NDSU NORTH DAKOTA STATE UNIVERSITY

STUDENT FOCUSED • LAND GRANT • RESEARCH UNIVERSITY

Challenges and Opportunities when Managing Soil Sulfur

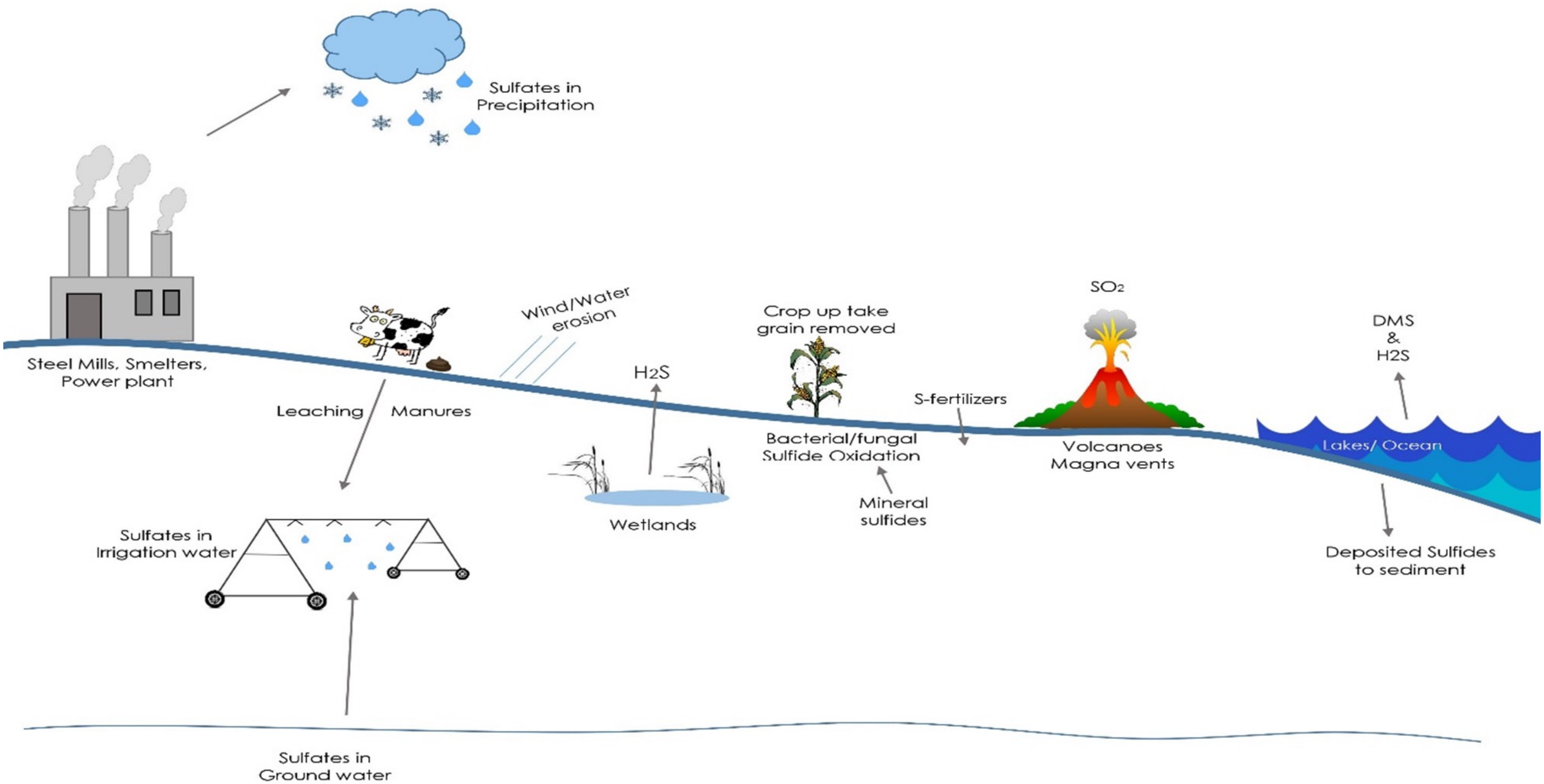
2024 Indiana CCA Conference

Dr. Brady Goettl
Assistant Professor of Extension Soil Science

NDSU NORTH DAKOTA STATE UNIVERSITY

Topic to Cover

- S in our environment
- The role of S in crop growth
- Forms of S and S cycle
- Sources of S in agriculture
- Testing soil S levels
- Practical S-fertility management



