Sulfur 101

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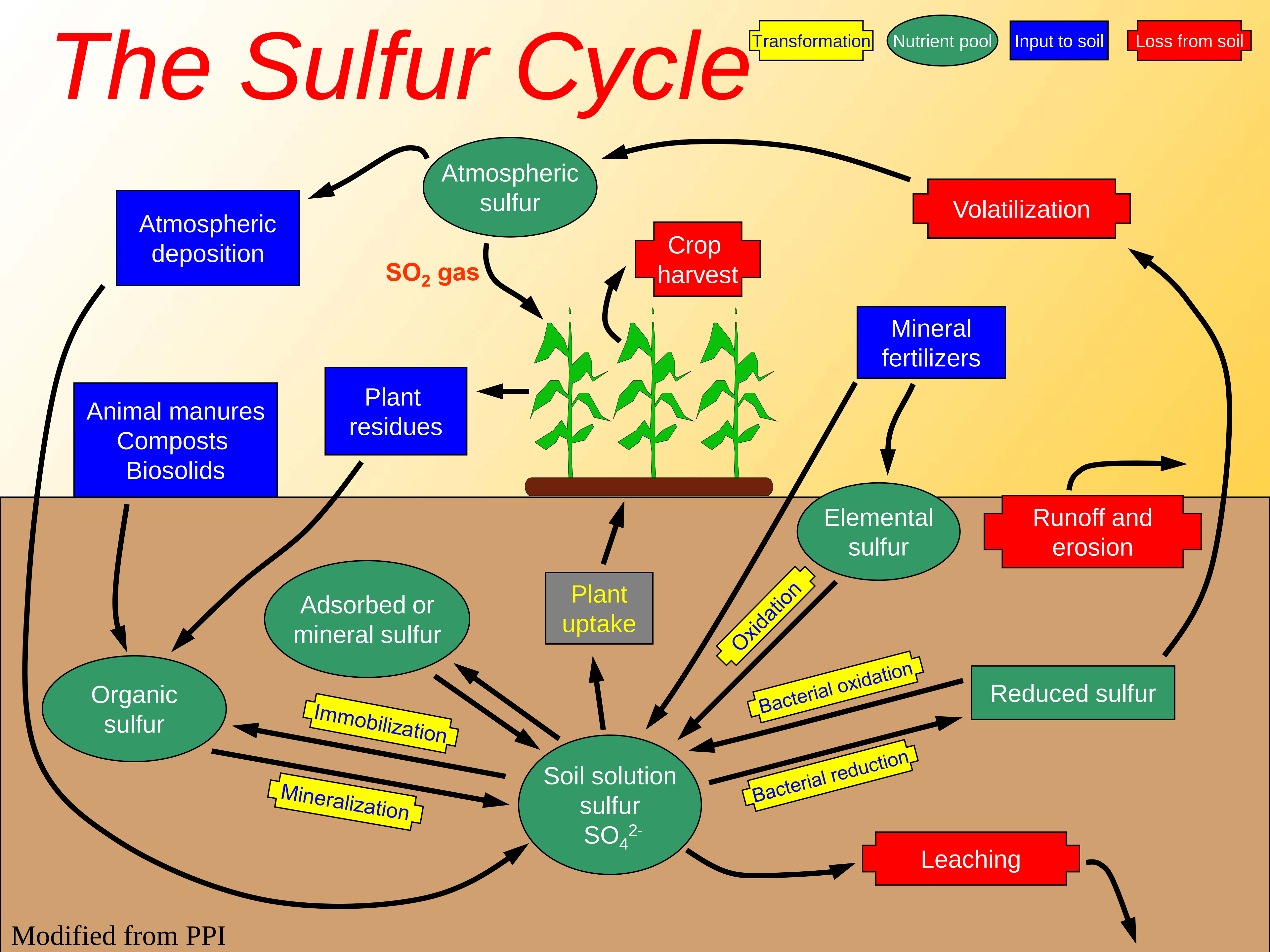
Learning Objectives

- Know the basic forms and functions of S in plants
- Learn the major sources and forms of S in soils
- Understand the factors affecting S transformations and S cycling
- Be able to describe how S transformations and S cycling determine S availability to plants and S transport in the environment


