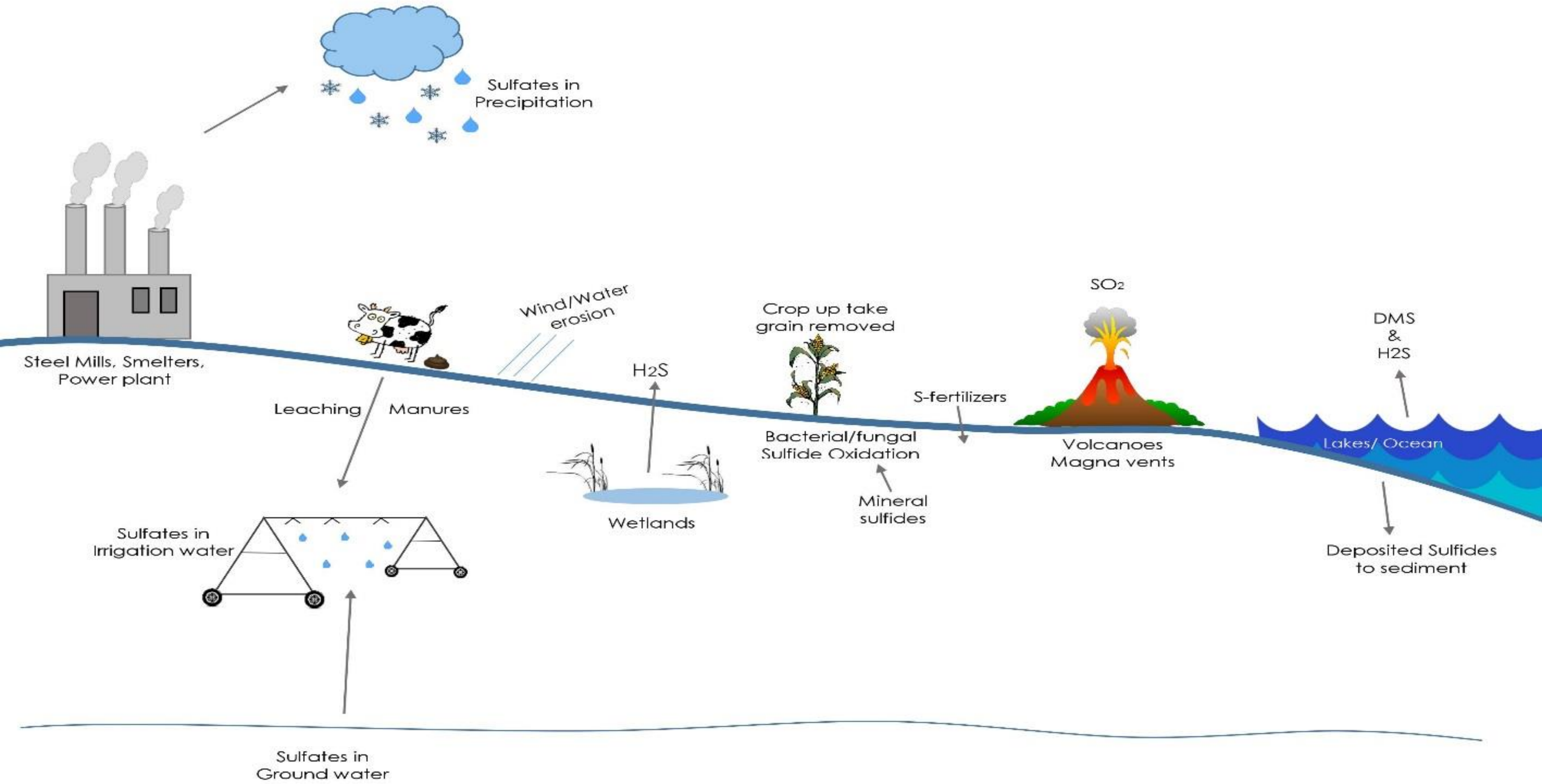
Sulfur Sources, Chemistry, Extent of Deficiencies, and Application Considerations

Dave Franzen, PhD
North Dakota State University
Professor Soil Science, Extension Soil Specialist



Sulfates in
Precipitation
Steel Mills, Smelters,
Power plant
Wind/Water
erosion
Crop up take
grain removed
SO2
DMS
&
H2S
H2S
Leaching
Manures
S-fertilizers
Bacterial/fungal
Sulfide Oxidation
Volcanoes
Magna vents
Lakes/ Ocean
Wetlands
Mineral
sulfides
Sulfates in
Irrigation water
Deposited Sulfides
to sediment
Sulfates in
Ground water

Sulfur gases emitted annually by volcanic activity over the past 100 years. (From Textor et al., 2003).

Species	SO_2	H_2S	COS	CS_2
Percent by volume	1-25	1-10	$10^{-4} – 10^{-2}$	$10^{-4} – 10^{-2}$
1,000 tons per year	1,650 - 55,000	1,100 - 3,100	7 - 110	8 - 105

Mt. St. Helens mushroom cloud as seen 35 miles away in the state of Washington (Rocky Kolberg, image)

Mt. St. Helens, 1980- 1.1 M tons of SO_2
Mt. Penetubo, 1991, Philippines 18.7 M tons SO_2
Tambora, Indonesia, 1815, 143 M tons SO_2

