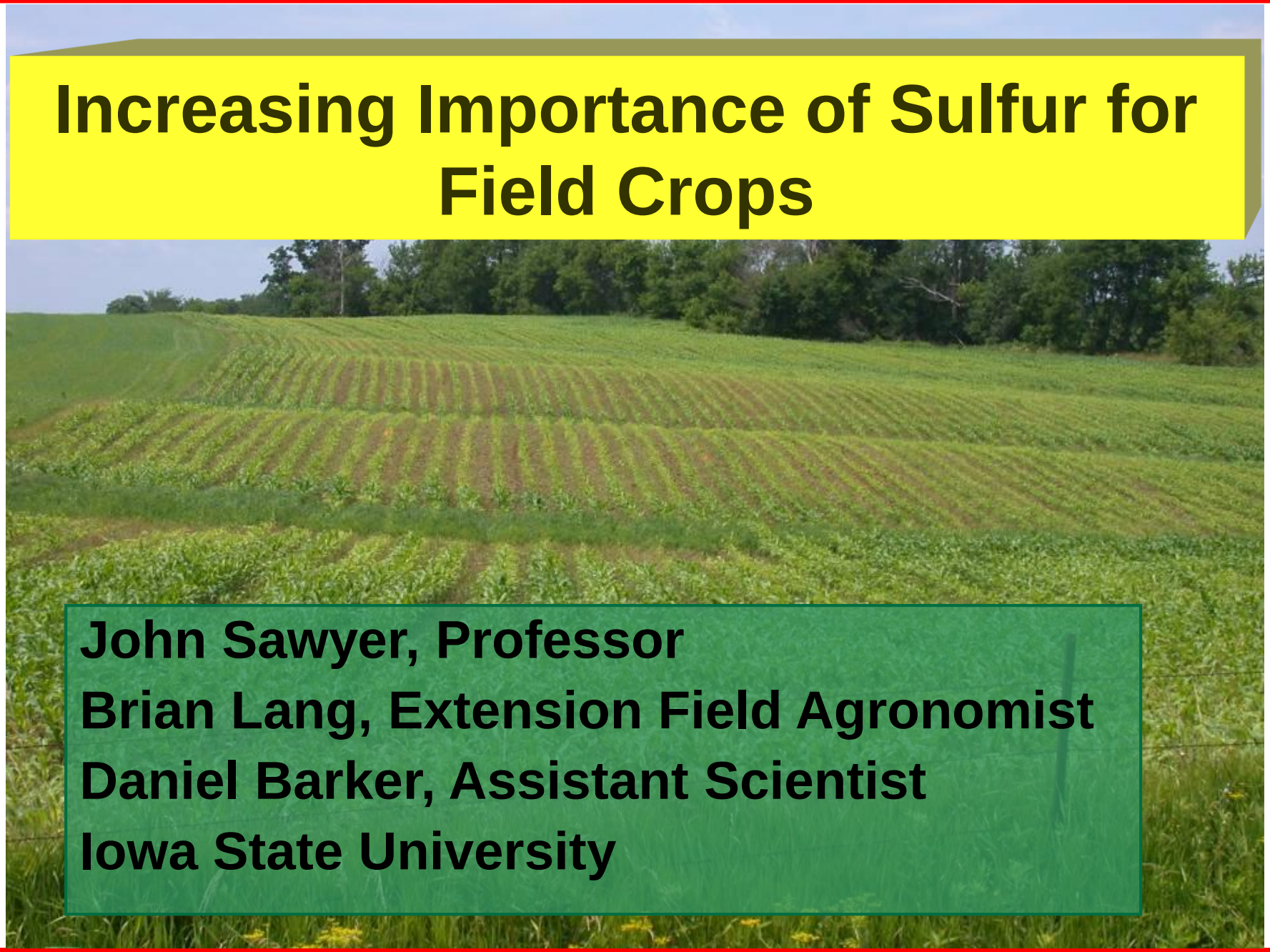
Increasing Importance of Sulfur for Field Crops



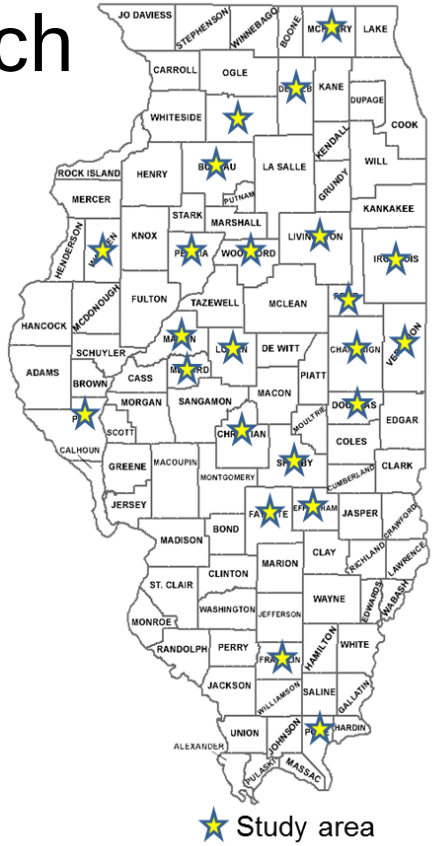
John Sawyer, Professor
Brian Lang, Extension Field Agronomist
Daniel Barker, Assistant Scientist
Iowa State University

Sulfur Research History

- 40+ years (before 2005) of research across Iowa (approximately 200 site-years)
  - Three times statistically significant yield increase
  - One study with multi-year average yield decrease
- My first research project was on sulfur
  - Illinois 1977-1979 statewide with corn
    - Sulfur response at 5 of 81 site-years
      - 11 bu/acre mean increase at the 5 sites
  - Response with surface soils in greenhouse
    - One soil first plant harvest
    - 60% of soils second harvest

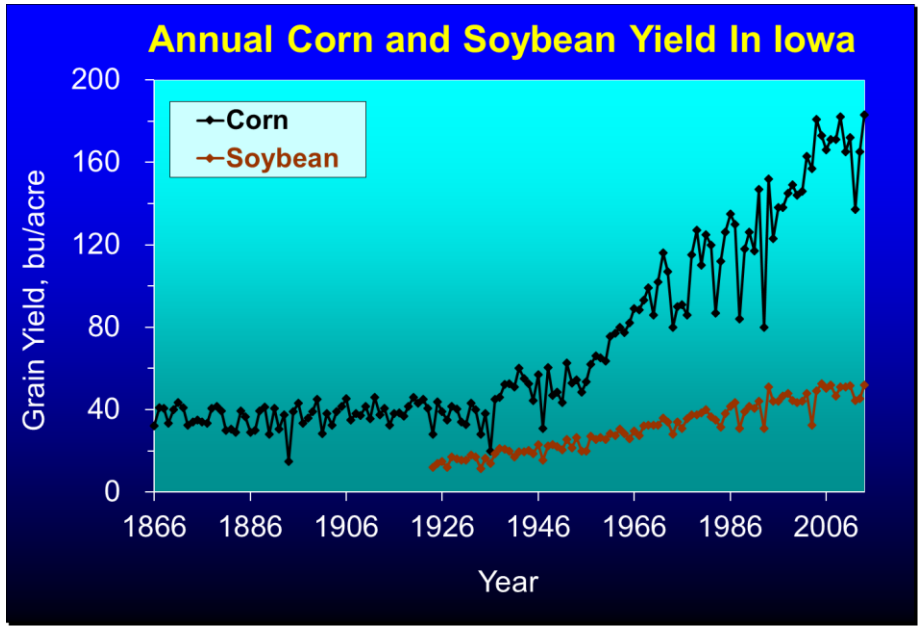
Sulfur Research History

- Southern IL - wheat (1990-1992)
  - No yield response – 2 research farms
- Recent University of Illinois research
  - Fernandez and Sutradhar, 2009-2011
  - 0 of 18 site-years small plot trial corn yield response
    - Mean of 9 sites: 11 bu/acre response
  - 2 of 22 site-years field strip trial corn yield response



