Sulfur: More than Rate and Timing: Choose the Right Source Too

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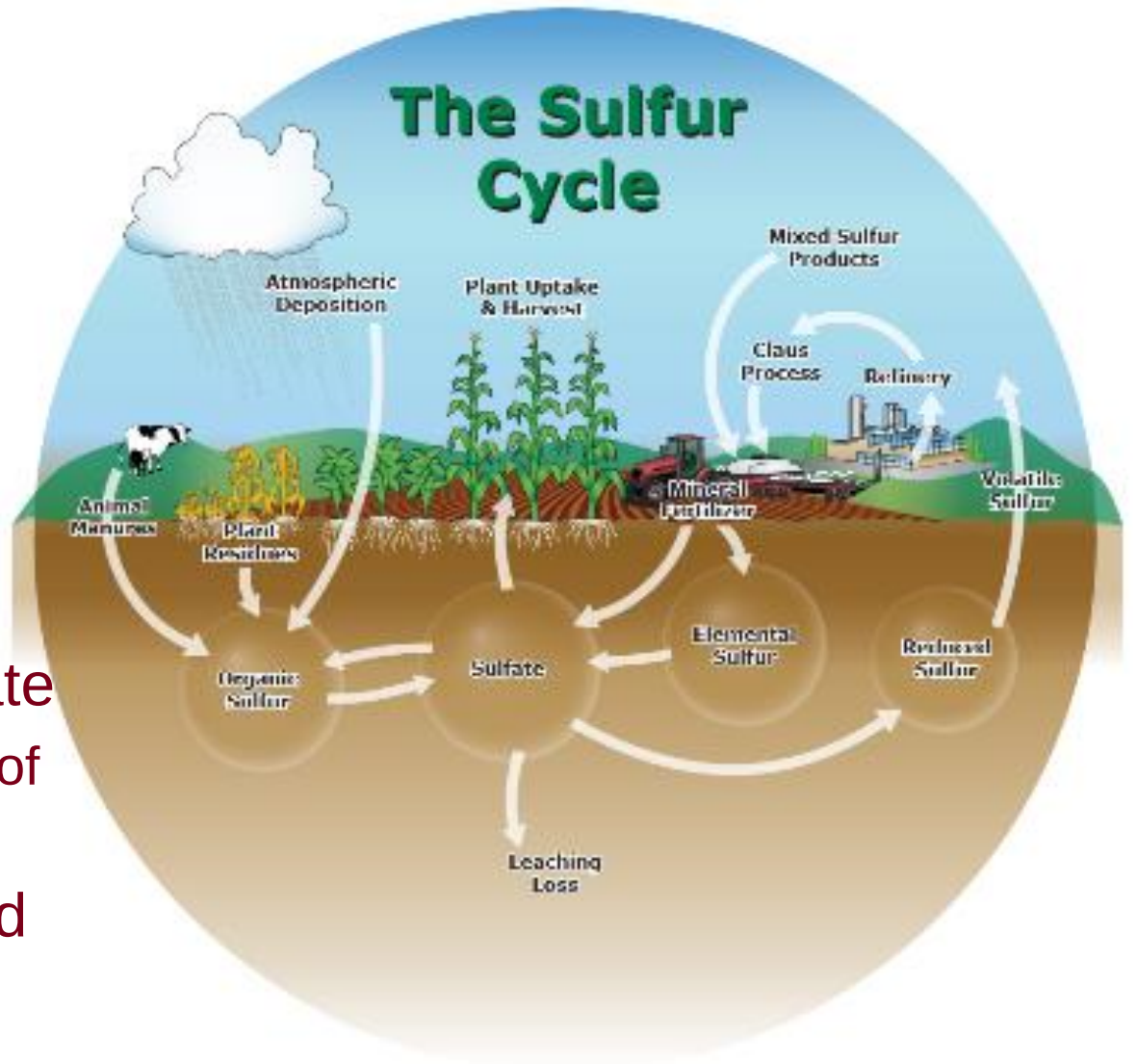
SOURCE OF SULFUR

- Sulfur is taken up as sulfate
- Fertilizers may contain
  - Sulfate
  - Elemental Sulfur
  - Thiosulfate
- Elemental sulfur must be oxidized to sulfate
  - Depends on temperature, soil moisture, size of particles
- Soil organic sulfur needs to be mineralized
- Manure availability is not well known (~65% available?)

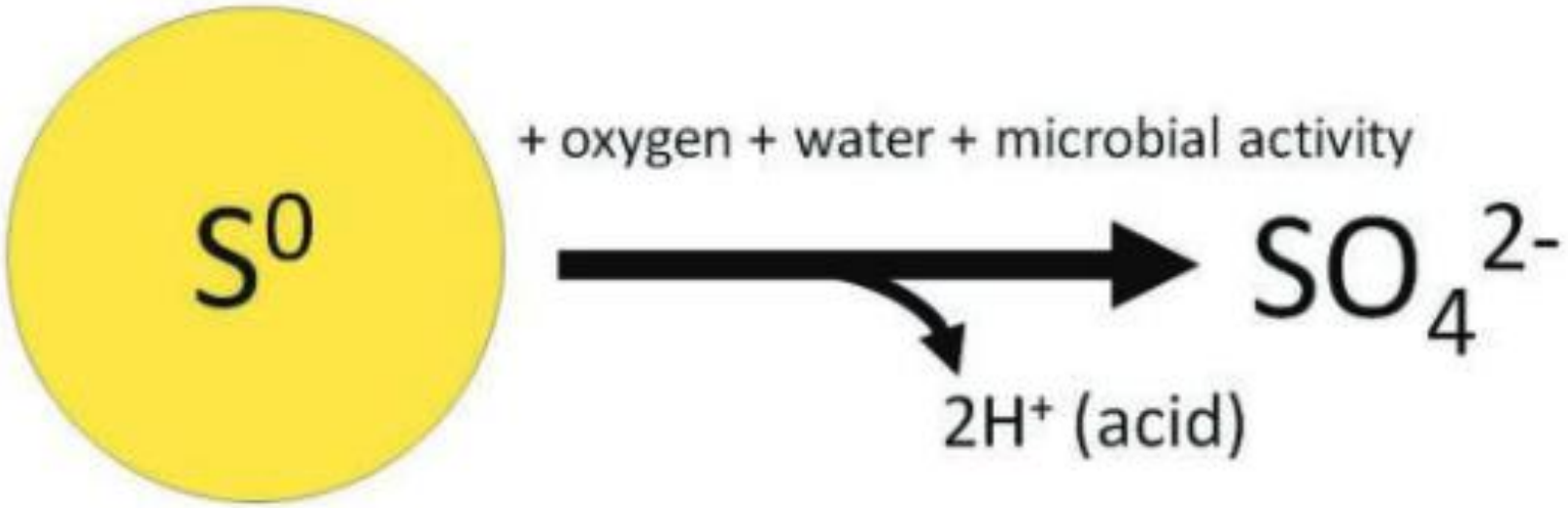


WHY THE INCREASE IN ELEMENTAL S PRODUCTS?