Reaction of SO_2 in atmosphere

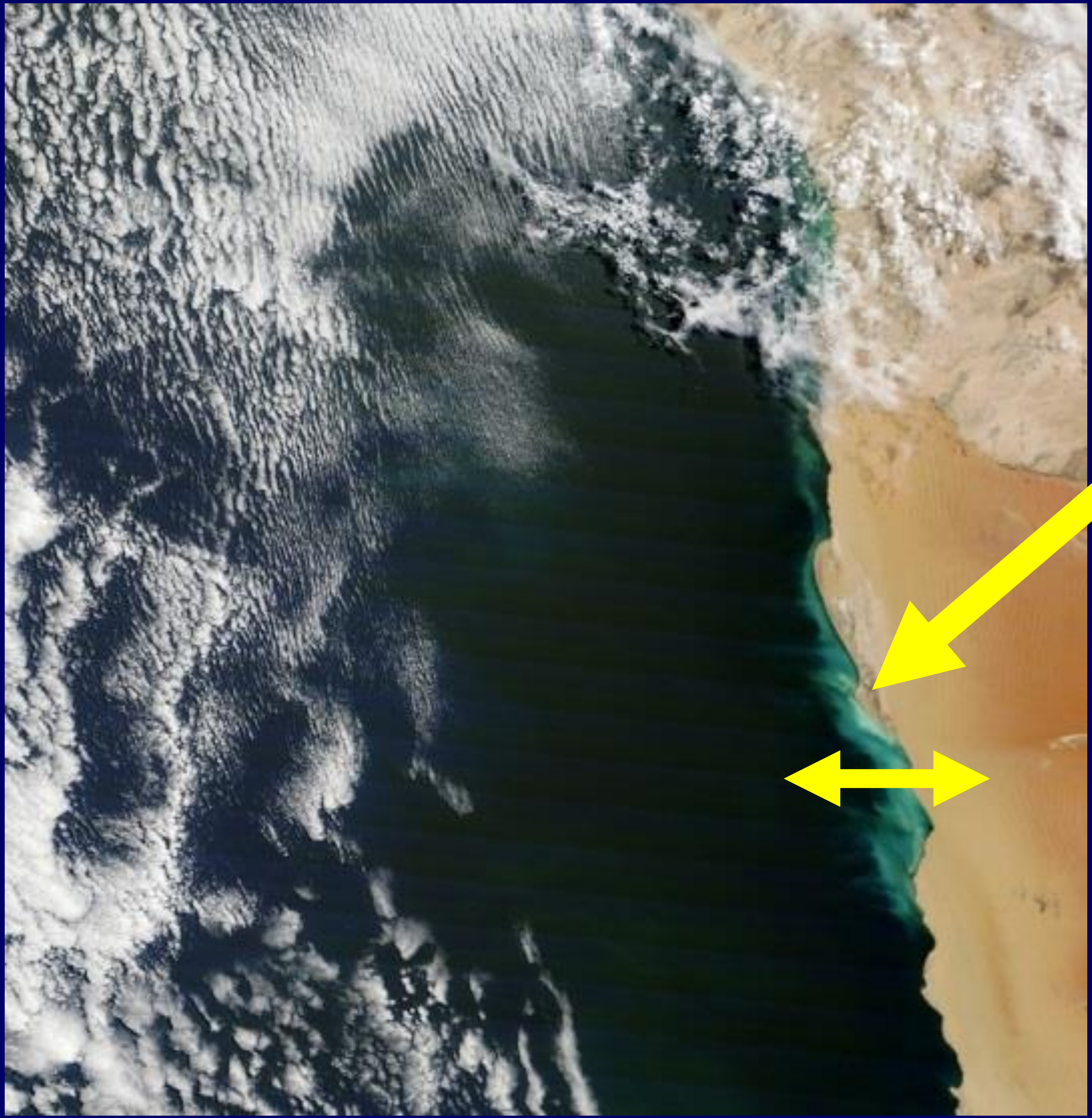
$$2SO_2 + O_2 + 2H_2O \rightarrow 2H_2SO_4$$

S emissions from oceans and coastal waters amount to about 16 million tons per year.

Rates of S emission from fresh water sources in North Central region of USA average 2 pounds S per acre of water surface.

Mostly as H_2S and DMS.

H_2S eruptions off African coast Namibia



40 miles

Source of S in soils is mostly the origin rock.

Igneous rocks – mostly pyrites (Fe sulfides)

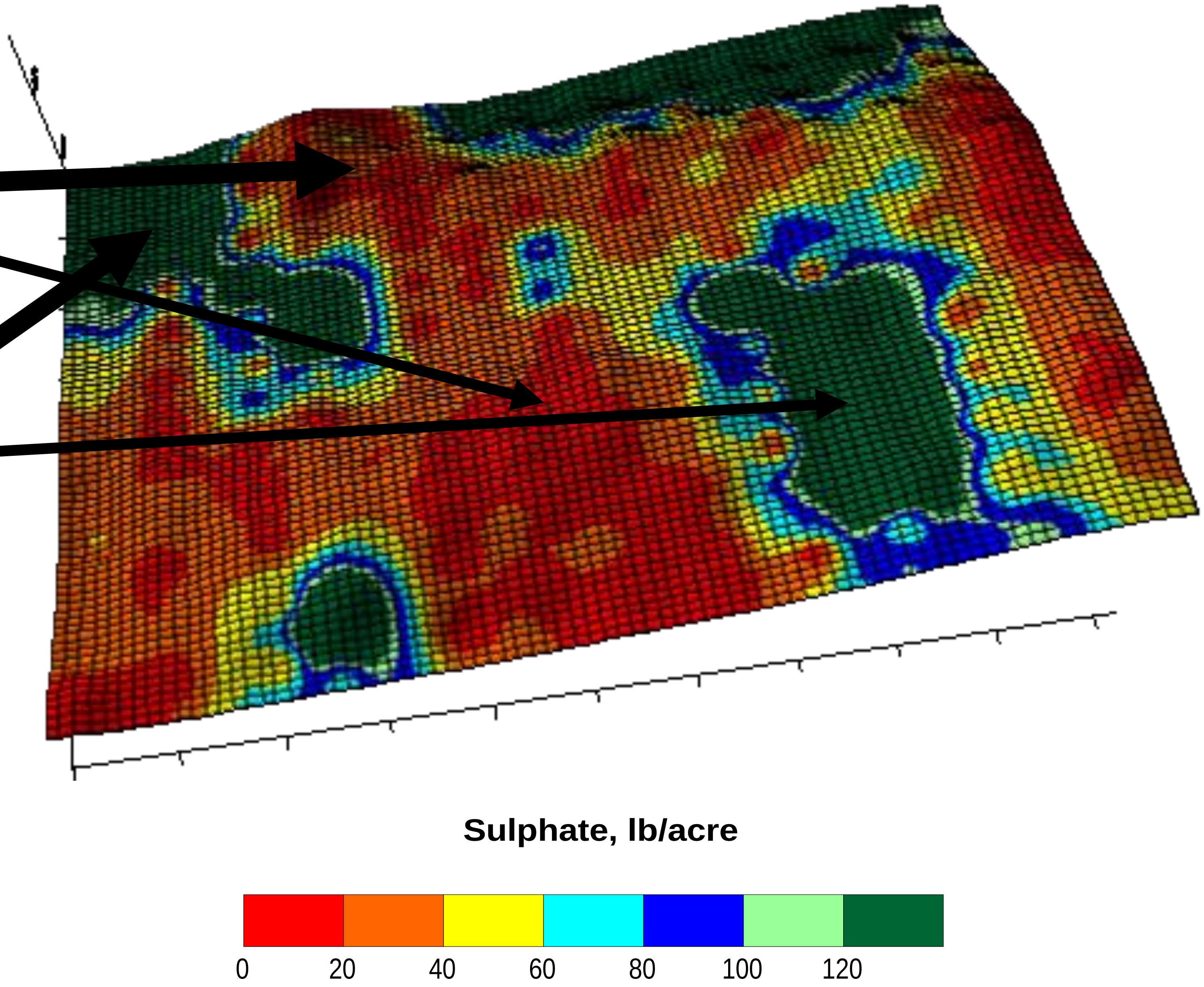
Sedimentary rock contains some igneous rock remnants, as well as products of previous oxidation/reduction reactions