The Sulfur Cycle
Transformation
Nutrient pool
Input to soil
Loss from soil
Atmospheric sulfur
Volatilization
Atmospheric deposition
Crop harvest
SO$_2$ gas
Mineral fertilizers
Plant residues
Animal manures Composts Biosolids
Elemental sulfur
Runoff and erosion
Plant uptake
Adsorbed or mineral sulfur
Oxidation
Organic sulfur
Immobilization
Bacterial oxidation
Reduced sulfur
Mineralization
Soil solution sulfur SO$_4^{2-}$
Bacterial reduction
Leaching
Modified from PPI

Forms of S Absorbed by Plants

- Some absorption of SO_2 by leaves
  - High concentrations are toxic
- Most S taken up by roots as sulfate (SO_4^{2-})
  - < 10% of total soil S is SO_4^{2-}
    - Except in arid climates
- Roots can also take up thiosulfate ($S_2O_3^{2-}$)
  - May be energetically advantageous
    - Less energy for S reduction

S Supply to Roots

- SO_4^{2-} moves in soil by both mass flow and diffusion
- Usually supplied to plant roots by mass flow
- Diffusion important in low S soils
  - Sandy, low organic matter soils

Forms and Functions of S in Plants

- S required by plants in relatively large amounts
  - Less than N and K
  - Similar to P, Ca, Mg
  - 0.1 – 0.5% in plant tissue (dw basis)
  - 200 bu/A corn accumulates ~ 25 lb S/A (60% in grain)
- Volatile compounds (secondary compounds)
  - Responsible for characteristic tastes and odors
    - Onion and crucifer (cabbage) family plants
- Essential amino acids
  - Cystine, cysteine, and methionine
    - ~90% of S in plants is in proteins
    - Disulfide (–S–S–) bonds
- Synthesis of chlorophyll, coenzyme A
- Redox reactions
    - Ferredoxin (Fe-S protein)
      - N fixation, nitrate and sulfate reduction

S Mobility

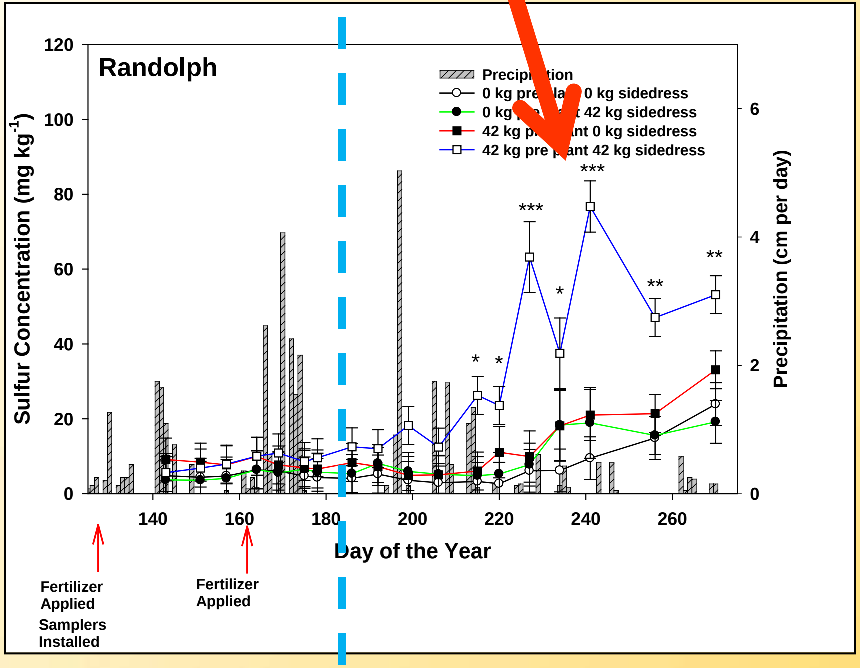
- Somewhat Mobile in the Soil
- Relatively immobile in plant
  - Not readily translocated from older leaves to young growing points
  - Deficiencies usually occur first on upper, younger leaves
    - May also occur uniformly over entire plant
    - Pale green color