There are literally mountains of elemental S out there

https://www.businessinsider.com/there-are-mountains-of-sulfur-growing-in-the-oil-sands-just-waiting-for-demand-to-increase-2012-4

WHAT HAPPENS WHEN ELEMENTAL S IS OXIDIZED



https://sciences.adelaide.edu.au/fertiliser/system/files/media/documents/2020-01/factsheet-oxidation-of-elemental-sulfur-in-soils.pdf

Optimum temperature ~90 ^oF

PARTICLE SIZE MATTERS

- Larger sized particles have less surface area for oxidation to occur
- The majority of products have particle sizes between 40 and 75 um
- Soil dispersion of the material is important
- Elemental sulfur is hydrophobic and will not dissolve in water
- Incorporation of material into the soil can limit dispersion

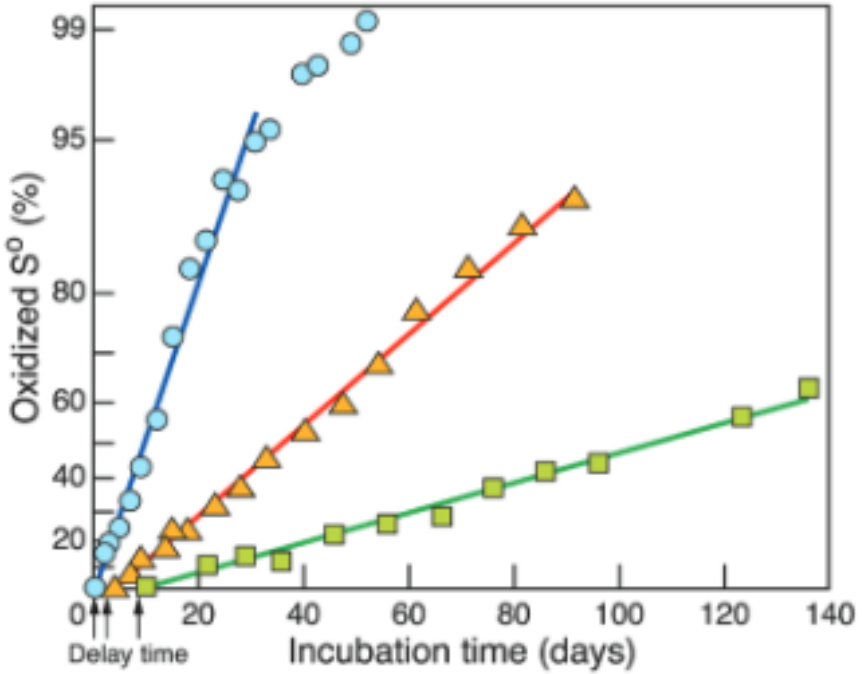


Figure 3. Effect of elemental S (S°) particle size on the rate of oxidation in soil at 30°C and where particles were dispersed throughout the soil (Watkinson and Blair 1993). ○ - 38-75 µm diameter, △ - 125-150 µm, and □ - 212-250 µm.

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SOURCE OF SULFUR'S IMPACT ON CORN YIELD

2022

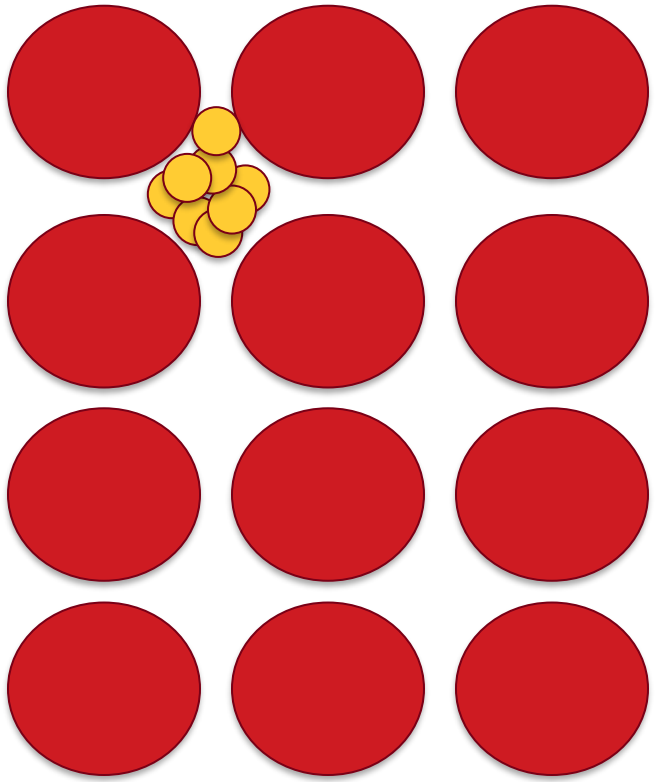
Site	Control	K-Sulfate	K-MST	Tiger 90
	bushels per acre at 15.5%			
Becker	186	187	181	192
Morris	195	192	201	202
Rosemount	160c	206a	196ab	191b
Waseca	110c	159a	149b	149b