In North Central Region, gypsum deposits are the result of the ancient location of coastal plains.

In drier climates of North Dakota/South Dakota and western Minnesota, groundwater may contain significant gypsum ($CaSO_4$), as well as magnesium sulfate and sometimes sodium sulfate.

Surface presence of sulfate is the result of groundwater movement.

Low sulfate at hilltops, ridges, high sulfate in areas with high water tables in local depressions.



S from Human activity- coal

Coal has been used in industry for over 2,000 years-
Greek, Roman, Chinese, probably others.

The contribution of these uses was small until 200 years ago- Industrial Revolution
The exchange of human and animal energy for alternate sources- wood, water.
Locations of industries with respect to wood and water sources resulted in replacement by coal.

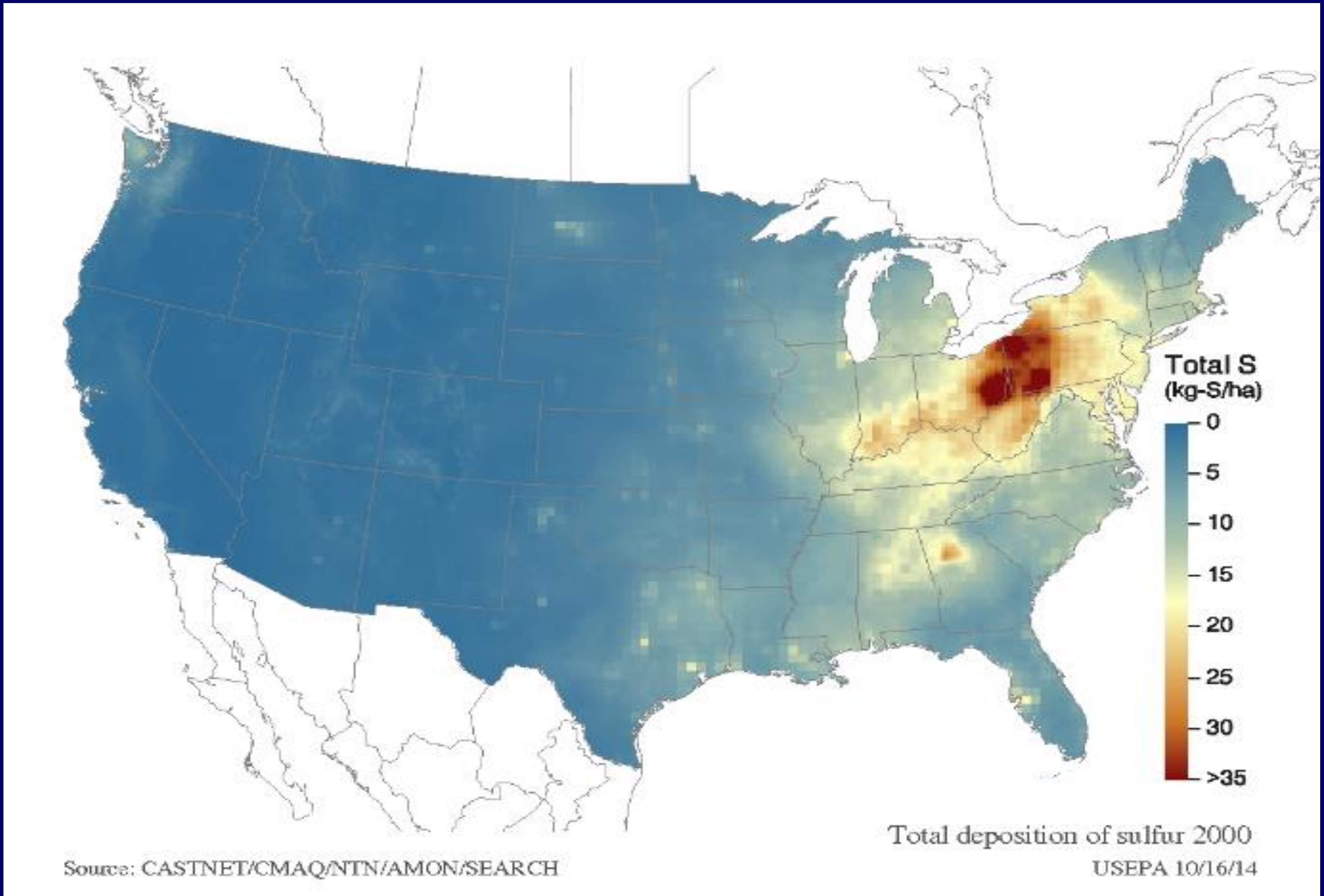
EPA was given authority by US Congress to regulate atmospheric emissions. 1990 Clean Air Act.