Sulfate Leaching Potential

S concentration in soil at 2'

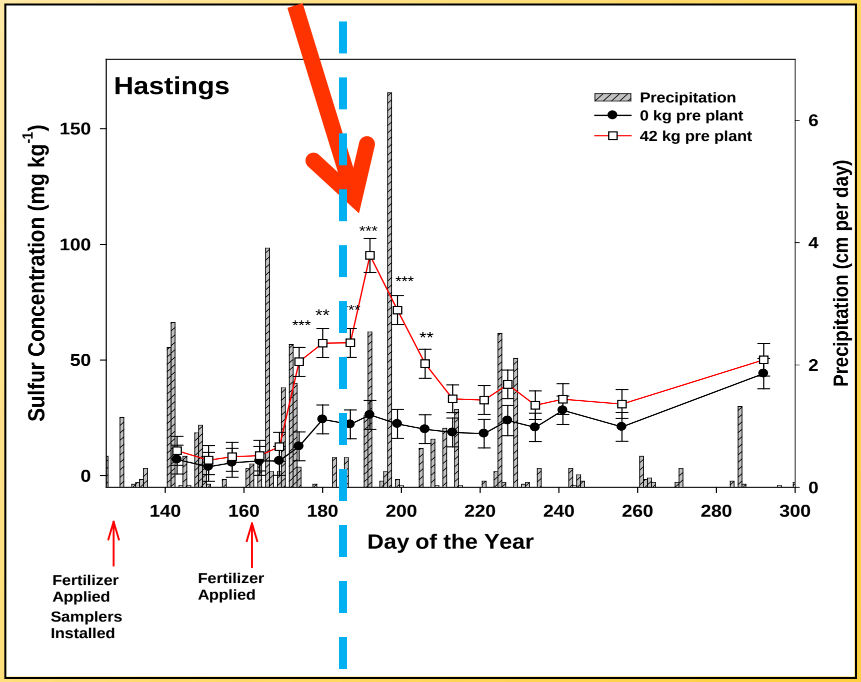
Loam Surface Soil

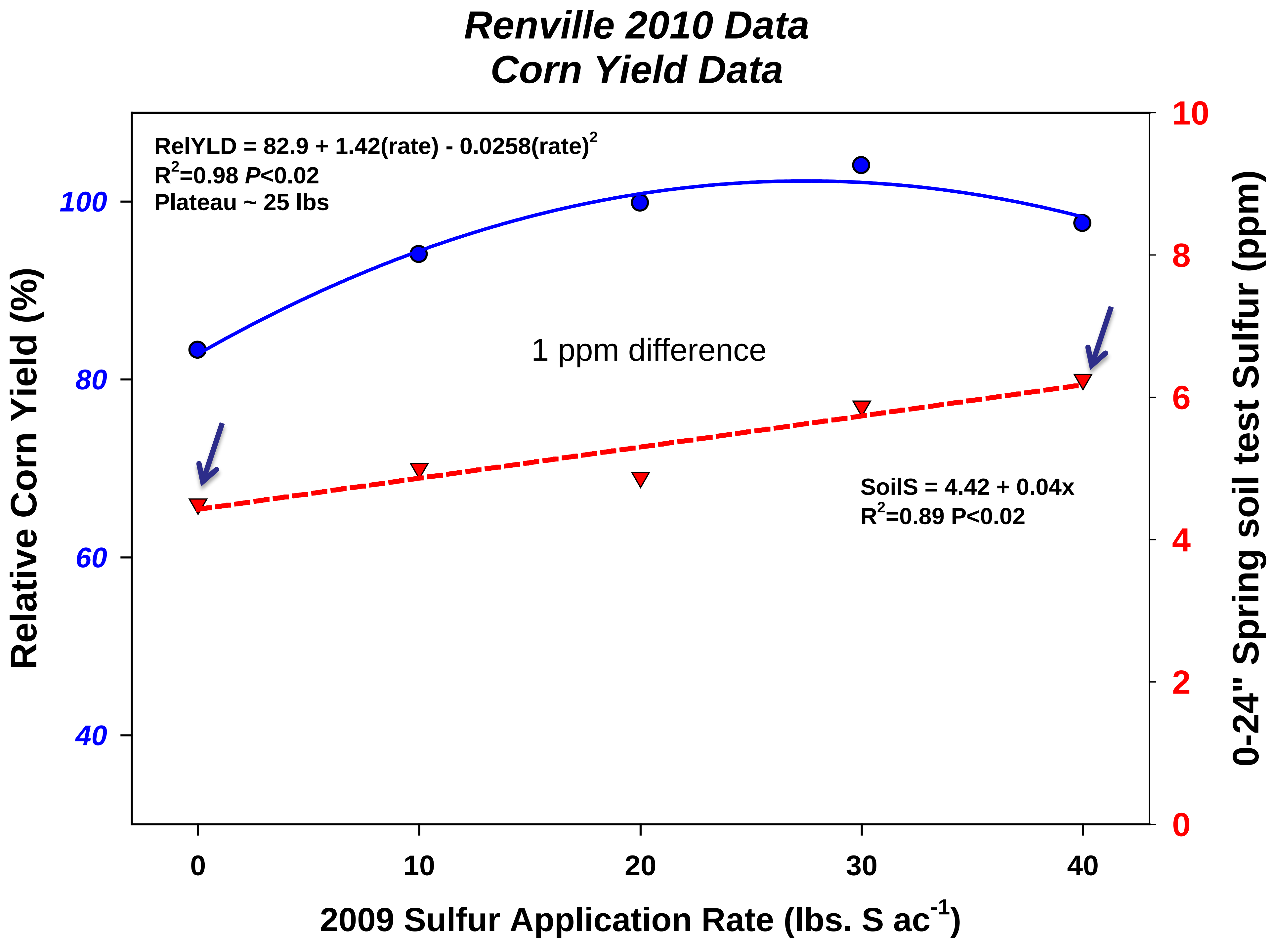
July 1



Sandy Surface Soil

July 1




Renville 2010 Data
Corn Yield Data
RelYLD = 82.9 + 1.42(rate) - 0.0258(rate)^2
R^2=0.98 P<0.02
Plateau ~ 25 lbs
1 ppm difference
SoilS = 4.42 + 0.04x
R^2=0.89 P<0.02
Relative Corn Yield (%)
100
80
60
40
0-24" Spring soil test Sulfur (ppm)
10
8
6
4
2
0
0
10
20
30
40
2009 Sulfur Application Rate (lbs. S ac^{-1})

Excess S

- Sulfate not directly toxic to plants or other organisms
- Can contribute to soluble salt problems
  - Often a major anion in saline soils
- High SO_4^{2-} leaching can increase cation losses
- S environmental issues are not due to agriculture

Sources of Soil S

- Organic matter decomposition
  - 90% of soil S is in organic form
    - Lower in arid soils
- Manure, compost, biosolids
- Adsorbed SO_4^{2-}
  - Anion exchange, Fe- and Al-oxides, clays
- S minerals
  - Sulfate minerals in dry climates
  - Sulfides in anaerobic conditions
- Atmospheric deposition
  - Industrial activities
- S fertilizers

Mineralization - Immobilization

- Cycling of organic S similar to cycling of organic N and P

- Balance between mineralization and immobilization affected by C:S and N:S ratios of OM
  – C:N:S ratio ~120:10:1.4
  – Soil organic matter ~1% S

Residue Levels and Sulfur Response

- Does the type of residue matter?
- C:S ratios (*source Soil Fertility and Fertilizers 7th ed.*)
  - <200:1 – mineralization
  - 200-400:1 no change
  - >400:1 - immobilization
- 2008 data – crop stover
  - Albert Lea, MN R6 Corn: 333:1
  - Clarkfield, MN R6 Corn: 151:1
  - Lewiston, MN R8 Soybean: 123:1
  - Hanska, MN R8 Soybean: 125:1
  - Strathcona, MN Wheat: 286:1
  - Perley, MN Wheat: 291:1