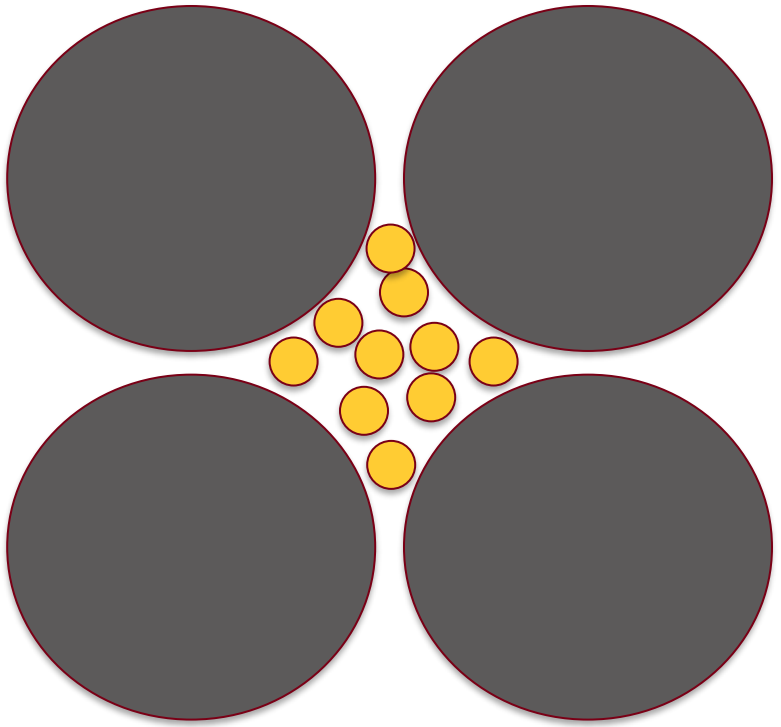
4-year average

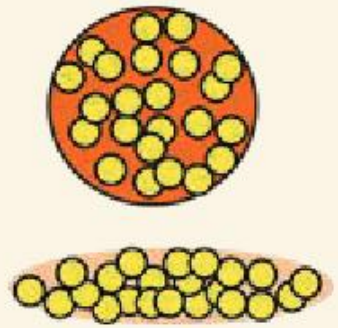
Site	Control	K-Sulfate	K-MST	Tiger 90
	bushels per acre at 15.5%			
Becker	197	200	196	197
Morris	201	201	200	203
Rosemount	186b**	207a	207a	201a
Waseca	119c**	177a	174a	153b

- Source responses at Rosemount and Waseca
  - Typically Sulfate = MST > Tiger 90 > control (Tiger 90 = other S at Rosemount)
  - Year x source interaction were significant at Rosemount and Waseca
- Tiger 90 seemed to get better at providing S over time at Rosemount but not at Waseca.
  - Tiger 90 could increase yield ~ 2/3 that of sulfate or MST

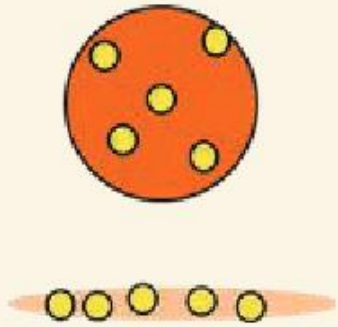
DISPERSION OF ELEMENTAL S WITHIN SOILS







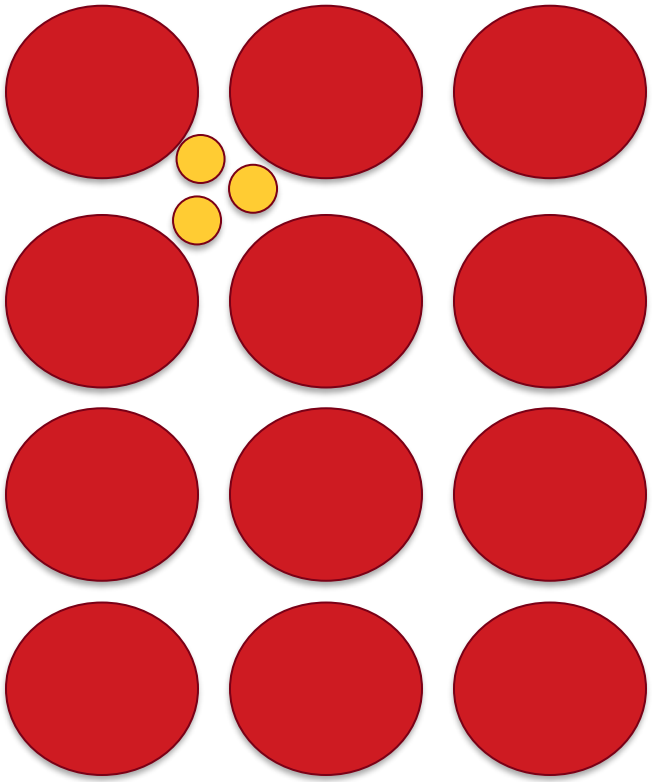
(a) Soluble nutrients (N, P) diffuse out and granule collapses. Not all S^0 particles are exposed to the soil (some surface is "masked") – oxidation slow

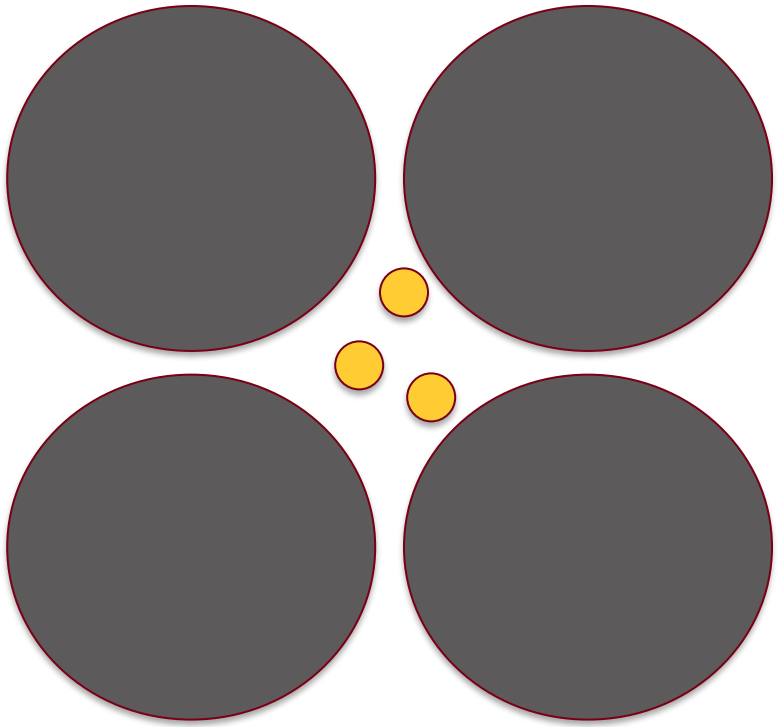


(b) Soluble nutrients (N, P) diffuse out and granule collapses. Because of the lower S^0 content, the surface of all particles is exposed– oxidation fast

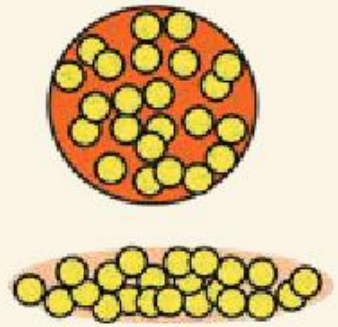
https://sciences.adelaide.edu.au/fertiliser/system/files/media/documents/2020-01/factsheet-oxidation-of-elemental-sulfur-in-soils.pdf

DISPERSION OF ELEMENTAL S WITHIN SOILS





Reducing the amount of elemental S in a granule can greatly increase the potential for oxidation.