Crop Sulfur Uptake

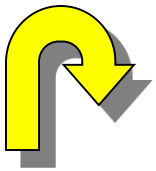
- Corn at 200 bu/acre (Iowa trials)
  - 8 lb S/acre grain (0.04 lb S/bu)
  - 5 lb S/acre vegetation (1.0 lb S/ton d.m.)
- Alfalfa (Iowa trials)
  - 5-6 lb S/ton d.m.
- Modern Corn and Soybean
  - Corn – 0.07 lb S/bu
  - Soybean – 0.10 lb S/bu
  - Alfalfa – 5 lb S/ton

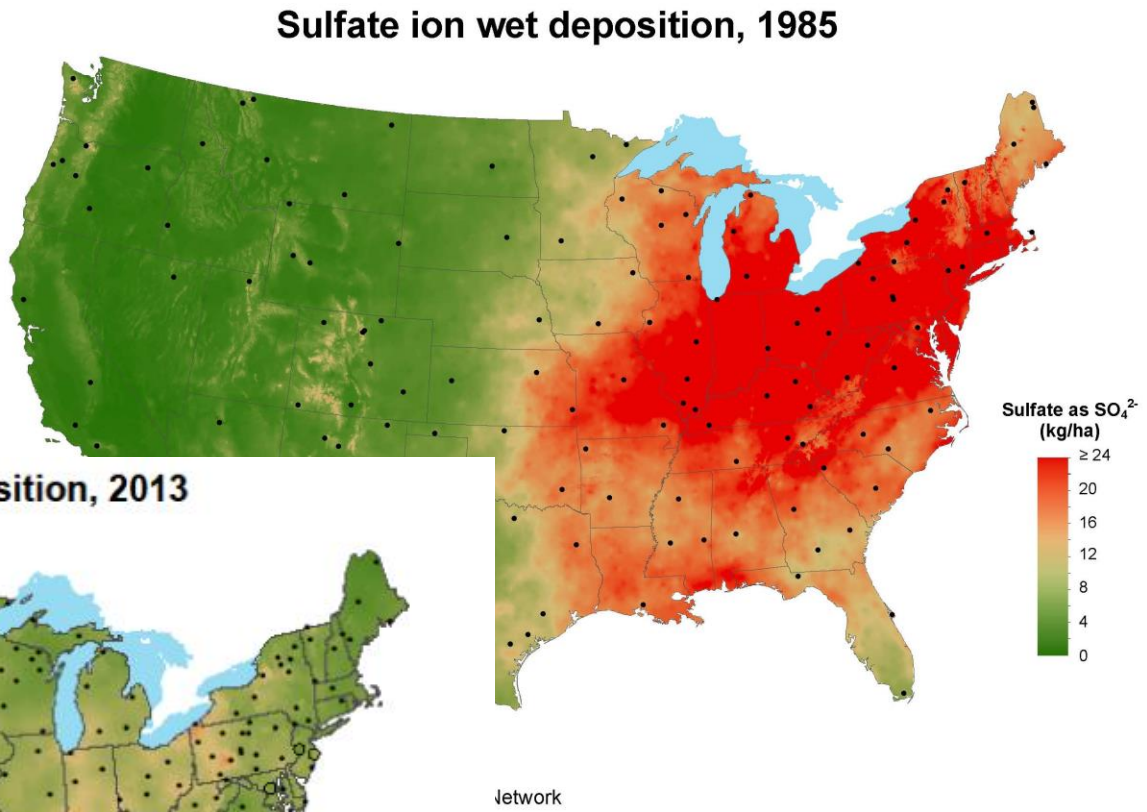


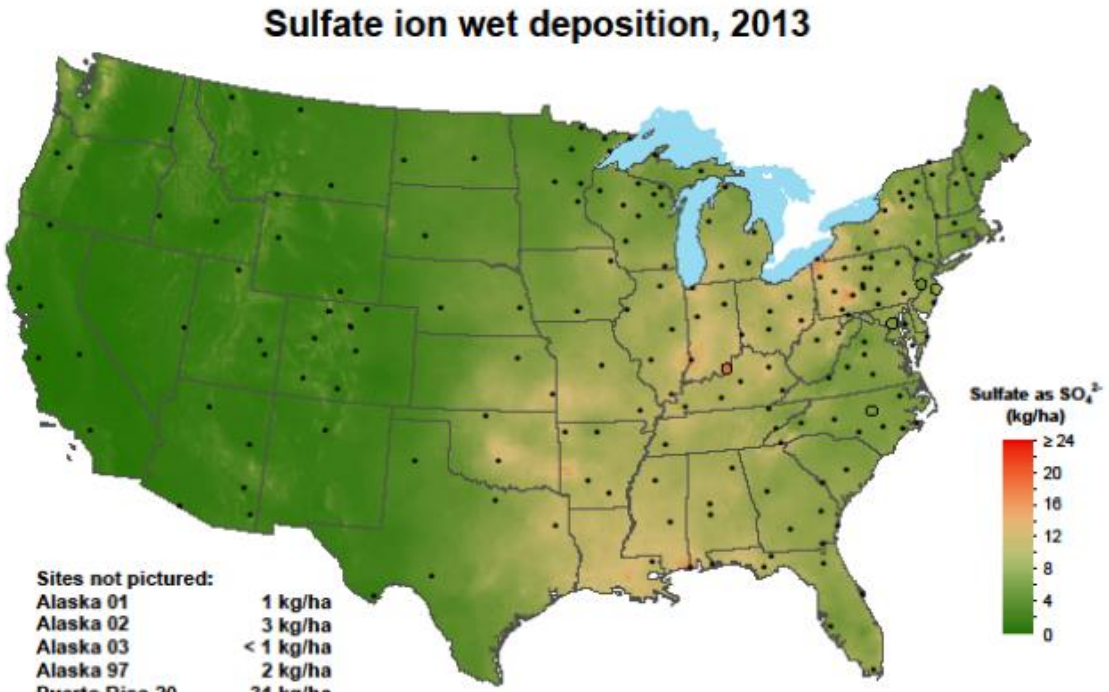
Sulfur Sources

- Where does crop-available sulfur come from?
  - Soil organic matter
    - Large pool of sulfur in most soils
  - Subsoil sulfate
  - Rock degradation/accumulated gypsum
  - Atmospheric deposition
    - Volcanic emission
    - Marine gases
    - *Coal/diesel burning*
  - Manure
  - Fertilizers/byproducts containing sulfur
  - Irrigation water