Title IV set goal of reduction of S emissions to 10 M tons S less than 1980 USA levels.

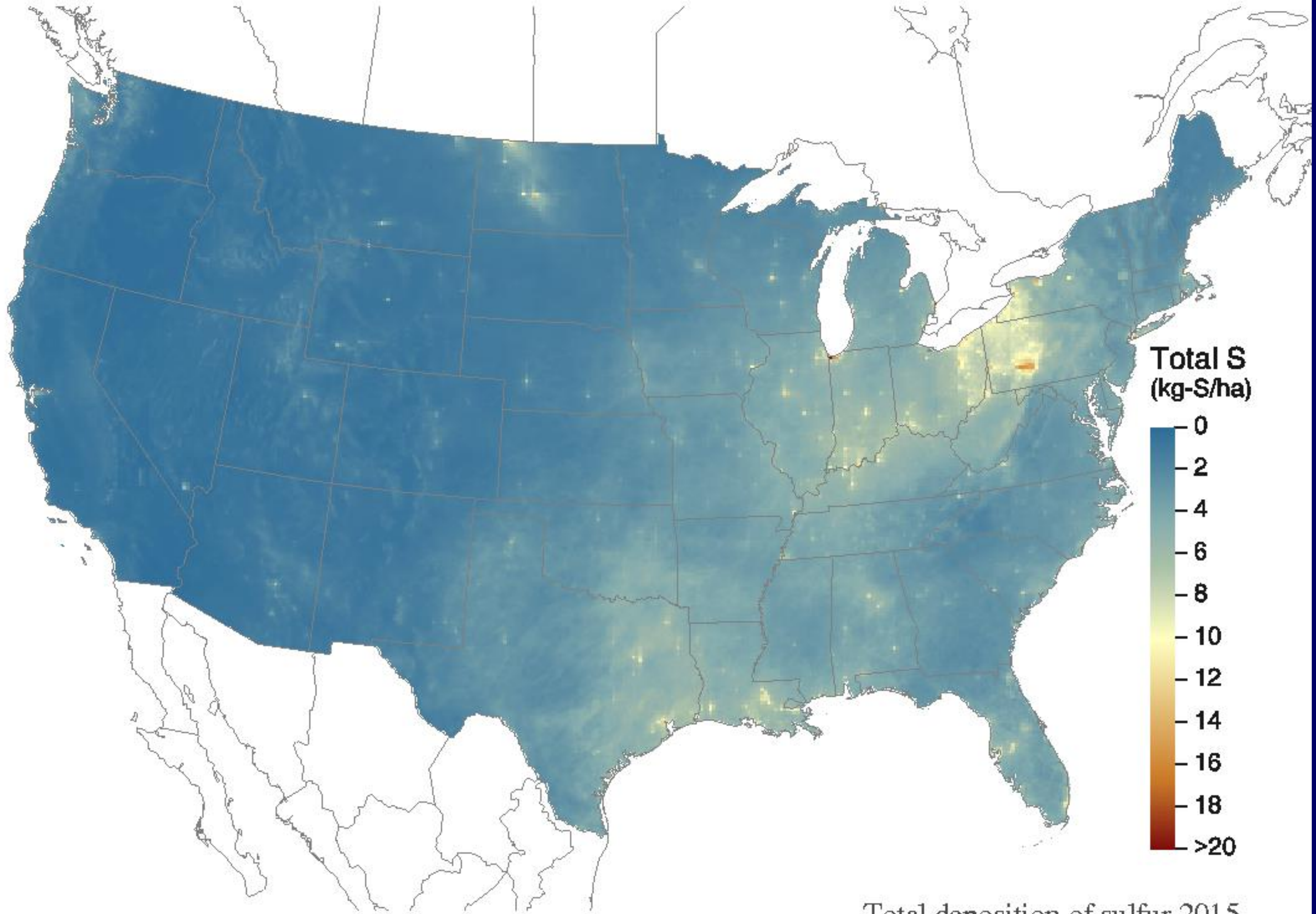
Additional regulation included not only large coal using industries, but smaller ones and those using oil and gas.