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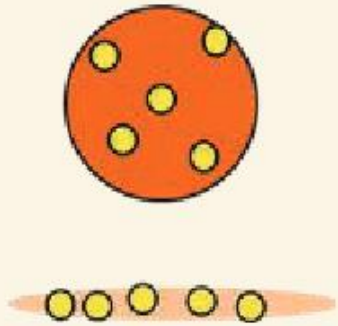

(b) Soluble nutrients (N, P) diffuse out and granule collapses. Because of the lower S^0 content, the surface of all particles is exposed– oxidation fast

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FORAGE YIELD RESPONSE TO S

ROSEMOUNT LTS ALFALFA TRIAL

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2020-2021: 2 cuttings

Sulfur	Source of Sulfur			
Rate	Control	K_2SO_4	K-MST	Rate AVG
lb/ac	Alfalfa forage Yield - lbs per acre			
10	5944	6859	6624	6476
20	5710	7518	7076	6768
30	5981	6817	6752	6517
Source Avg.[1]	5878b	7065a	6818a	

+1064 lbs Forage with S
@$150/ton returns ~ $80/ac
@$0.50/lb S and assuming $6/ac spreading
10 lbs S returned ~ $69/ac

2021-22: 4 cuttings

Sulfur	Source of Sulfur			
Rate	Control	K_2SO_4	K-MST	Rate AVG
lb/ac	Alfalfa forage Yield - lbs per acre			
10	12751	16047	15703	14833b
20	13328	16648	16572	15516ab
30	13383	16951	16951	15803a
Source Avg.[1]	13154b	16548a	16450a	

+3345 lbs Forage with S
@$150/ton returns ~ $251/ac
@$0.50/lb S and assuming $6/ac spreading
20 lbs S returned ~ $235/ac

10-20 lbs S returned ~ $304/ac over 2 years

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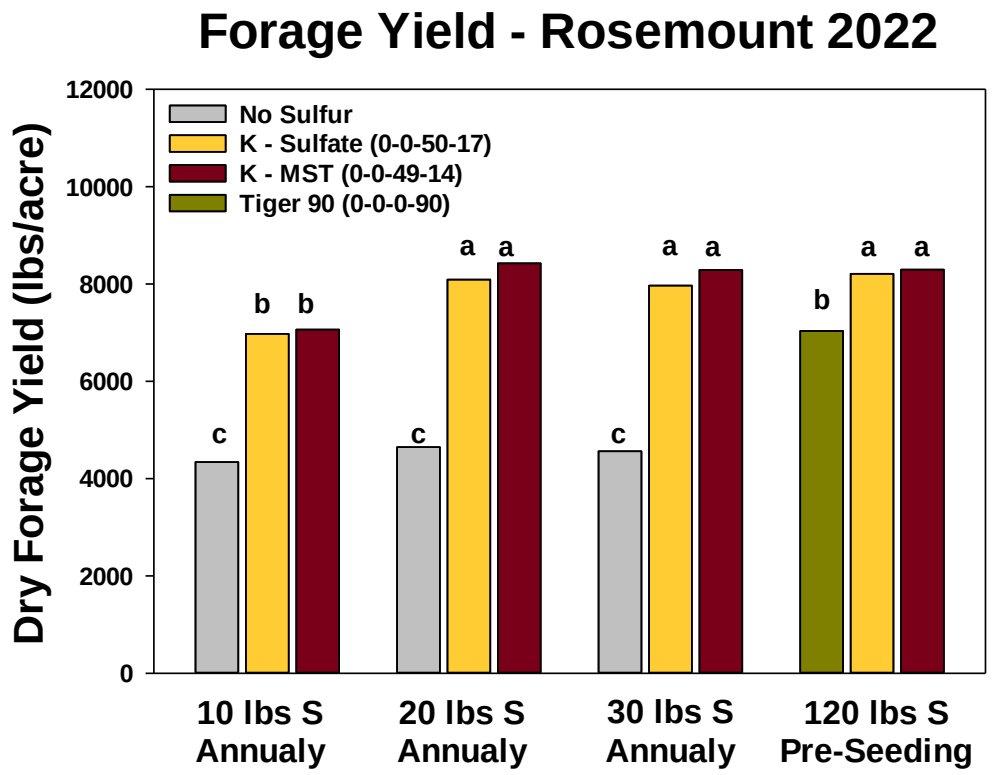
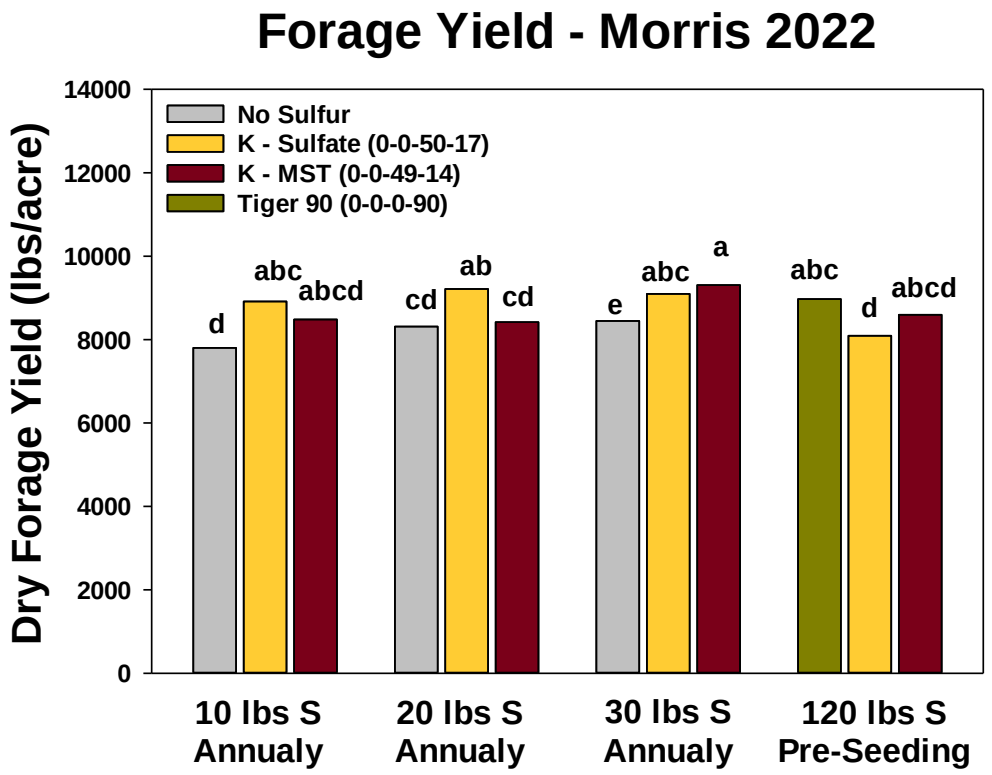
DRY FORAGE YIELD BROKEN DOWN BY SULFUR APPLICATION