Mineralization - Immobilization

- Organic matter decomposition
  - S release affected by same factors discussed for N, P, and OM decomposition in general
    - Activity of bacteria, fungi, and actinomycetes
    - Temperature, moisture, aeration
    - pH, nutrient content, residue incorporation, particle size, surface area

Adsorption - Desorption

- Adsorbed SO_4^{2-} is a labile S pool
  - Usually readily available
    - Replenishes (buffers) solution SO_4^{2-}
  - S soil tests measure readily soluble and adsorbed sulfate
    - Ca-phosphate extraction
    - Only reliable for predicting S deficiency on sandy soils in MN

Adsorption - Desorption

- S adsorption similar to P adsorption, but held much less strongly
  - $NO_3^- < SO_4^{2-} < H_2PO_4^-$
- Most important in highly weathered soils
  - High adsorption potential
- May be important process in subsoils of other regions (higher clay content)

Adsorption - Desorption

- Factors affecting adsorption capacity
  - Fe-, Al-oxides
    - Primary adsorption sites in many soils
  - Soil clay content
    - Higher for 1:1 clays
  - Soil pH
    - Adsorption greatest in acid soils
      - pH dependent charge, anion exchange
      - Very low at pH > 6.0

Precipitation - Dissolution

- Gypsum ($CaSO_4$) in arid climates
  - Co-precipitates with Ca-carbonates in calcareous soils

- Sulfides in anaerobic, waterlogged soils
  - H_2S precipitates as metal (Fe) sulfide minerals
  - Dissolution requires S oxidation
    - Acidifying
    - Process also occurs in acid mine drainage

Oxidation - Reduction

- S exists in a number of oxidation states
  - From -2 to +6
  - S oxidation and reduction in soil are both microbially mediated processes
  - Readily oxidized in most agricultural soils

- SO_4^{2-} is the most oxidized form
  - Plants must reduce SO_4^{2-} for incorporation into organic compounds
    - Similar to NO_3^-

Volatilization

- Volatile S losses
  - Products of microbial transformations in soil
  - Impact on soil fertility generally insignificant
- Volatile S additions
  - Atmospheric SO_2 from industrial activities
  - Sulfate deposition through rainfall
    - Contributes to acid rain
    - Significant source of S fertility in some areas

Fertilizer S Management

- Deficiencies
  - Sandy soils most often S deficient
    - Low OM
    - SO_4^{2-} leaching losses
  - Sensitive crops/plants
    - Alfalfa, clovers, corn, small grains
    - Turfgrass, potatoes, onions
    - *Brassicas* (cabbage, canola, forage types)
  - May be favored with high residue

Fertilizer S Sources

- Dry Sources
  - Ca, K, NH4 sulfates
  - Elemental S
- Manure
- Liquid Fertilizer
  - Ammonium & potassium thiosulfate
    - 26% S and 17% S
    - Can be mixed with most other liquid fertilizers
  - Roots can take up thiosulfate ($S_2O_3^{2-}$)
  - In soil, $S_2O_3^{2-}$ readily split into one atom of S° and one molecule of SO_4^{2-}
    - $S{-}S{-}O_3 \rightarrow S° + SO_4^{2-}$