Source: D. Franzen, NDSU

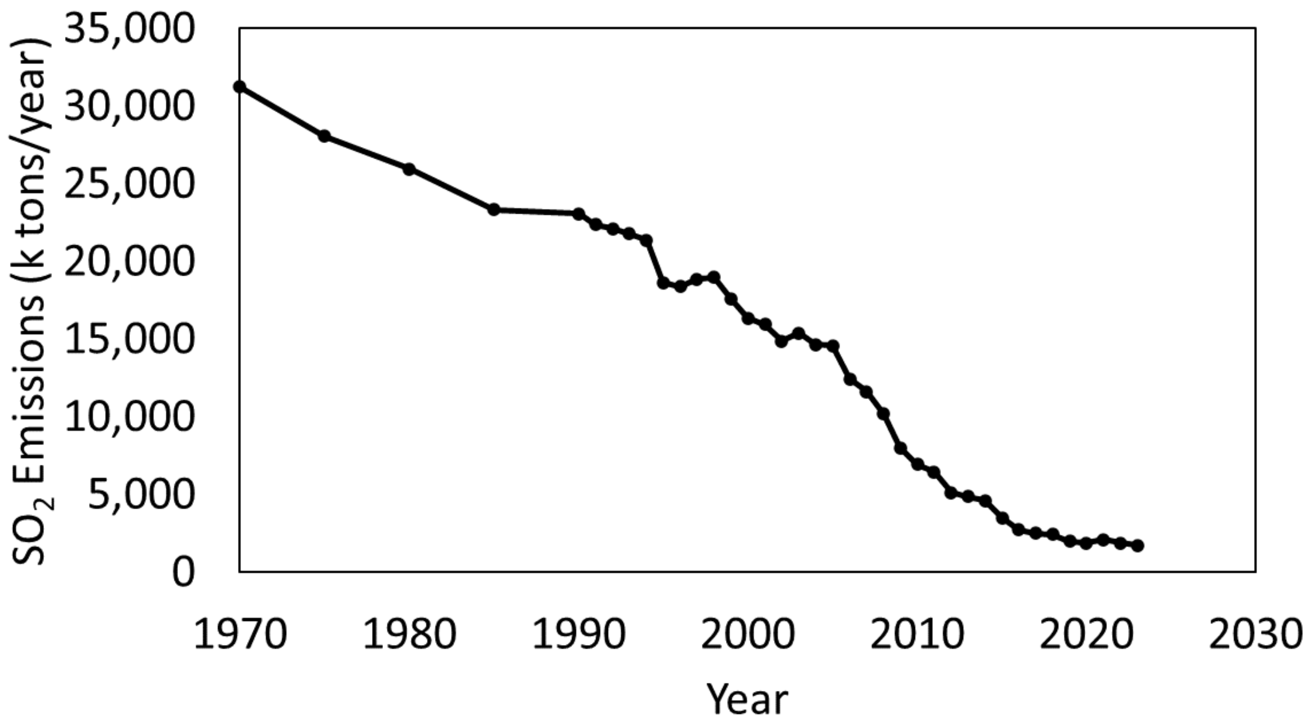
Sulfur in the Atmosphere

- 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

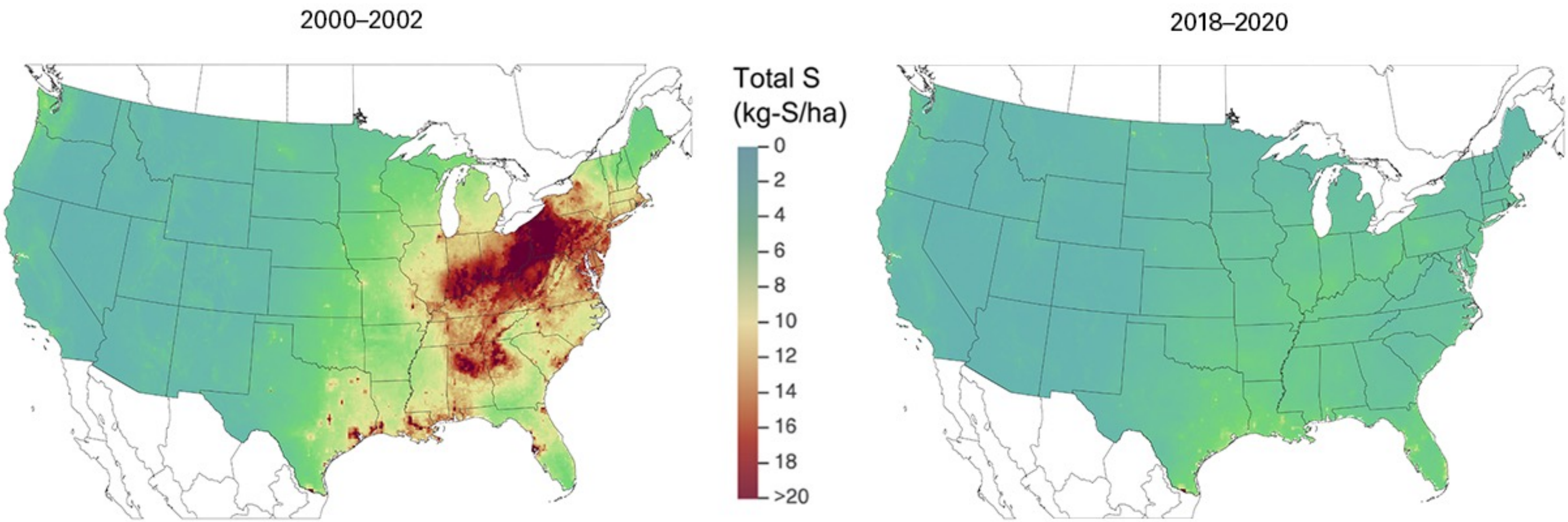
US Anthropogenic SO_2 Emissions



NDSU NORTH DAKOTA STATE UNIVERSITY

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

Three-Year Average of Total Sulfur Deposition



Source: CASTNET/CMAQ/NADP
USEPA, 2021

NDSU NORTH DAKOTA STATE UNIVERSITY

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

“In 1860, sulfur was recognized as an essential nutrient… referred to as the ‘fourth major nutrient’ following nitrogen, phosphorous, and potassium”