S emissions, M tons per year

	1975	2000	2010	2019
USA	38	13	8.6	~1
China	13	35	36	~2
India	--	--	--	~4



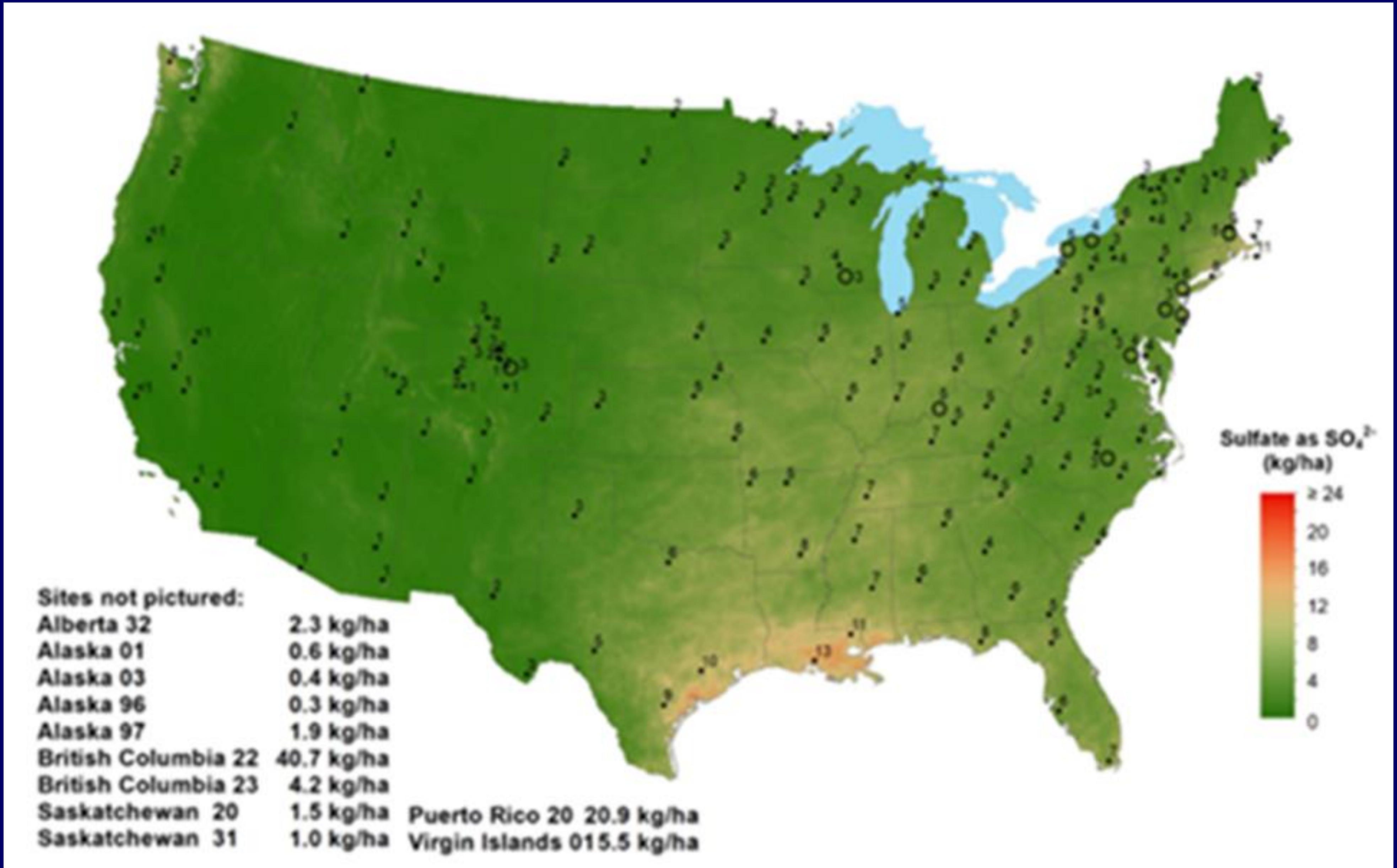
2000 S deposition



Total deposition of sulfur 2015

Source: CASTNET/CMAQ/NTN/AMON/SEARCH

USEPA 09/14/16



2021 S deposition

Biological S oxidation-

Chemolithotrophs- oxidize S when oxidizable S is present

Heterotrophs- oxidize S similarly as chemolithotrophs, but only when other oxidizable materials are not present. They do not have to oxidize S for metabolism and reproduction.

In a Saskatchawan soil survey of S oxidizing organisms, heterotrophs by far dominated the numbers of organisms. (Lawrence and Germida, 1991, Canadian Journal Soil Science).

This may explain the poor oxidation of S in that province and in North Dakota, directly to the SE of the study.

What we perceive as ‘natural’ sulfur nutrition is really crop uptake from a combination of sulfate received by the soil from the atmosphere from human and natural sources and sulfate available from groundwater capillary action, sulfate-bearing minerals, and S oxidation of sulfides from S oxidizing organisms

Until about 30 years ago, S deficiency in the NC Region was confined to low organic matter (eroded) soils with deep sandy textures.

That changed with the introduction of canola. Canola has always had a special requirement for S far above any crop grown in the region.

Yield of canola as affected by sulfur rate, source, and landscape position, Rock Lake, ND, no-till system.

From Deibert et al., 1996.

S rate, lb/acre	S source	Yield from different soil series/landscape position		
		Buse/hilltop	Barnes/slope	Svea/footslope
		lbs/acre		
0		30	240	1460
20	Ammonium sulfate	1650	1670	1720
40	Ammonium sulfate	1800	1860	2170
40	Elemental S	620	1060	1630

Changes in cropping in the region in the past 50 years-

Dramatic increases in yield due to genetic and crop management advances.