Sulfur Oxidation

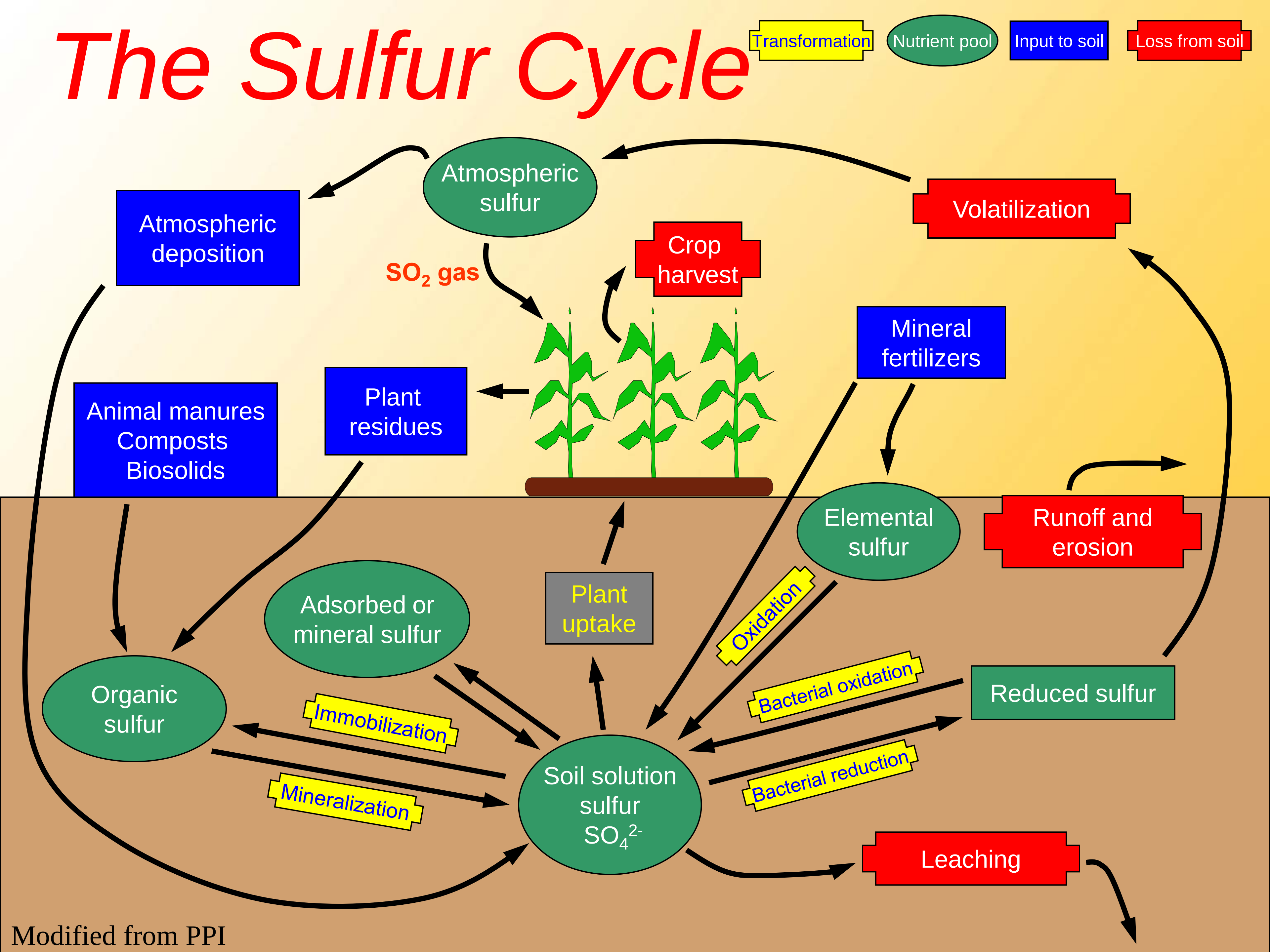
- Elemental S (S°) used agriculturally for soil acidification
  - Also as an S fertilizer source

- Oxidation of elemental S
  - $2S + 3O_2 + 2H_2O \Leftrightarrow 2H_2SO_4 \Leftrightarrow 4H^+ + 2SO_4^{2-}$
  - Acidifying reaction
  - *Thiobacillus* and other microbes
  - Favored at high soil temps ~35^{O}C


Elemental Sulfur is Produced
During the refining of oil and natural Gas

S and the Environment

- Reduced S can be a contaminant
  - Industrial emissions, acid mine drainage, acid mine spoils
- Contamination not caused by agriculture
  - Reclamation of acid soils can be an agricultural problem
    - Mining affected land
    - Drained coastal marsh land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Proposed Corn Sulfur Guidelines for Southern Minnesota

Broadcast sulfur to apply (lbs S per acre)				
		0-6” Soil Organic Matter		
Rotation		0-2	2-4	>4%
Corn-Corn		20-25??	15-20??	10-15†
Corn-Soybean		10-15??	10-15	0
Sandy Soils		25	25	25??

** ??, denotes where we have limited data on response and need more data

Thank You
Questions?

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http://www.extension.umn.edu/nutrient-management/index.html