Sulfate Deposition 1985 – 2013



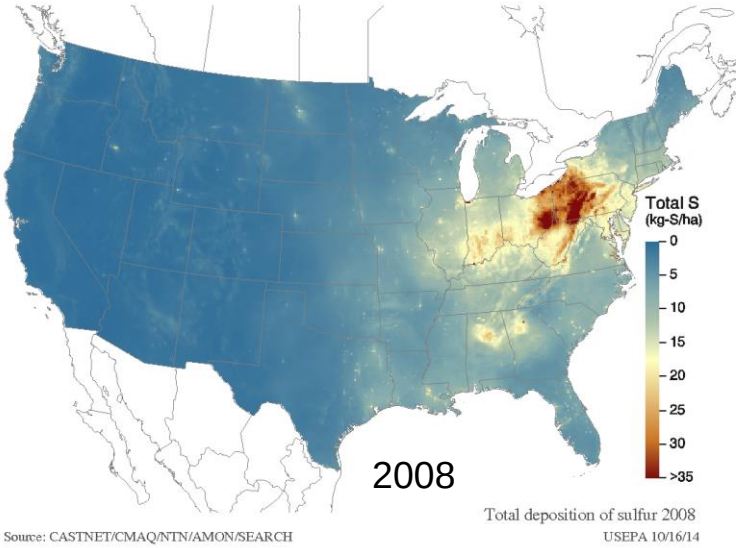


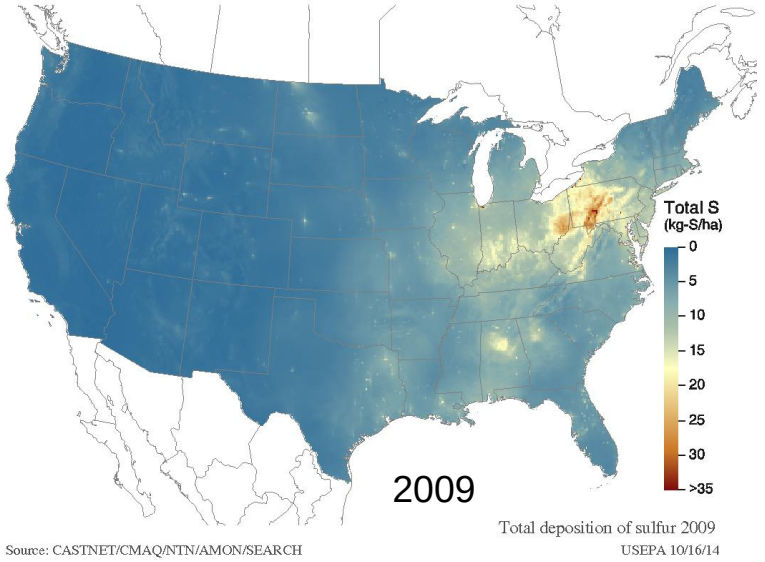


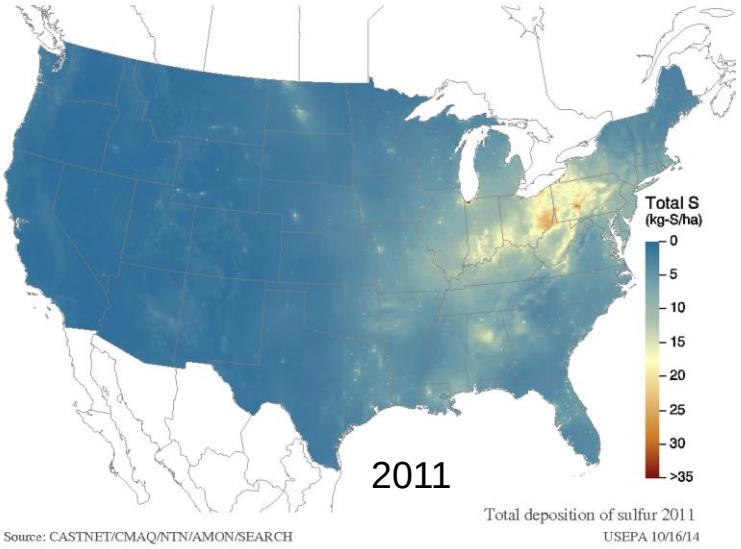
National Atmospheric Deposition Program (NADP)

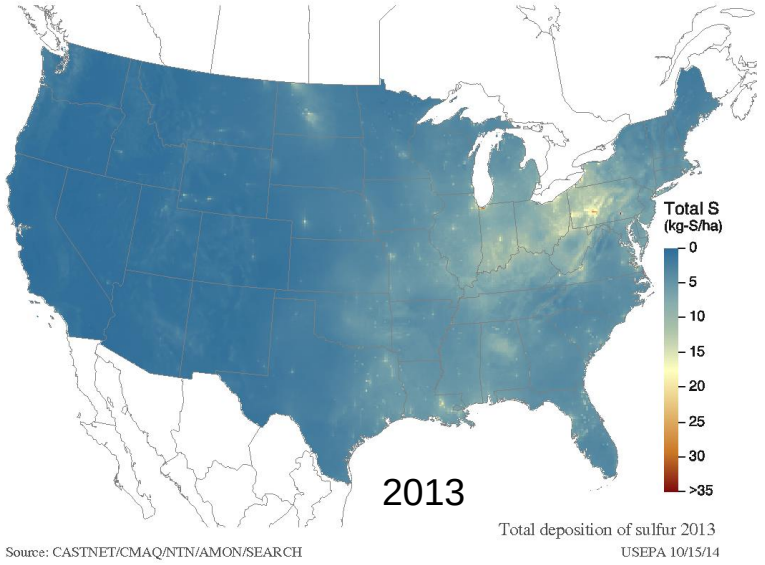
10 kg SO_4/ha = 3 lb S/acre

Total S Deposition - National Atmospheric Deposition Program









Things Changed in Iowa

Observation of poor alfalfa growth in Northeast Iowa

Visual Response in Alfalfa to S Application

J.E. Sawyer, Iowa State Univ.

Alfalfa Response to S Application in Field Areas with Poor and Good Coloration of Alfalfa, 2005-2006

Sulfur	2005				2006	
	Cuts 2+3 DM Yield		Cut 2 Plant Top S		Cut 1 DM Yield	
	Observed Growth Area					
Treatment	Poor	Good	Poor	Good	Poor	Good
	- - ton/acre - -		- - - % S - - -		- - ton/acre - -	
None	1.18a	2.99b	0.14a	0.22b	1.10a	2.04b
Am. sulfate	2.76b	3.26b	0.40d	0.35c	2.18b	2.22b
Ca. sulfate	2.49b	3.21b	0.41d	0.37c	2.14b	2.19b
	6.6	7.4	Soil Sulfate-S (ppm)			

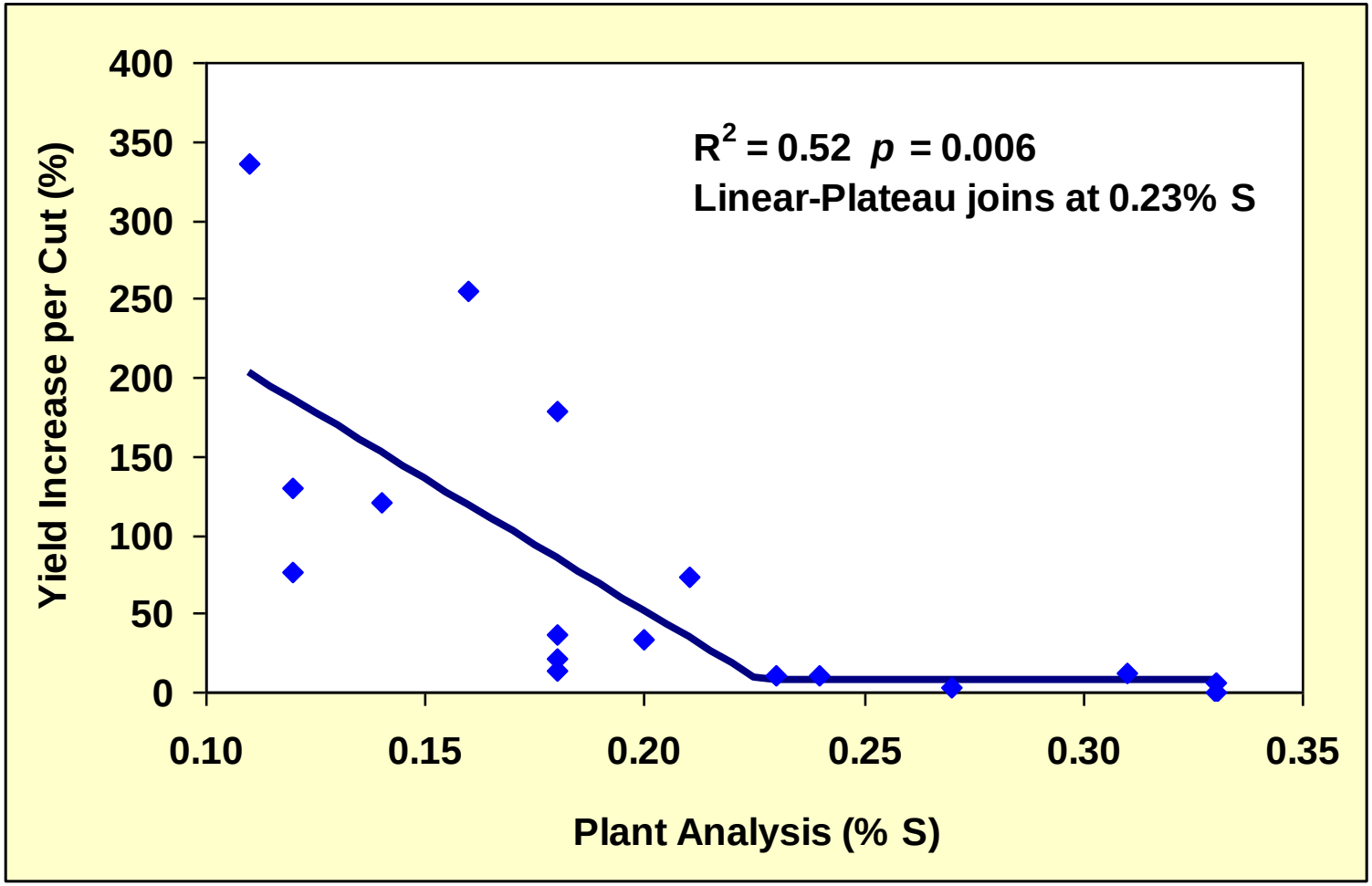
Three field sites in 2005, Elgin, Gunder and West Union, IA (Fayette & Downs sil soils).