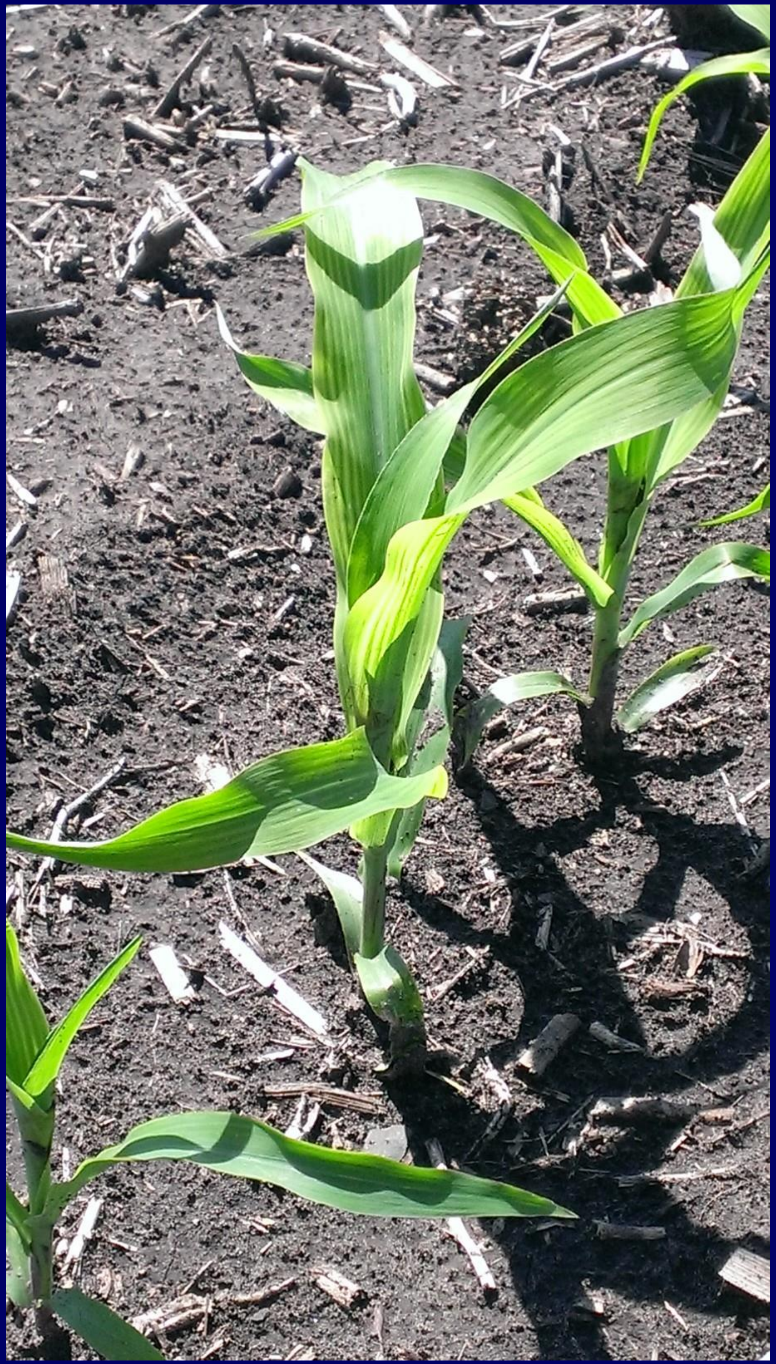
Continued topsoil erosion in some areas.

Reduction in anthropogenic-source S deposition.

Increased rainfall/leaching in some years.

In North Dakota, since 2010 S deficiency has been seen on corn on all soil textures. Below is on sandy loam near Oakes, dryland. Green is from farmer 2X2 S application. Greenest plots in N study are check plots.

S deficiency in corn, near Valley City, 2014



S deficiency in spring wheat near Valley City, 2010

Response of corn at six locations in Minnesota to sulfur (Rehm, 2005).

* Response is significant at P > 0.05

Site/texture	S applied, lb/acre	
	0	6
	Yield, bu/acre	
loamy fine sand	166	174*
silty clay loam	184	184
loamy fine sand	99	108*
Loam	150	161*
sandy loam	140	154*
silt loam	149	160*

Kim, Kaiser, and Lamb, AJ 2013

Applied broadcast S and starter S treatments in corn experiments by landscape position on loam and silt loam soils

When OM < 2%, S increased yield at 2 of 3 sites
OM 2-4%, S increased yield at 1 of 3 sites

No yield increase from S when OM >4%.
Many soils in central/south Minnesota have OM 4-8%.

Before 2005, S deficiency in Iowa was virtually unknown. A series of experiments in 2005-2006 showed a consistent response to S in some soils.

In 2007 17 of 20 sites showed a significant response to S
In 2008, 11 of 25 sites showed a significant response to S
Average response to S was 13 bu/acre

When grouped by texture within responsive sites, heavier soil increase was 15 bu/acre

Sandier soil increase was 28 bu/acre
(Sawyer, 2009)

Iowa S rescue on corn. 40 lb S/acre as gypsum broadcast side-dress early season after on-set of deficiency symptoms. Sawyer, 2009.

Site/Texture	Yield w/o S	Yield w/S
1 / loamy fine sand	123	151
2 / loamy fine sand	154	198
3 / loamy fine sand	88	108
4 / loam	196	204 (NS)
5 / silt loam	118	171
6 / silt loam	129	167
Across all sites	129	167

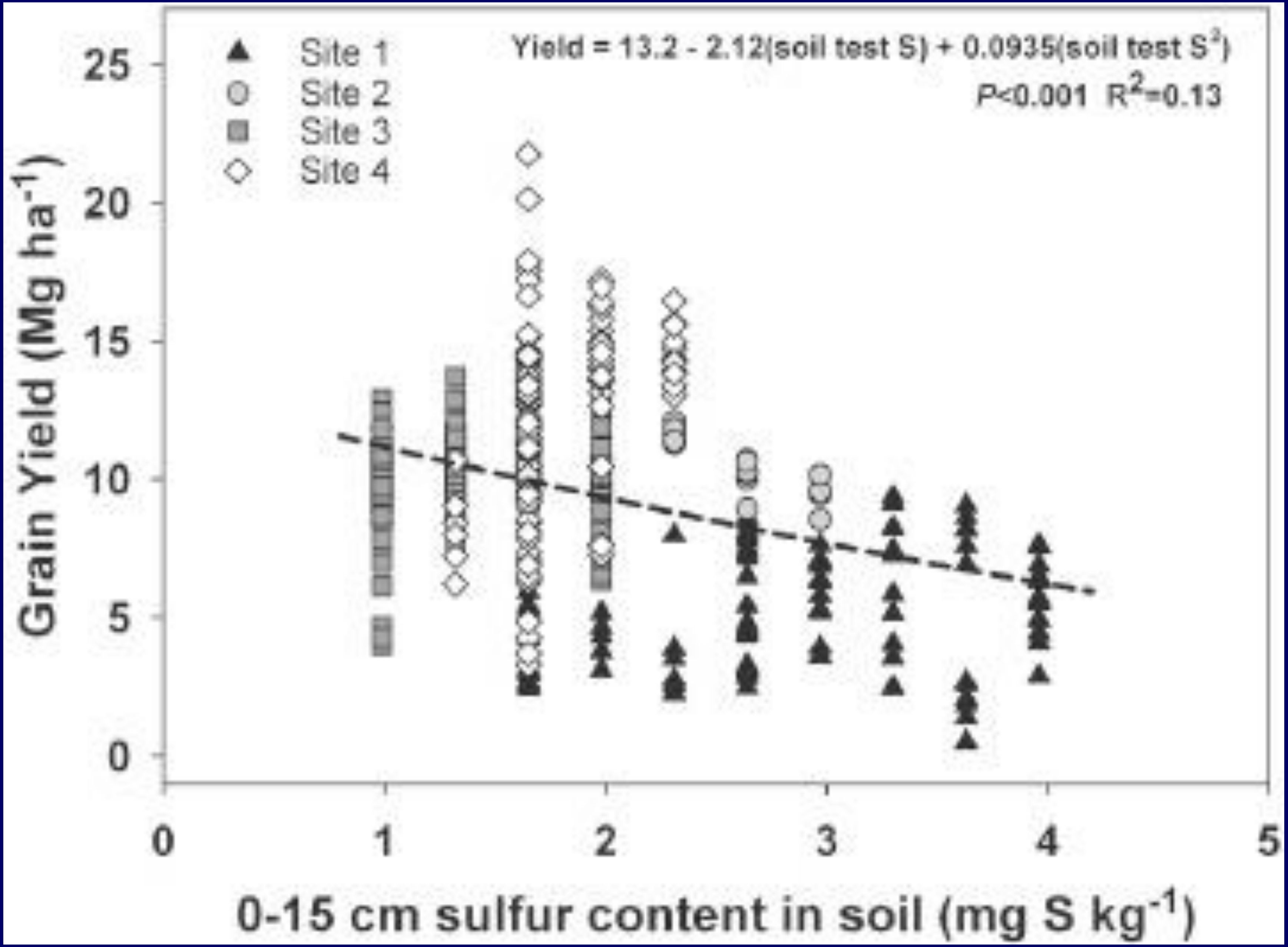
The current S soil testing procedure in the North Central Region is the Monocalcium Phosphate Extraction Procedure.