Source: *Sulfur: A Missing Link between Soils, Crops, and Nutrition, 2008*

The Role of Sulfur in Plants

- Component of amino acids—“the building blocks of protein”
- Component of *nitrate reductase*
  - Converts NO_3 to organic N within the plant
  - Deficiency of S interferes with N metabolism

NDSU NORTH DAKOTA STATE UNIVERSITY

Sulfur Deficiency

- Light green coloring of the whole plant
- Interveinal chlorosis
- Best diagnosed with tissue testing

NDSU NORTH DAKOTA STATE UNIVERSITY

Is Sulfur Demand Increasing?

- Reduced SO_2 emissions
- Lower S concentration in synthetic fertilizers compared to organic sources
- Increased crop removal

Sulfur in the Soil

Inorganic

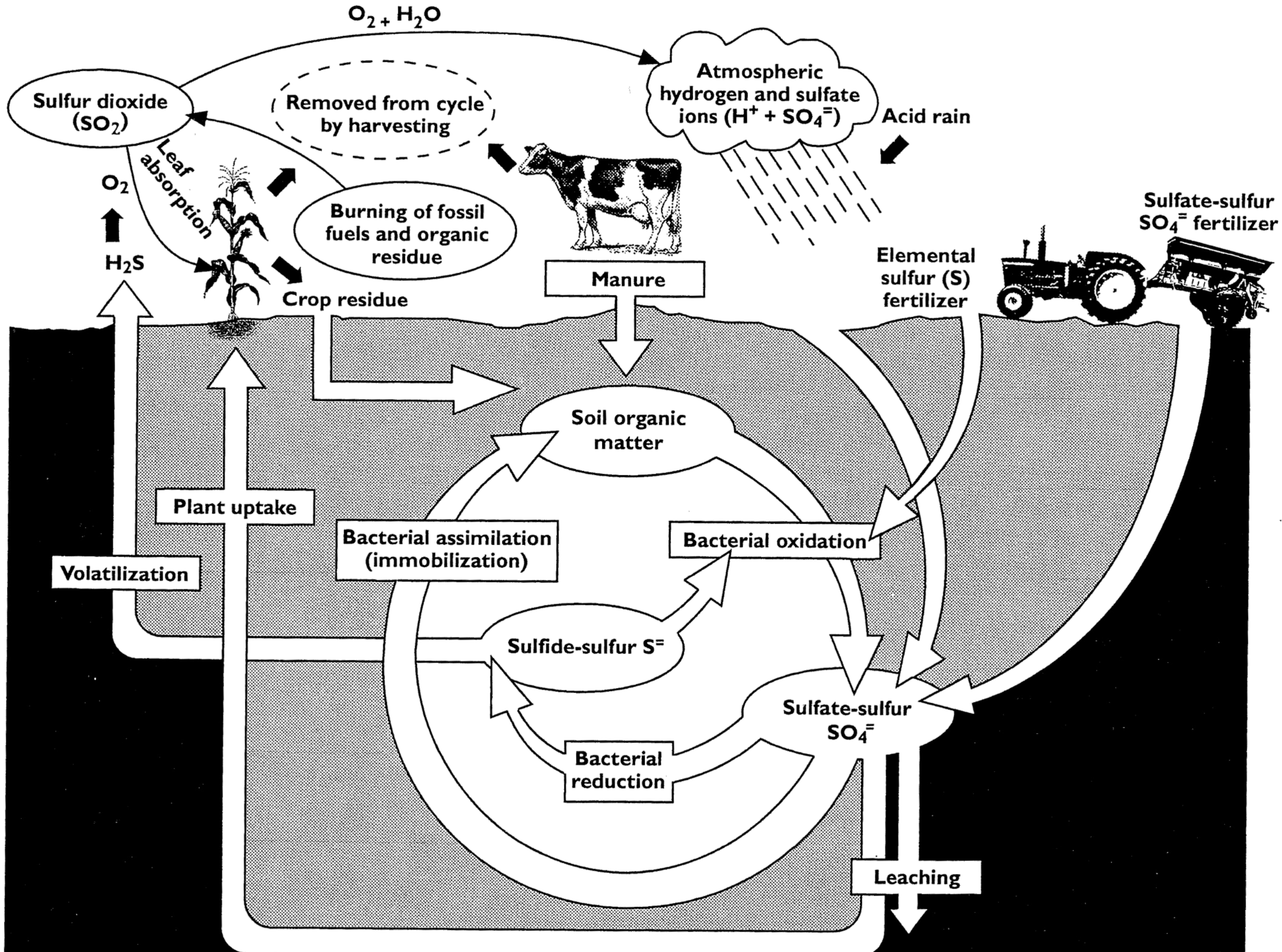
- Sulfate (SO_4^{-2})
- Elemental sulfur (S)
- Hydrogen sulfide (H_2S)
- Salt/Mineral
  - Gypsum ($CaSO_4$)
  - Epsomite ($MgSO_4$)
  - Pyrite (FeS_2)