Two field sites in 2006, Elgin and Gunder, IA.

Sulfur materials were applied at 40 lb S/acre after first cut in in 2005.

Treatment means followed by the same letter are not significantly different ($p \leq 0.10$).

Alfalfa Yield Increase to Applied S vs. Plant S Concentration (six-inch plant top)



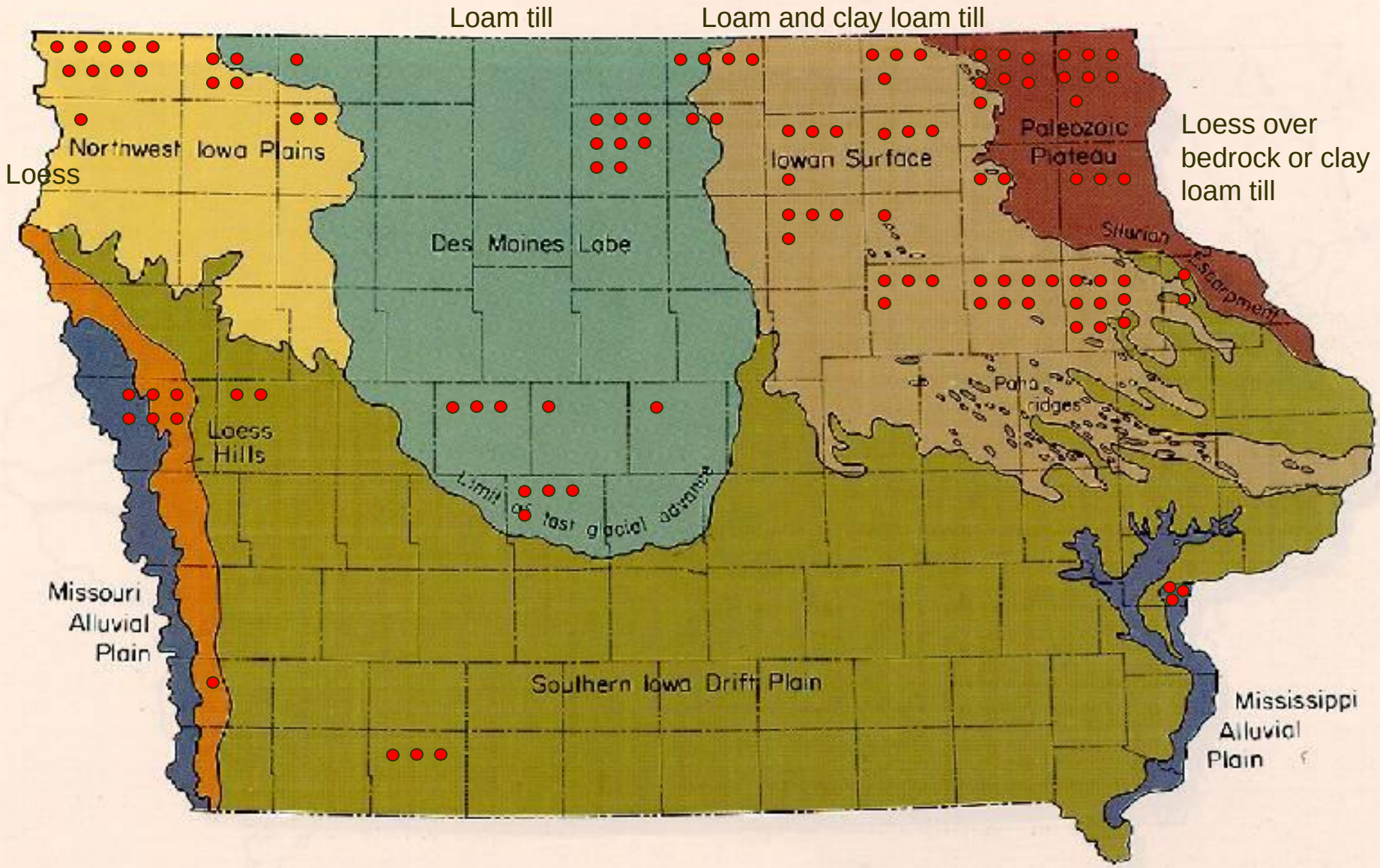
Things Changed

Photo from B. Lang, ISU
Waukon – 6/26/2006

Visual Response in Corn to Sulfur Application

S Check S Check S Check

Photo from B. Lang, ISU
Waukon – 8/2006



Corn and soybean S trial sites, 2006-2013

Sulfur Fertilizer Trials on Corn in Problem Field Areas, Northeast Iowa, 2006

Location	Soil type	Sulfur	Yield
			bu/acre
Lamont 1	Sparta lfs	No	123 a
		Yes	151 b
Lamont 2	Sparta lfs	No	154 a
		Yes	198 b
Thorpe 1	Chelsa lfs	No	88 a
		Yes	108 b
Thorpe 2	Kenyon l	No	196 a
		Yes	204 a
Waukon	Fayette sl	No	96 a
		Yes	172 b
Waterville	Fayette sl	No	118 a
		Yes	171 b

Sulfur applied as calcium sulfate at 40 lb S/acre.

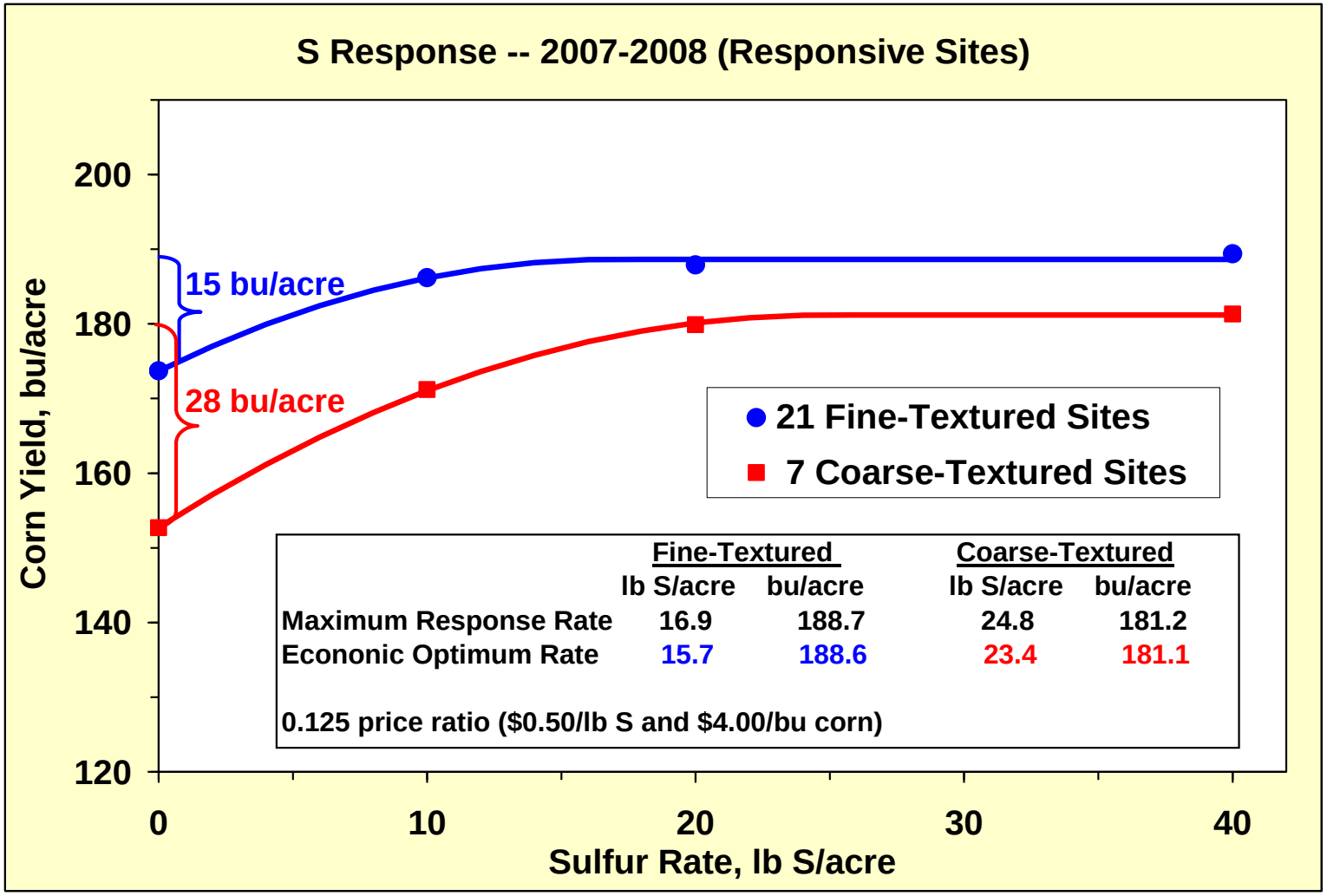
Forty-Seven Corn S Rate Sites in 2007-2009
Northeast – North Central Iowa