The acetic acid form of this procedure was identified by Hoeft et al. (1973) as the method that most predicted S deficiency and response in alfalfa.

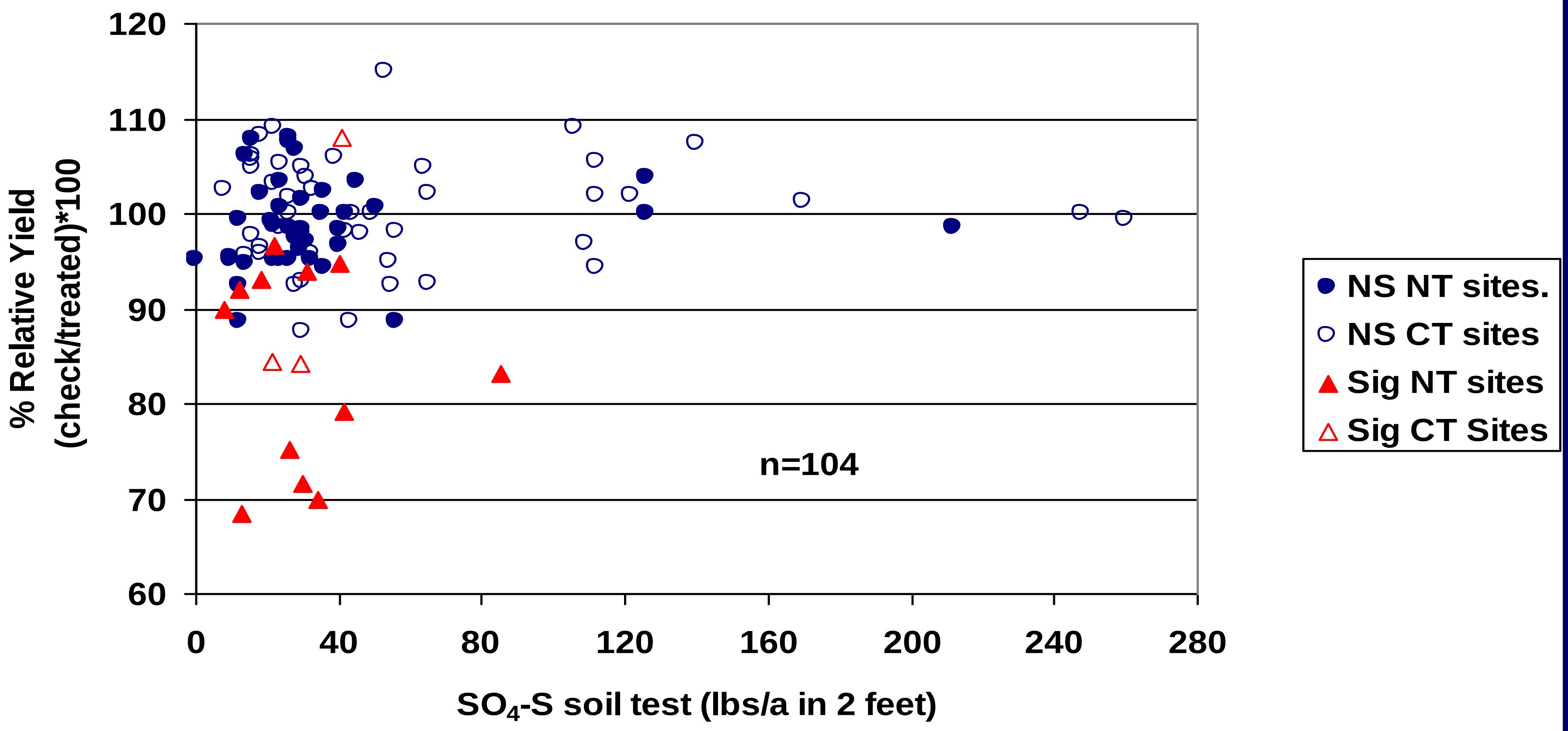
The acetic acid MP method is tedious, so an alternate method of MP was soon adopted. This alternate method was tested by Hoeft et al. and found not nearly as predictive as the acetic acid method.