Organic

- Organic sulfates
- Carbon-bonded sulfur

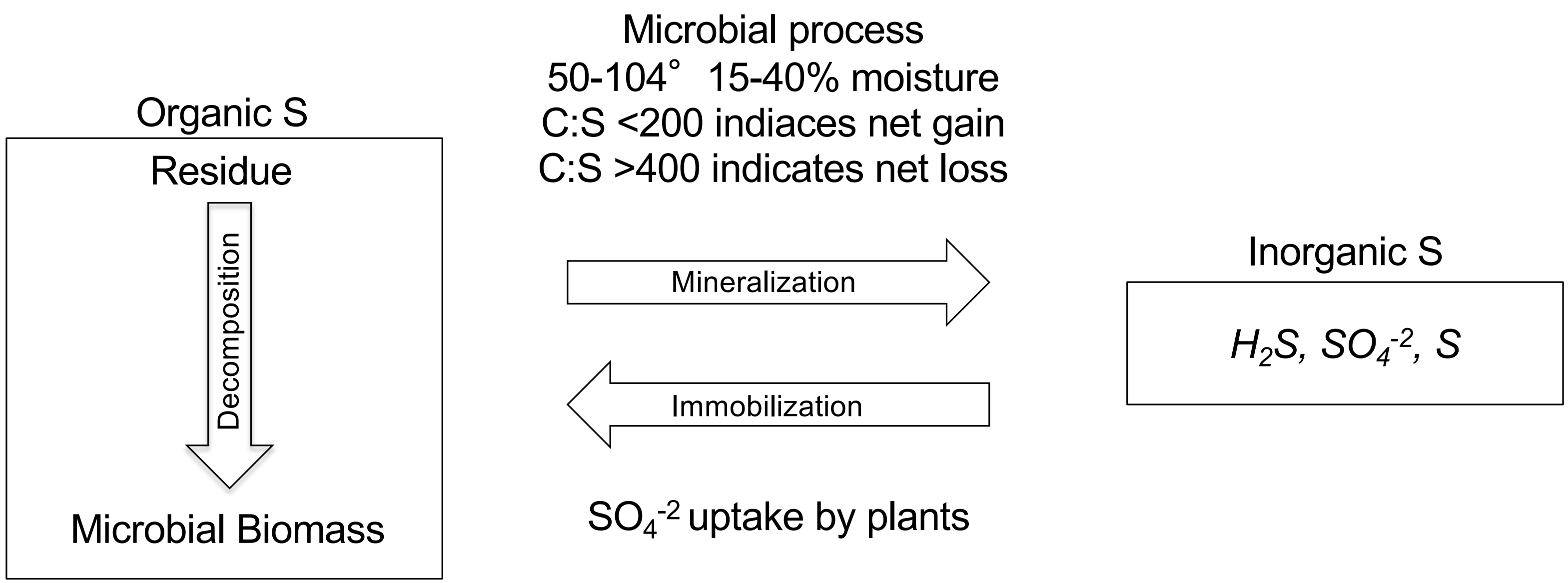
Most soils S is in organic forms, so S is highly correlated to organic matter

Figure 9-6. The sulfur cycle.