- Sulfur (gypsum) at 0, 10, 20 and 40 lb S/acre
- 2007
  - 17 of 20 sites responded to S application
    - 18 bu/acre average yield increase across all sites
- 2008
  - 11 of 25 sites responded to S application
    - 7 bu/acre average yield increase across all sites
- 2009
  - 2 sites with no response to S application
- Soils: l, sil, fsl, lfs, sl, sicl, cl

Twenty-Eight Responsive S Rate Sites

2007-2008 North Central - Northeast Iowa

Soils: 21 fine texture (cl, sicl, sil, l); 7 coarse texture (fsl, lfs, sl)



Phosphorus and Sulfur Product Evaluation

- Two sites in northeast Iowa
  - 2006 (silt loam and loam soils)
  - Simplot 13-33-0-15S (SEF)
- Five sites in central to north-central Iowa
  - 2008 – 2010 (four loam and one loamy fine sand soils)
  - Mosaic 13-33-0-15S (MES15)
  - Mosaic 12-40-0-10S (MES10)
- Compared to AMS and MAP
- Sulfur applied at 10 and 30 lb S/acre
  - N and P equalized at rate with highest S rate

Phosphorus and Sulfur Product Evaluation

- Sulfur response at two 2006 sites

Treatment	Ear Leaf S	Grain Yield
	%	bu/acre
S-CON	0.15a	196a
SEF-10	0.18b	211b
AMS-10	0.18b	211b

Mean response across both sites, 2006.

- No S yield response at five 2008-2010 sites
  - Leaf S concentration increased with all products
- Across all sites (2006-2010)
  - Yield response to P with all products (17 bu/acre)
  - Leaf P concentration increase with all products

On-Farm Strip Trials
Central and Northeast Iowa, 2009

Site	County	Previous Crop	Sulfur Rate	Corn Yield - S	Corn Yield + S	Resp.
			lb S/acre	- - - -	bu/acre - - - -	
3	Greene	corn	40	225	229	
4	Greene	corn	40	210	215†	5
5	Greene	corn	40	217	228†	11
6	Dallas	soybean	40	201	200	
9	Dallas	corn	40	147	152†	5
10	Dallas	corn	40	135	134	
1	Fayette	soybean	15	224	236†	12
2	Howard	soybean	20	186	192†	6
7	Dubuque	soybean	30	216	229†	13
8	Floyd	---	20	199	203	
11	Winneshiek	soybean	30	215	212	

† Significantly different, P ≤ 0.10.

Sulfur applied as gypsum.

55% site response

ISU FARM Strip Trials
NW-W-SW Iowa, 2012-2013

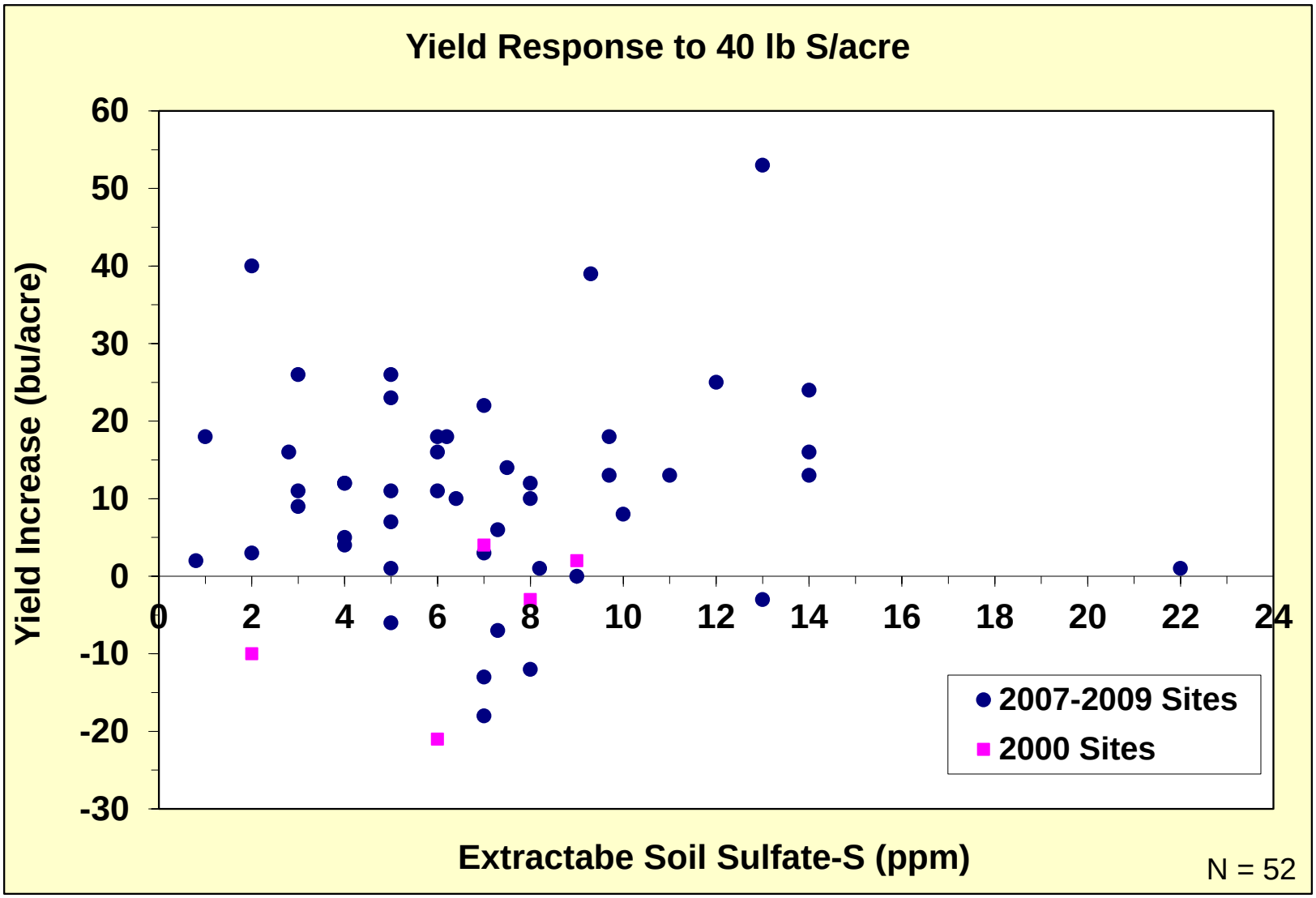
ISU FARM On-Farm Strip Trials, 2012, 2013, and 2013 Residual Year