Early in his Illinois career, Hoeft tried to use the acetic acid MP method to predict S response in corn, and found it unpredictive.

Relationship S test to grain yield Kim/Kaiser/Lamb

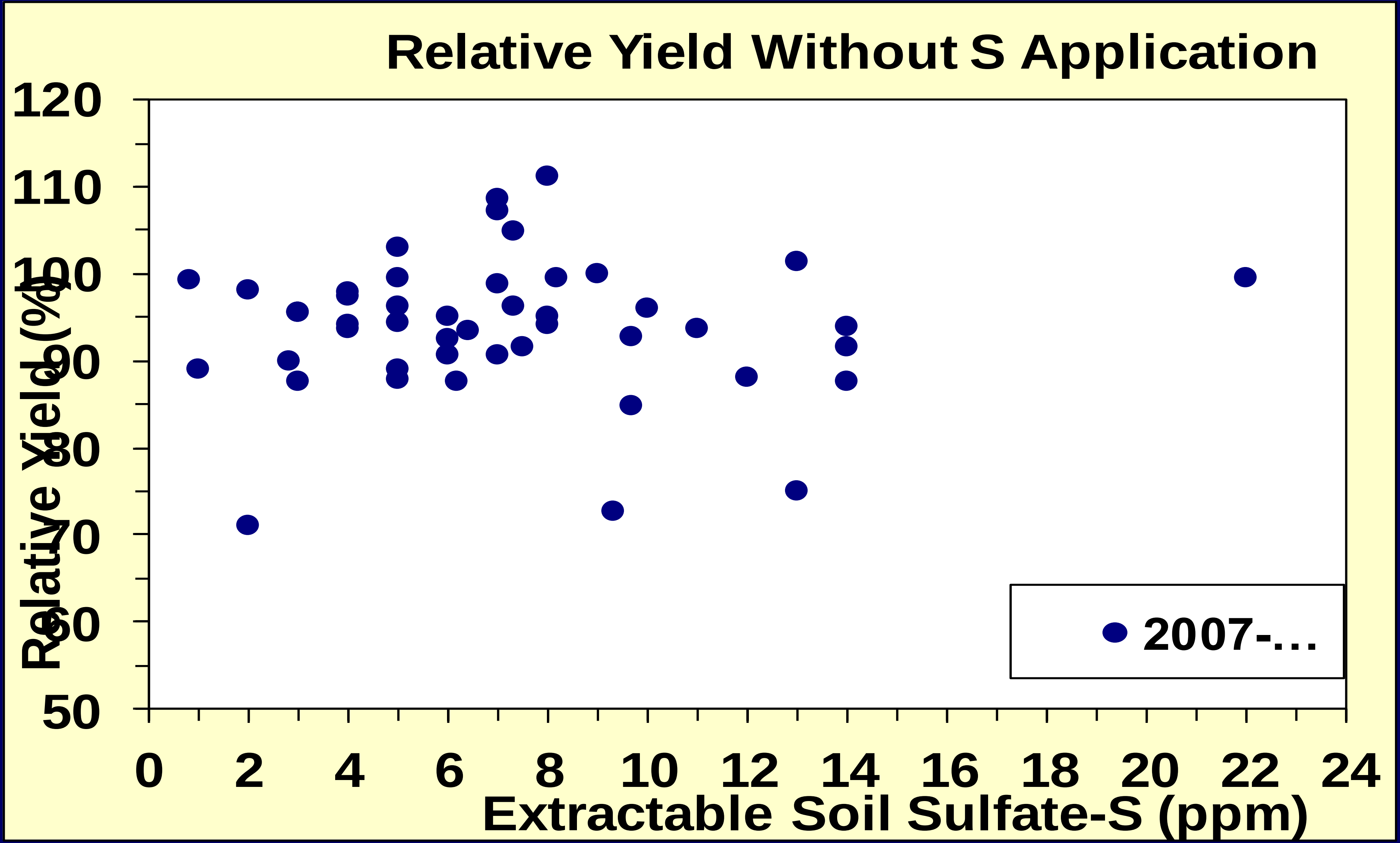


Relative corn grain yield to S soil test, Gelderman, SD.



No relationship of relative yield with S soil test

Relative corn yield to S test, IA, Sawyer.



The sulfate-S soil test is non-diagnostic and should not be used as the sole diagnostic strategy to determine whether crops might need S or not.

In ND, canola always receives 20 pounds sulfate-S regardless of any conditions.

Other crops, fall rainfall, snowmelt, early spring rains, soil texture, length of spring rain and persistence of wetness in forecast, landscape position all play a role.

Soybean and sunflower particularly not very S responsive.

Grain crops and corn are responsive.

S sources-

Manures- varies with analysis

Dry manure 1-3 lb S / ton

Liquid manure 4-9 lb S / ton

Previous crop residues-

Kaiser found that soybean response to S lower when S was applied to corn the year before. Some of the S released to soybean probably comes from residue decomposition.

S sources-

Ammonium sulfate (20 to 21 - 0-0-24S)
Gypsum (0-0-0-14to20S)
Potassium sulfate (0-0-50-18S)
Potassium magnesium sulfate (0-0-22-22S)

Ammonium thiosulfate 12-0-0-26S
Potassium thiosulfate 0-0-25-17S

Elemental S?

Consistently less effective across the NC Region rate S/rate compared sulfate/thiosulfate sources.
Type of elemental S used in trials is a very fine grind, bound with bentonite clay to improve dispersion.

Oxidation is the problem, not fineness of material.

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Timing of S application-

Just as nitrate is not a fall fertilizer, neither is sulfate.

Elemental S applied in the fall will partially oxidize to sulfate, which will leach in the spring- leaving elemental S which oxidizes slowly. Not a great plan.

Sulfur is a spring fertilizer.

Dave Franzen

701-799-2565
David.Franzen@ndsu.edu