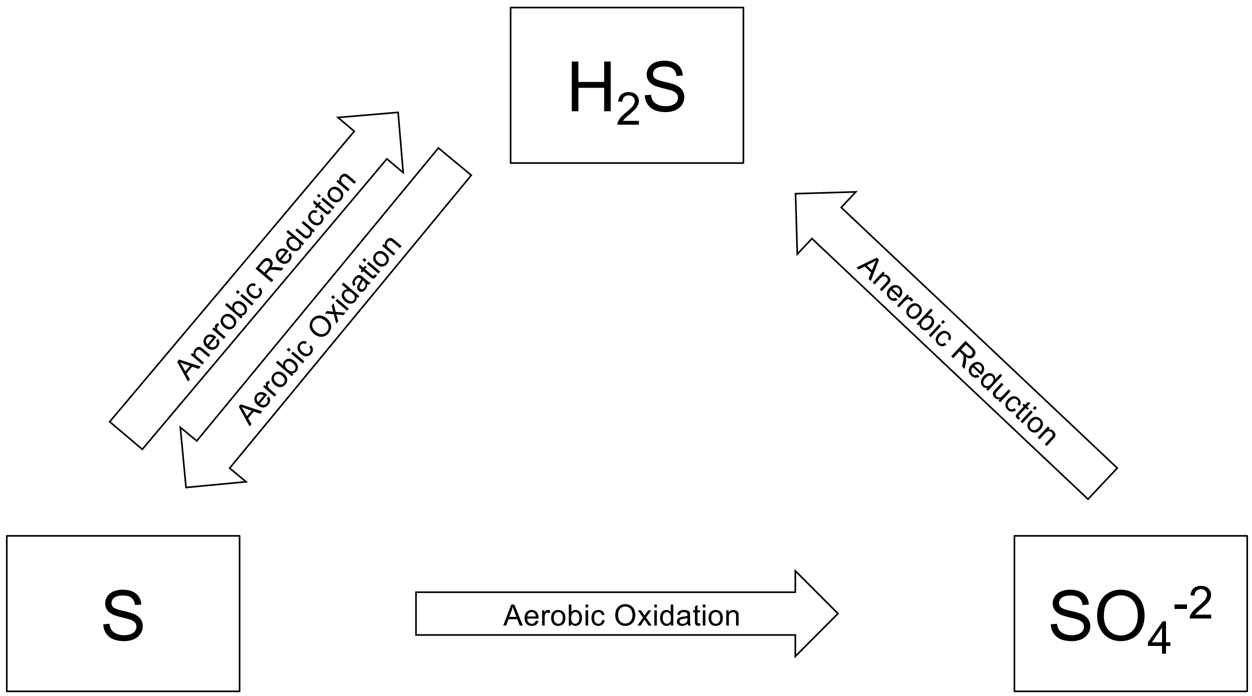


Source: Management of Wisconsin Soils, 2009

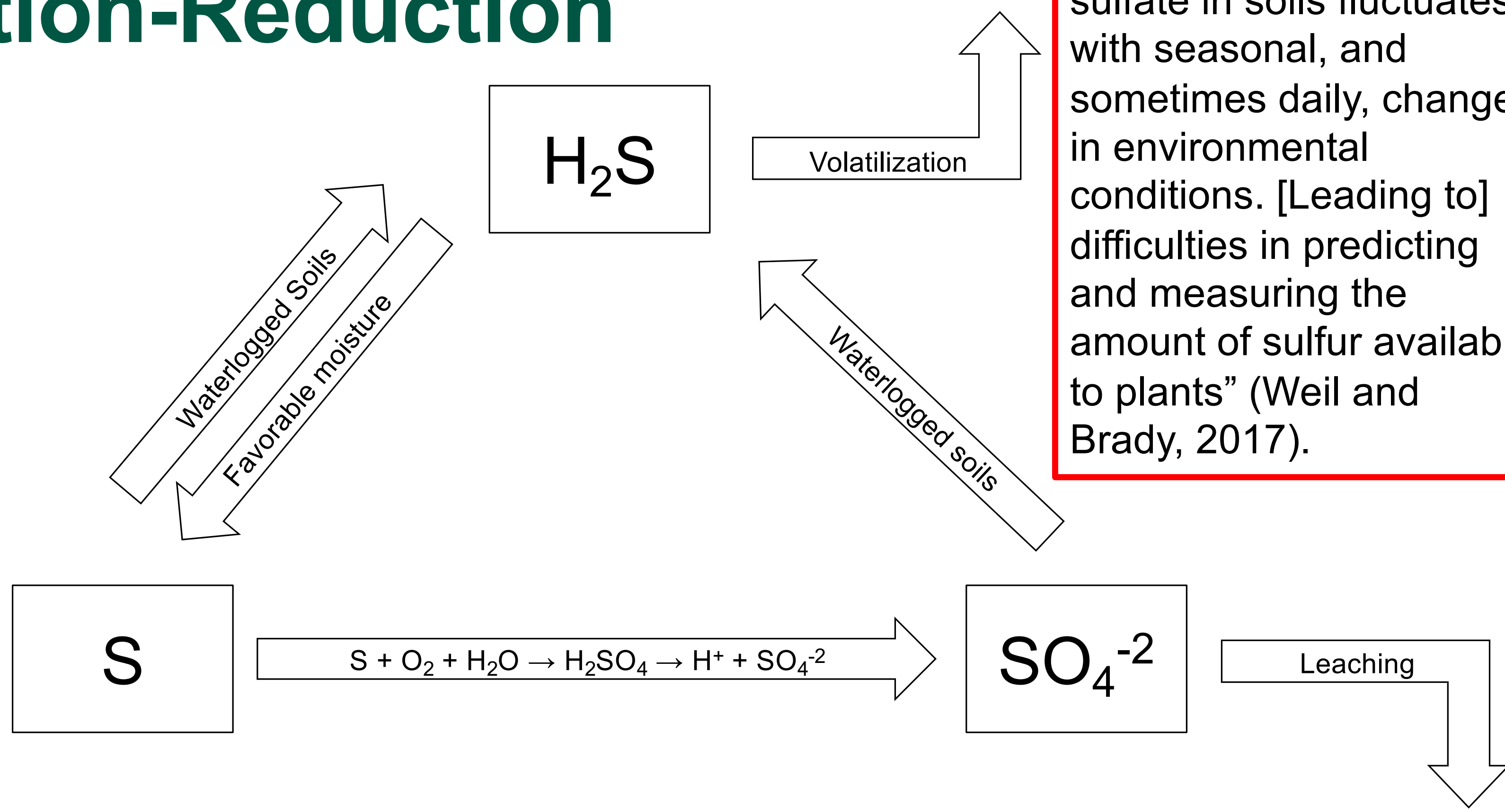
Mineralization-Immobilization



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).