Site	County	Previous Crop Yr 1	Sulfur Rate	2012 Yield - S	2012 Yield + S	2013 Yield - S	2013 Yield + S	Response '12	Response '13
			lb S/acre	bu/acre					
1c	Mills	soybean	17	217	218	--	--		
2c	Taylor	soybean	17	99	106*	--	--	7	
3c	Lyon	soybean	15	157	160	40.5	44.3*		3.8
4c	Osceola	soybean	15	198	197	--	--		
5c	Dickinson	soybean	15	213	214	--	--		
6c	Lyon	soybean	15	140	134*	43.7	42.7	-6	
7c	Lyon	soybean	15	88	79	55.5	53.6		
8c	Crawford	soybean	15	100	132*	45.0	49.1*	32	4.1
9c	Monona	soybean	15	190	195	228	240		
10c	Monona	soybean	15	232	228	69.3	69.5		
11c	Clay	soybean	15	231	235 *	54.8	55.2	4	
1s	Osceola	corn	15	50.2	52.4	201	205		
2s	Monona	corn	15	64.3	63.3	230	236*		6
1n	Taylor	soybean	17	--	--	172	181*		9
1n	Taylor	corn	17	--	--	45.3	44.1		

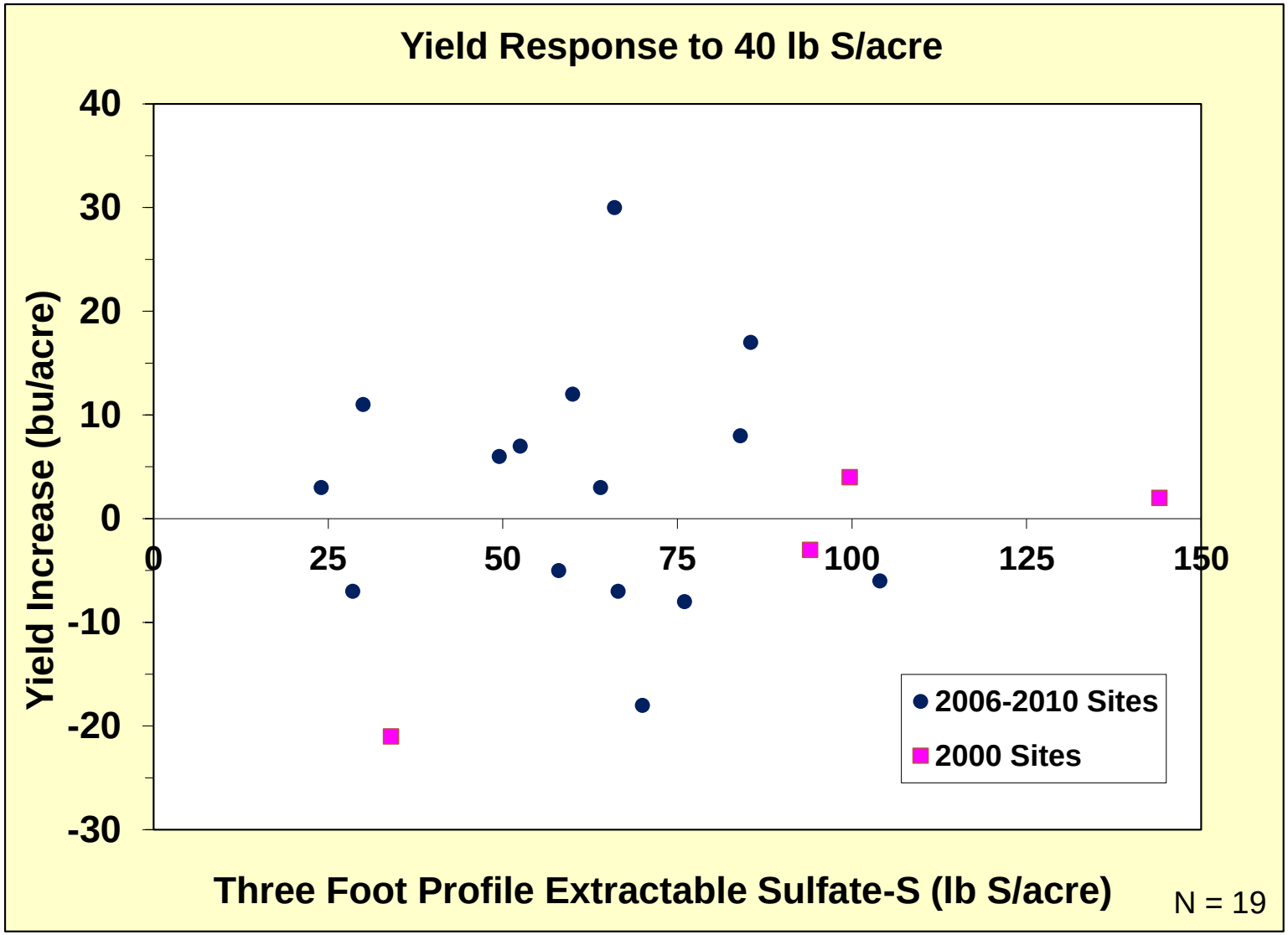
* Significant difference at P ≤ 0.10. Sulfur applied in spring as gypsum.

29% site positive response

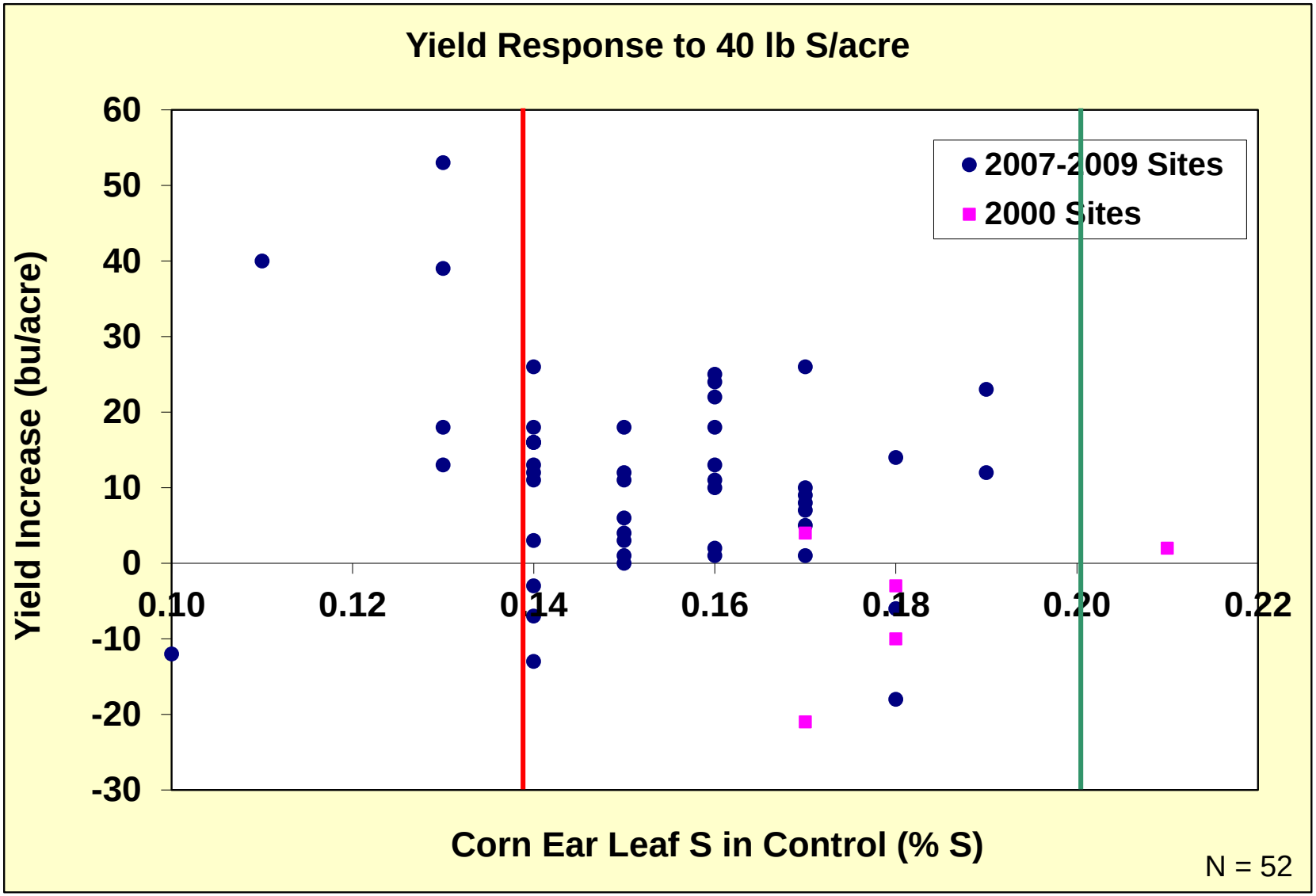
Extractable Soil Sulfate-S (0-6 inch depth)