LTS ALFALFA TRIAL

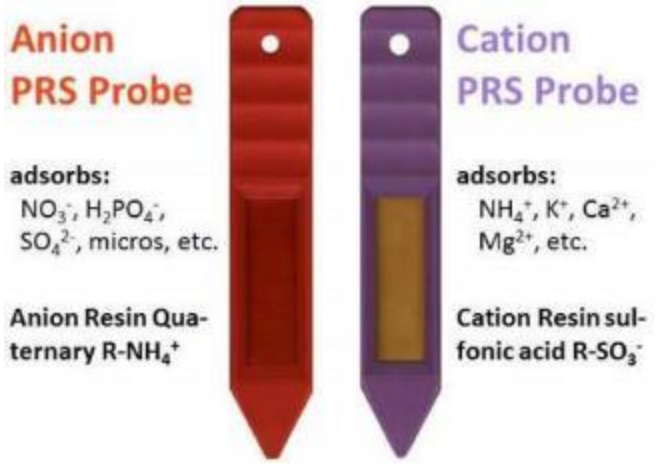
2022: 3 cuttings (2-4) - Rosemount



2022: 3 cuttings (2-4) - Rosemount



PLANT SULFUR SUPPLY



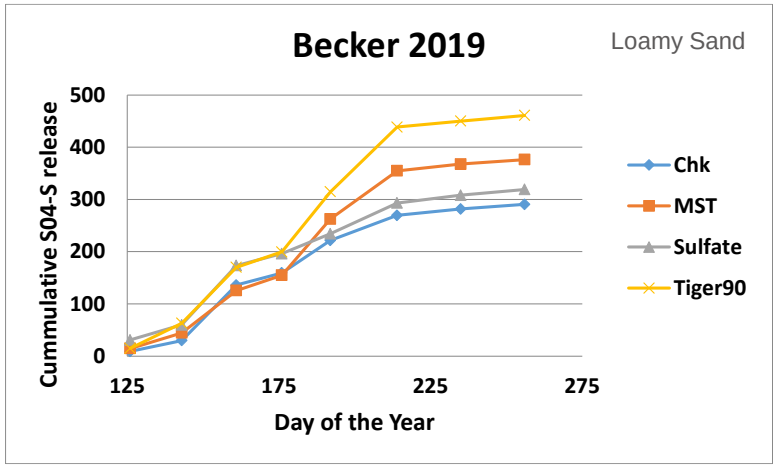
PRS Probes: Western Ag. Innovations, Saskatoon SK

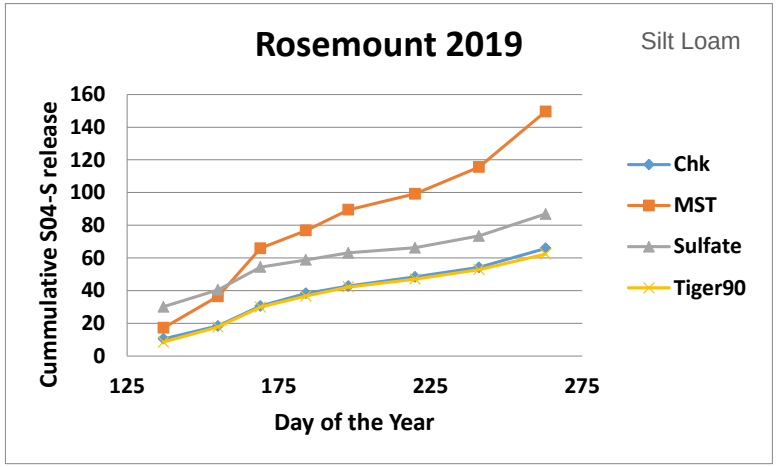
P>F

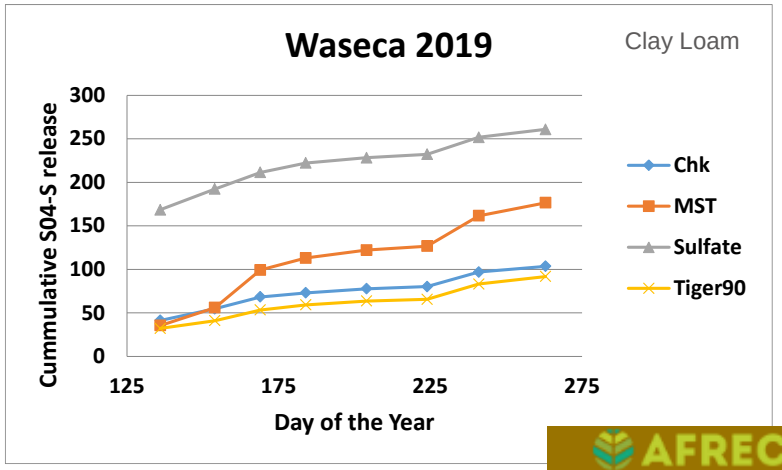
Becker
Time = <0.001
S Source =0.24
Time x Source = 0.05