Sources of Sulfur

- Organic (crop residue, manure)
  - Variable depending on crop and animal species
  - Approx. 60% of manure S is available the first year
- Fertilizer
  - Solubility varies
  - May require chemical transformations before it is plant-available

Sources of Sulfur

Table 9-12. Sulfur fertilizers.

Material	Chemical formula	Fertilizer analysis $N\text{–}P_2O_5\text{–}K_2O$	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	$K_2SO_4 \cdot 2MgSO_4$	0-0-22	23
Ammonium thiosulfate[a]	$(NH_4)_2S_2O_3 + H_2O$	12-0-0	26
Magnesium sulfate (Epsom salts)	$MgSO_4 \cdot 7H_2O$	0-0-0	14
Ordinary superphosphate	$Ca(H_2PO_4)_2 + CaSO_4$	0-20-0	14
Slightly soluble			
Calcium sulfate (gypsum)	$CaSO_4 \cdot 2H_2O$	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

Similar effectiveness whether surface applied or incorporated

NDSU NORTH DAKOTA STATE UNIVERSITY

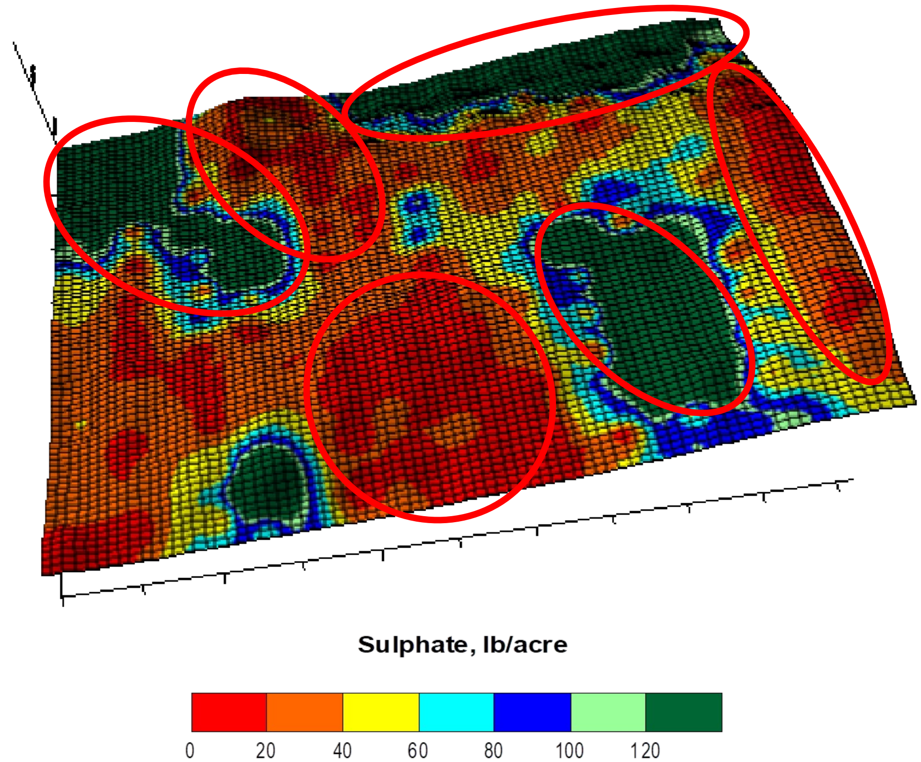
Elemental Sulfur

- 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 deficient fields should include SO_4-S application for immediate availability

NDSU NORTH DAKOTA STATE UNIVERSITY

Sulfur Across the Landscape

- Gypsum deposits in the North Central Region
- Groundwater in ND, SD, and Western MN is enriched with gypsum and other sulfate salts
- Groundwater moves sulfate to the surface



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!

NDSU NORTH DAKOTA STATE UNIVERSITY

Source: Deibert et al., 1996

Developing a Soil Test

- Correlation
  - Relationship between plant uptake of a nutrient and the amount of nutrient extracted by a soil analysis
  - Test should quantify the amount and form of nutrients taken up by the plant

Photo Credit: NDSU Soil Testing Lab

Developing a Soil Test

- Calibration
  - Establish meaning between soil test measurements and crop response across a wide array of fields and fertility levels

