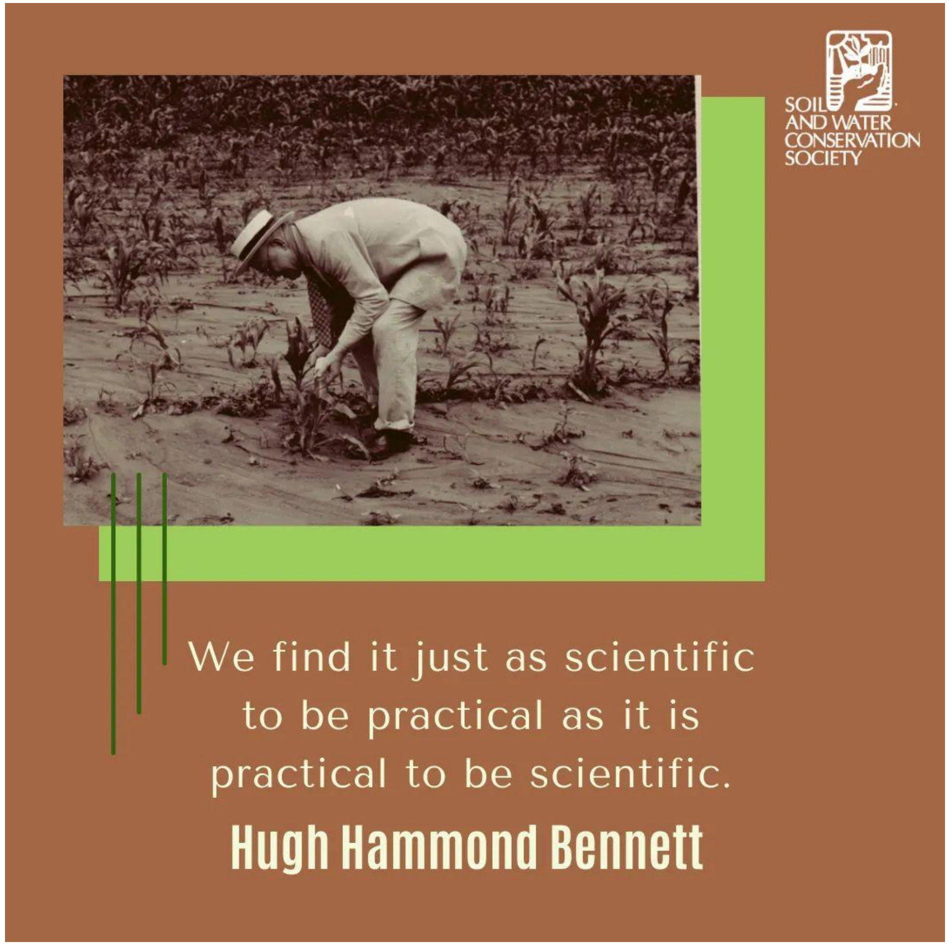
CROP ADVISER



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