Rosemount
Time = <0.001
S Source =0.05
Time x Source <0.01

Waseca
Time = <0.001
S Source < 0.001
Time x Source <0.001







Units are given as Micrograms S $10cm^{-2}$ $10cm^{-1}$

Data are collected from the 10 lb S application rates

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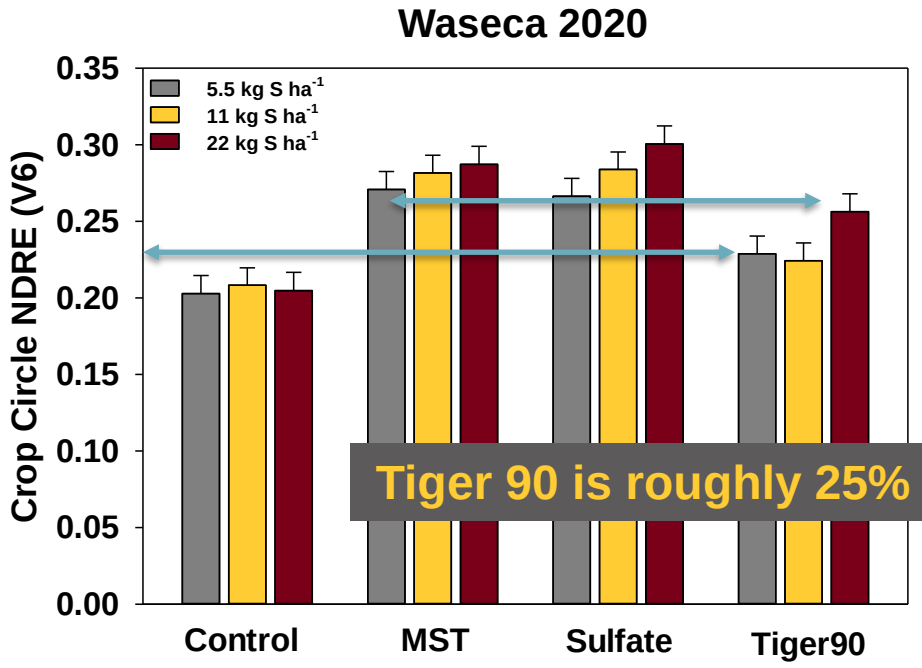
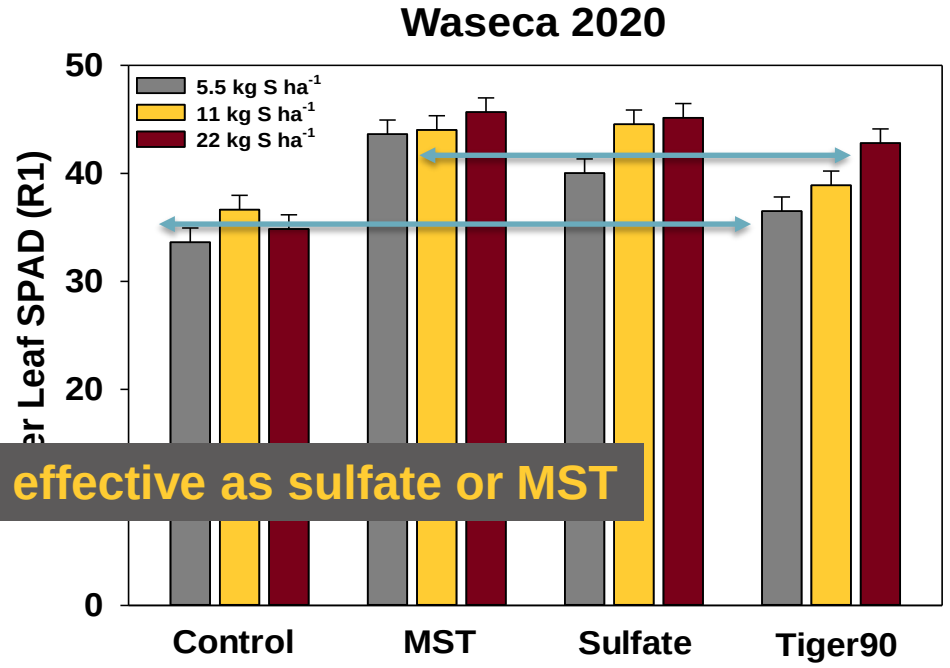
ARE ALL ELEMENTAL S PRODUCTS EQUAL?

- Concentration of elemental S in the material is important when it comes to dispersion of material within the soil
- Particle size dictates oxidation rate after dispersion (Degryse et al., 2016)
  - Tiger 90 – Ranges from 30-130 um, estimated median 60 um
  - Microessentials S10/S15 - Ranges 25-100 um, estimated median 56 um
    - Microessentials also contains ammonium sulfate (AMS)
  - MST (Sulvaris/Nutrien) ~ Ranges from 1-15 um, granular products average 15 um
- For co-granulated products the carrier material can also impact availablity due to differences in dissolution of the product in the soil
  - P based fertilizers like MAP or DAP do not dissolve quickly

CORN GROWTH AND GREENNESS

- No consistent impact of S on plant greenness at Becker and Morris in 2020
- MST was generally not as effective as sulfate in 2019
  - More comparable to sulfate in 2020
- Rosemount results are similar to Waseca results shown





Tiger 90 is roughly 25% as effective as sulfate or MST

P>F

V6
S Rate = 0.05
S Source < 0.001
Rate x Source = 0.05

R1
S Rate = 0.01
S Source < 0.001
Rate x Source = 0.03

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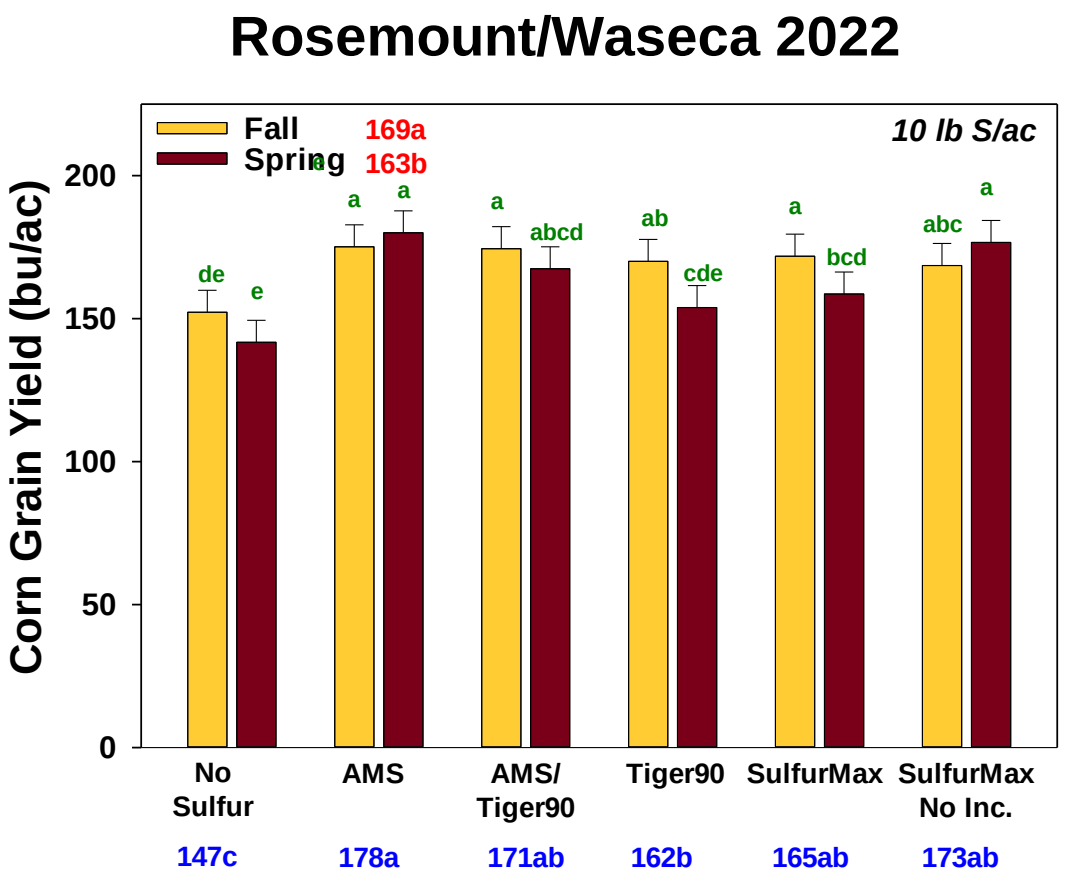
FALL VERSUS SPRING APPLICATION