NDSU NORTH DAKOTA STATE UNIVERSITY

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

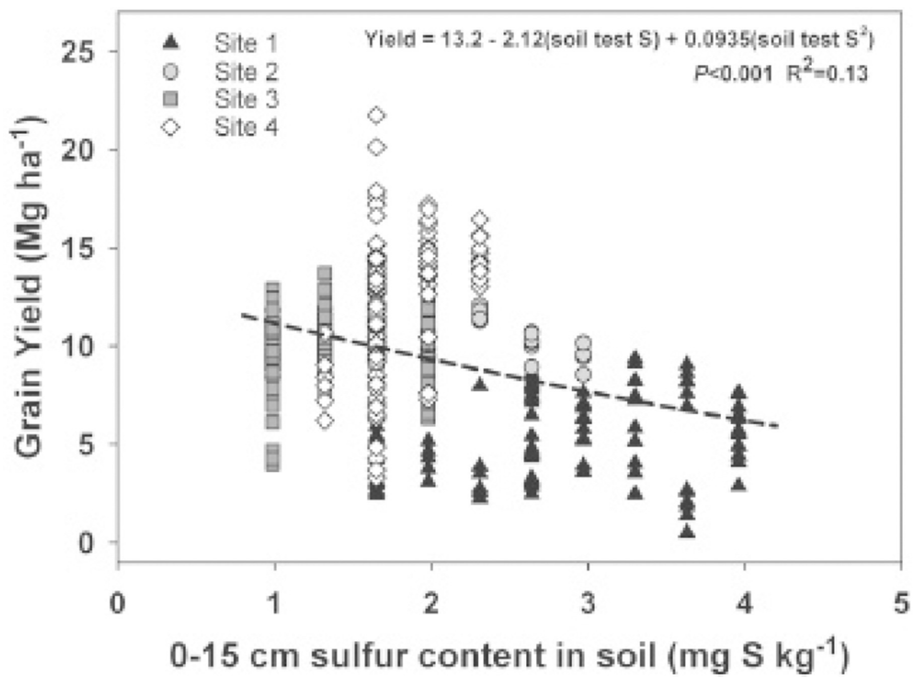
Photo Credit: No-Till Farmer

NDSU NORTH DAKOTA STATE UNIVERSITY

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

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

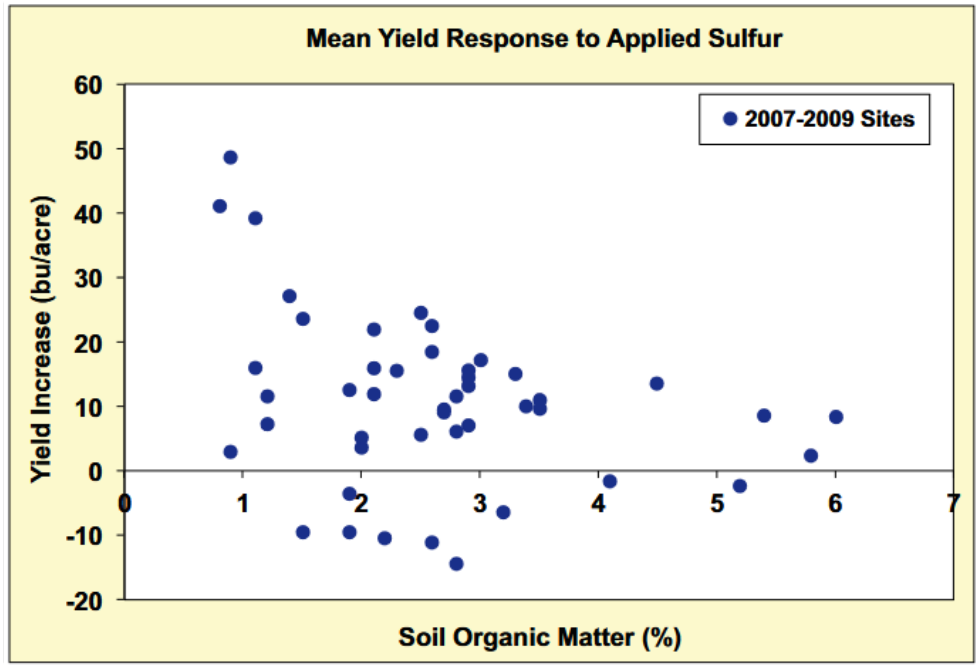


NDSU NORTH DAKOTA STATE UNIVERSITY

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

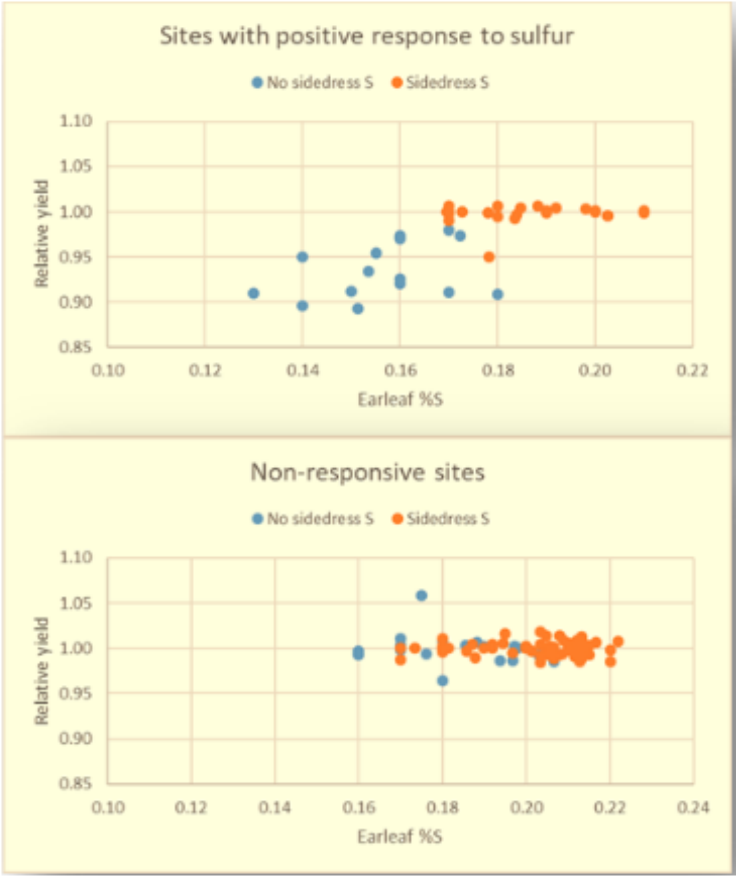


NDSU NORTH DAKOTA STATE UNIVERSITY

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

Sulfur Tissue Test

- Indiana, 2017-2022
- Corn yield was increased by sidedress S in 15 of 40 trials
- Pre-sidedress S concentration <0.18% may benefit from S application



NDSU NORTH DAKOTA STATE UNIVERSITY

Source: https://ag.purdue.edu/department/agry/agry-extension/_docs/soil-fertility/corn-response-to-sulfur-in-in.pdf

Practical Sulfur Management

- Do all fields/crops require a sulfur application?
  - Likely not
- How do we know when to apply S when the tests are not good predictors?
  - Consider aggravating factors of S deficiency

Practical Sulfur Management