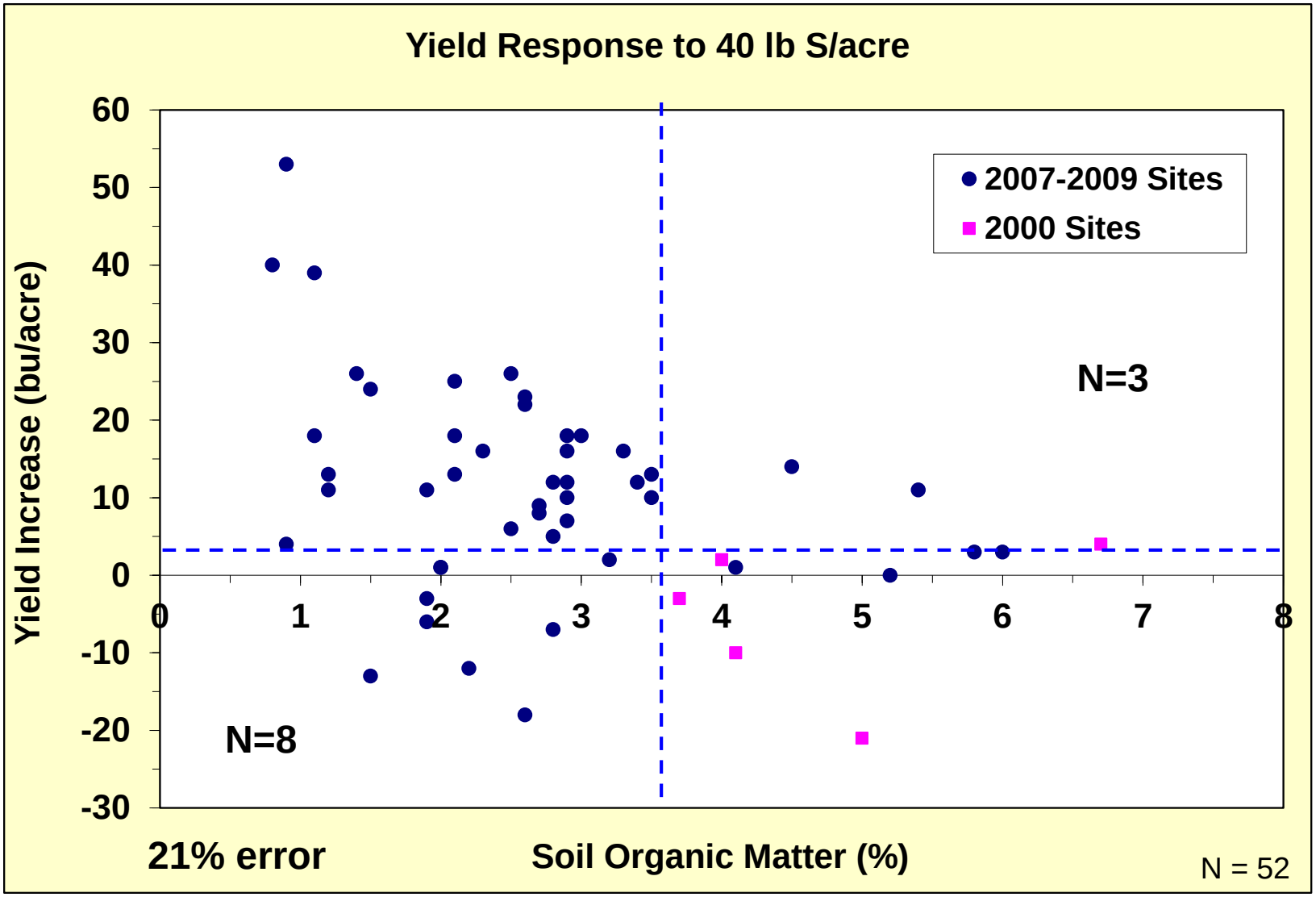
Soil Profile Extractable Sulfate-S



Corn Ear Leaf S Concentration (R1 Stage)



Soil Organic Matter (0-6 inch depth)