- The sulfate anion will leach in soils
- Sulfate tends to leach at a slower rate than nitrate
- Elemental S is typically what I find most growers go to for fall application
  - Availability is an issue
- Data isn't always straightforward on effects of timing
  - High application rates make timing less critical even with sulfate
- Products like Tiger 90 may be better not incorporated in the fall
  - P and K are better incorporated if you can

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RATE OF SULFUR'S IMPACT ON CORN YIELD

2022

Site	5 lbs S	10 lbs S	20 lbs S
	bushels per acre at 15.5%		
Becker	177	192	190
Morris	200	202	190
Rosemount	181b	179b	205a
Waseca	133b	142ab	150a

4-year average

Site	5 lbs S	10 lbs S	20 lbs S
	bushels per acre at 15.5%		
Becker	189b	200a	202a
Morris	201	201	202
Rosemount	197b@	195b	209a
Waseca	147b@**	157a	162a

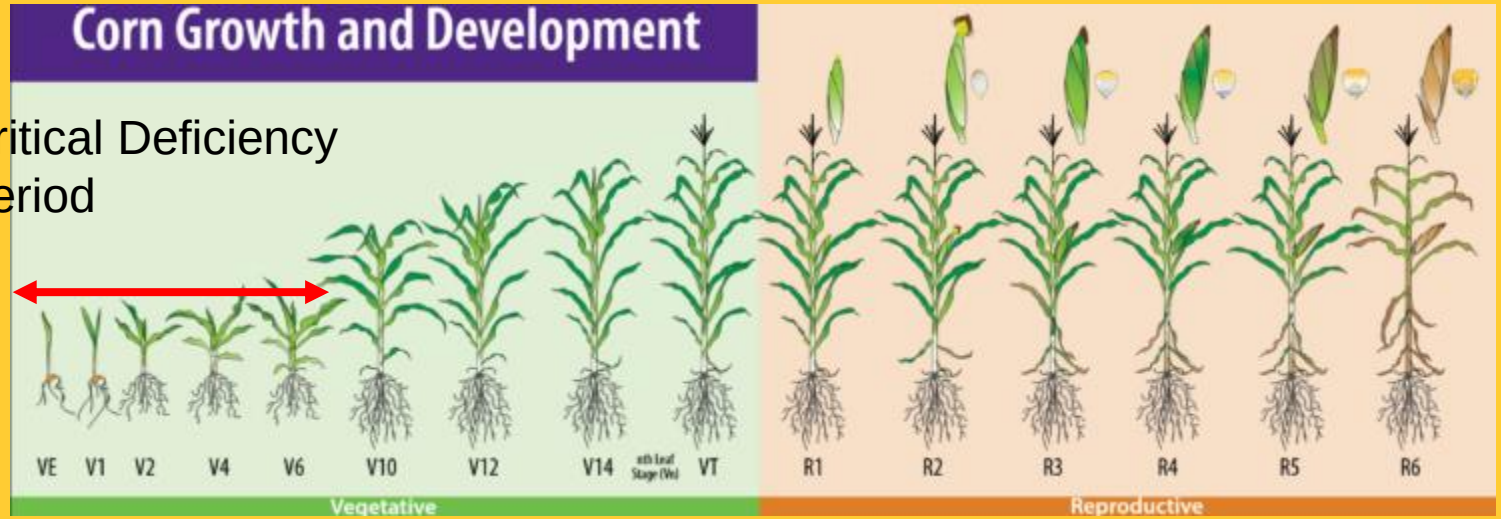
- Rate of sulfur application has consistently differed at Becker and Waseca
  - Rate x year interaction was significant at Waseca – less S was needed in early years compared to later.
  - Rate x source interaction was significant at Rosemount and Waseca

PUTTING IT ALL TOGETHER

- The availability of elemental S from Tiger 90 can range from 25-100% the year it is applied
  - Higher clay soils present a greater problem for oxidation of elemental S
- Elemental sulfur in co-granulated products appear to have similar effectiveness as sulfate
  - Potassium and ammonium sulfate have similar availabilities
  - Gypsum products can vary in solubility but most of the time they should be 100% available
- A product like Tiger 90 needs some additional thought on how to manage the product
  - If it takes 4x the product, is it economically feasible?
- Low rates of sulfate applied in the spring can be highly effective at increasing corn grain yield