- Pay particular attention to crops with high S demand
  - Alfalfa, canola/forage brassica, cole crops, high biomass crops
- Conditions favorable to S deficiency:
  - High precipitation, low soil OM, coarse soil textures, high water table, saturated conditions

4Rs of Sulfur Management

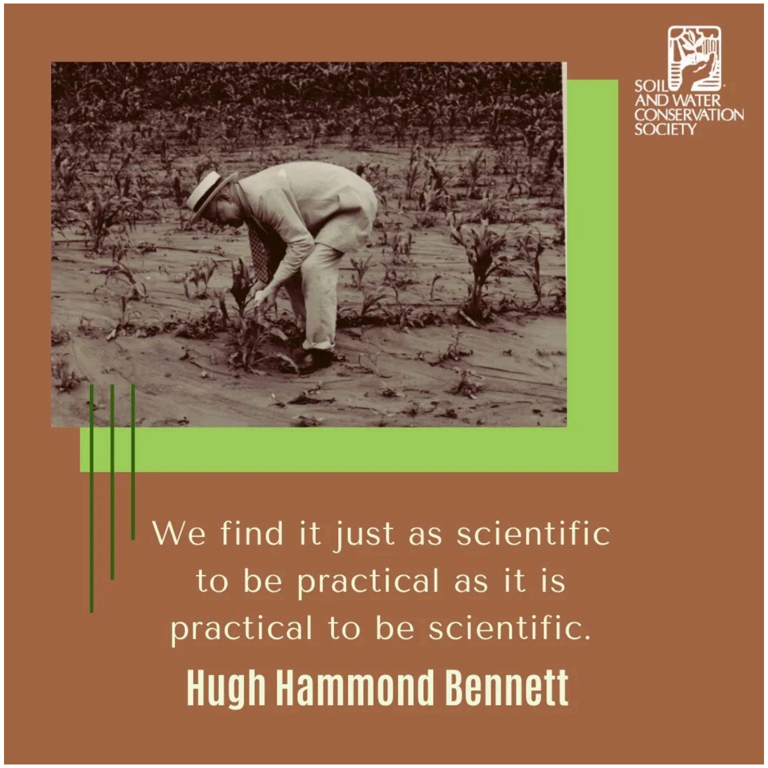
- Right *rate*
  - Recommendations range from 10-50 lb S/ac
- Right *source*
  - SO_4-S is plant available, elemental S must be oxidized
- Right *time*
  - Spring applied SO_4-S has a lower risk of leaching loss
- Right *placement*
  - Broadcast, incorporated, or banded are equally effective

Take-Home Points

- S deficiency is becoming more common
- Diagnostic tests are not reliable for determining crop demand/response to S
- Soil and field conditions can be help indicate the potential need for fertilizer S
- Sulfate fertilizers should be used to ensure plant availability

NDSU NORTH DAKOTA STATE UNIVERSITY

Brady Goettl, PhD, CCA
Extension Soil Science Specialist
brady.goettl@ndsu.edu
School of Natural Resource Sciences
NORTH DAKOTA STATE UNIVERSITY



CERTIFIED CROP ADVISER

NDSU NORTH DAKOTA STATE UNIVERSITY