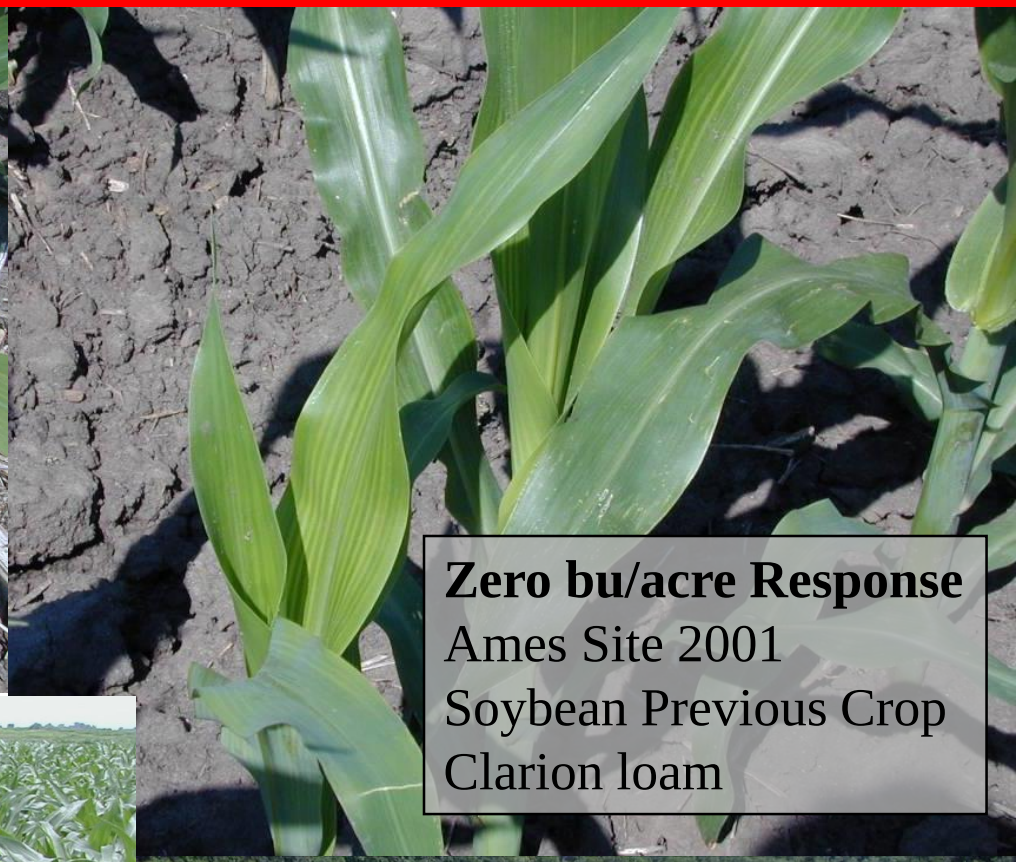


76 bu/acre Response
Site WK 2006
Alfalfa Previous Crop
Fayette sil

42 bu/acre Response
Site D 2007
Soybean Previous Crop
Sparta lfs

20 bu/acre Response
Site T1 2006
Soybean Previous Crop
Chelsa lfs

Zero bu/acre Response
Site Mason City 2008
Soybean Previous Crop
Readlyn loam

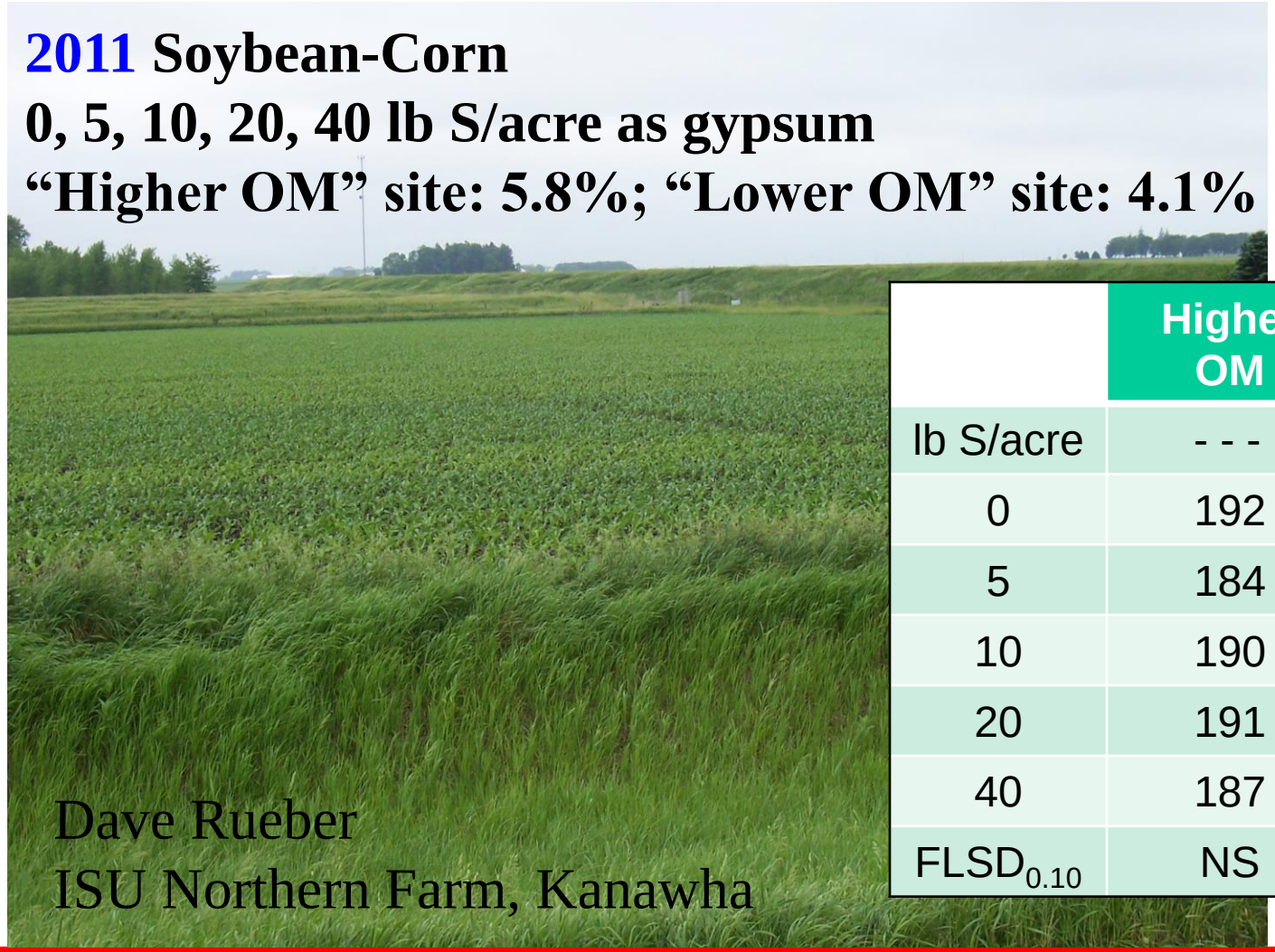


Zero bu/acre Response
Ames Site 2001
Soybean Previous Crop
Clarion loam

No Response or Small Response

Early Season Sulfur Deficiency Symptoms Can Disappear

2011 Soybean-Corn
0, 5, 10, 20, 40 lb S/acre as gypsum
"Higher OM" site: 5.8%; "Lower OM" site: 4.1%



Dave Rueber
ISU Northern Farm, Kanawha

	Higher OM	Lower OM
lb S/acre	- - - bu/acre - - -	
0	192	187
5	184	188
10	190	187
20	191	191
40	187	183
$FLSD_{0.10}$	NS	NS

Sulfur Rate Trials – Northern Research Farm

	Higher OM Site (5.8%)					Lower OM Site (4.1%)				
	2011	2012	2013			2011	2012	2013		
S Rate	SC	SCC	SCCC			SC	SCC	SCCC		
lb S/acre	- - - - bu/acre - - - -			NDVI		- - - - bu/acre - - - -			NDVI	
0	192	82	152	0.557		187	80	174	0.577	
5	184	100	171	0.591		188	99	192	0.619	
10	190	105	180	0.657		187	109	191	0.649	
20	191	105	179	0.629		191	113	179	0.663	
40	187	111	181	0.638		183	104	185	0.671	
Sign. (0.10)	NS	*	*	*		NS	*	*	*	

Higher OM site Webster clay loam; lower OM site Clarion loam.
S rates (as gypsum) applied in spring 2011 and 2013 before corn.
Significance either rate, linear, quadratic, cubic, or +S vs. –S.
Dave Rueber, ISU Northern Research Farm, Kanawha, IA.
NDVI from Crop Circle at V10 corn growth stage.

Sulfur Rate Trials
Muscatine Island Research Farm

S Rate	2011	2012	2013
lb S/acre		bu/acre	
0	72.4	211	259
10	74.4	207	258
20	69.6	214	254
40	72.2	210	262
Sign. (0.05)	NS	NS	NS

Fruitfield coarse sand (1 to 1.5% OM), irrigated.
S rates (gypsum) applied post-emergence.
Leaf S concentrations increased each year with S application.
2013: 1.7 lb SO_4-S/acre-inch irrigation (27 lb S/acre in 16 inches).
Vince Lawson, ISU Muscatine Island Research Farm, Fruitland.

Summary

- Sulfur deficiencies an issue in Iowa
  - 60% corn S rate sites responsive to S application
    - 68% sites responsive with l, sil, fsl, lfs, sl soils
    - 14% sites responsive with sicl, cl soils
  - Especially coarse textured, sideslope landscape, eroded, low organic matter soils; no-tillage, reduced-tillage, high crop residue, alfalfa prior crop, no manure application, no S applied in fertilizers or irrigation
- 47% S response frequency for 110 trials statewide from 2006 – 2013

Summary

- Sulfur application rate when needed
  - Alfalfa: topdress 20 to 30 lb S/acre
  - Corn: 15 lb S/acre fine textured soils
    25 lb S/acre coarse textured soils
- Tools to indicate S deficiency
  - Alfalfa – top six-inch plant growth at early bud
  - Corn and soybean – ??
    - General field/soil characteristics
    - Visual coloration and growth response
    - Strip trials +/- S for multiple years

Sulfur Fertilizers

- Ammonium Sulfate (21-0-0-24S)
- Ammonium Thiosulfate (12-0-0-26S)
- Gypsum (Calcium Sulfate) (0-0-0-17S)
- Elemental Sulfur (0-0-0-90S)
- Magnesium Sulfate (0-0-0-14S)
- Potassium Magnesium Sulfate (0-0-22-23S)
- Potassium Sulfate (0-0-50-18S)
- N-P-S products (ex. 13-33-0-15S)
- Polyhalite (0-0-14-19S)
- By-Products
  - Lysine manufacturing
  - Soybean soapstock refining process water (Plant Food Solution)
  - Wallboard (gypsum)

Research Support

- Honeywell International, Inc.
- J.R. Simplot Company
- Mosaic Fertilizer, LLC
- Foundation for Agronomic Research
- Calcium Products, Inc.
- Iowa State University Extension
- Iowa State University Research Farms
- Iowa State University FARM

Photo from B. Lang, ISU