ELEMENTAL S OXIDATION – LONG TERM

Year 1



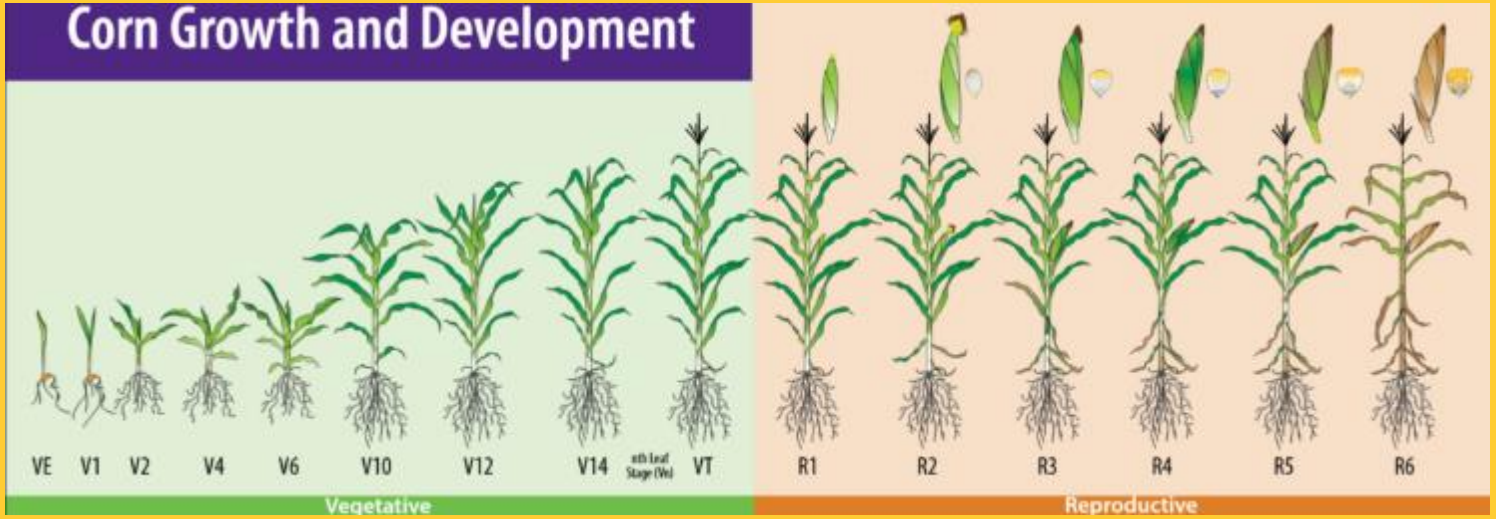
Critical Deficiency Period

Soil SO4-S

Application of Elemental S

Mineralization increases
Oxidation increases

Year 2



Soil SO4-S

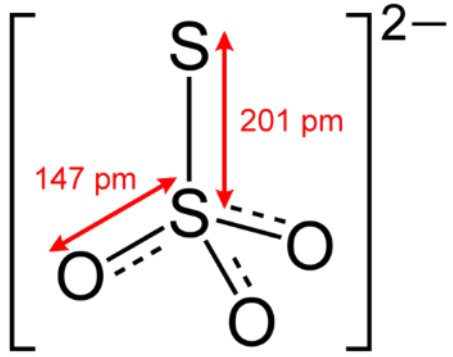
Application of Elemental S
Carried over Sulfate-S

Mineralization increases
Oxidation increases

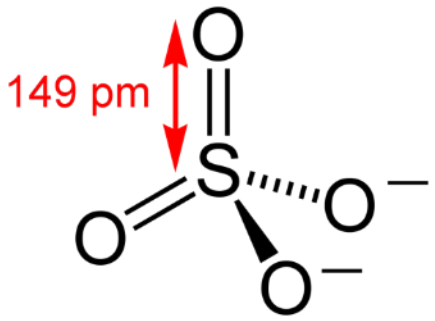
ELEMENTAL S STRATEGIES FOR USE

- Elemental S must be broken down into smaller particles before it can be effectively oxidized
- Likely more effective to not incorporate sulfur+bentonite products if applying in the fall to allow for the bentonite in the product to absorb water, swell, and disperse the elemental S
  - Surface application without incorporation is not ideal for fall fertilizer application, particularly on sloping ground or situations where water is more likely to move rapidly off a field
- Oxidation of elemental S in co-granulated products is limited by the particle size of the elemental S and will not be greatly impacted whether the material is incorporated or not.

THIOSULFATE IS PART ELEMENTAL S BUT IT IS NOT THE SAME AS GRANULAR FERTILIZER



- Thiosulfate Ion is not plant available
- Thiosulfate is in solution
- Dissociates into elemental S and Sulfate ions



Sulfate Ion is plant available

CORN GRAIN YIELD DATA BY SOIL ORGANIC MATTER LEVEL – CONTINUOUS CORN

	Low (<4.0% SOM)				High (>4.0% SOM)			
S Rate	AMS-Br	ATS-Br	ATS-Ba	Avg.‡	AMS-Br	ATS-Br	ATS-Ba	Avg.‡
-lb S/ac-	----------bu/ac----------							
0	227	226	229	227b	212	211	209	211c
2.5	230	231	221	227b	214	213	216	215bc
5.0	231	228	232	**230ab**	221	215	217	**217ab**
10.0	231	233	231	**231ab**	215	221	212	**216b**
20.0	231	237	228	**232a**	224	216	223	**221a**
Avg.‡	230ab	231a	228b		217	215	216	

† Sulfur source: ATS-Ba, Ammonium thiosulfate banded; ATS-Br, ammonium thiosulfate broadcast; AMS-Br, ammonium sulfate broadcast.

‡ Avg., treatment mean; within rows and columns, numbers followed by the same letter are not significantly different at the P≤0.05 probability level.

ACIDIFICATION CAN OCCUR FOLLOWING SULFUR APPLICATION

Table I. Lime required to neutralize the soil acidity produced by fertilizers if all ammonium-N is converted to nitrate-N.

Nitrogen source	*Composition*	*Lime required (lb $CaCO_3$/lb N)*
Anhydrous ammonia	82-0-0	1.8
Urea	46-0-0	1.8
Ammonium nitrate	34-0-0	1.8
Ammonium sulfate	21-0-0-24	5.4
Monoammonium phosphate	10-52-0	5.4
Diammonium phosphate	18-46-0	3.6
Triple super phosphate	0-46-0	0.0

Adapted from Havlin et al., 1999.

https://extensionpublications.unl.edu/assets/html/g1503/build/g1503.htm

Sulfur sources

- 3 lb CaCo3 / 1 lb S
- Thiosulfate is less than elemental S
- Calcium and potassium sulfate are neutral salts and will not affect pH
- With more S being applied soil pH should be monitored and lime application may be required
  - Strongly buffered high pH soils should not be impacted

DO YOU NEED TO APPLY SULFUR IF YOU ARE APPLYING MAP OR DAP?

- Sulfuric acid is used to treat rock phosphate in order to create P fertilizer and can leave S as an impurity in MAP or DAP
- MAP and DAP will contain roughly 1-3% total S which is not accounted for on the fertilizer analysis
  - This sulfur is available
  - Liquid fertilizer vary considerably in S contamination
    - Low salt sources have less S

Total Sulfur content of Some P Fertilizers

Nitrogen source	*Composition*	*Total S content (%)*
Triple Superphosphate	0-46-0	1.8, 1.9
MAP	10-52-0	1.8, 2.2, 1.8
DAP	18-46-0	1.2, 1.5
Liquid	3-18-18	0.009, 0.01
Liquid	6-24-6	0.06, 0.8
Liquid	10-34-0	0.84
Liquid	9-18-9	0.05

Total S in solid fertilizer tested using dry combustion analysis
Total S in liquid fertilizers measured directly via ICP
Source: Kaiser 2022


P-K-S Study Red Wing, MN 6/23/15
No P or S
167 bu/ac
+ P No S
210 bu/ac
+ S No P
218 bu/ac
+ P & S
235 bu/ac
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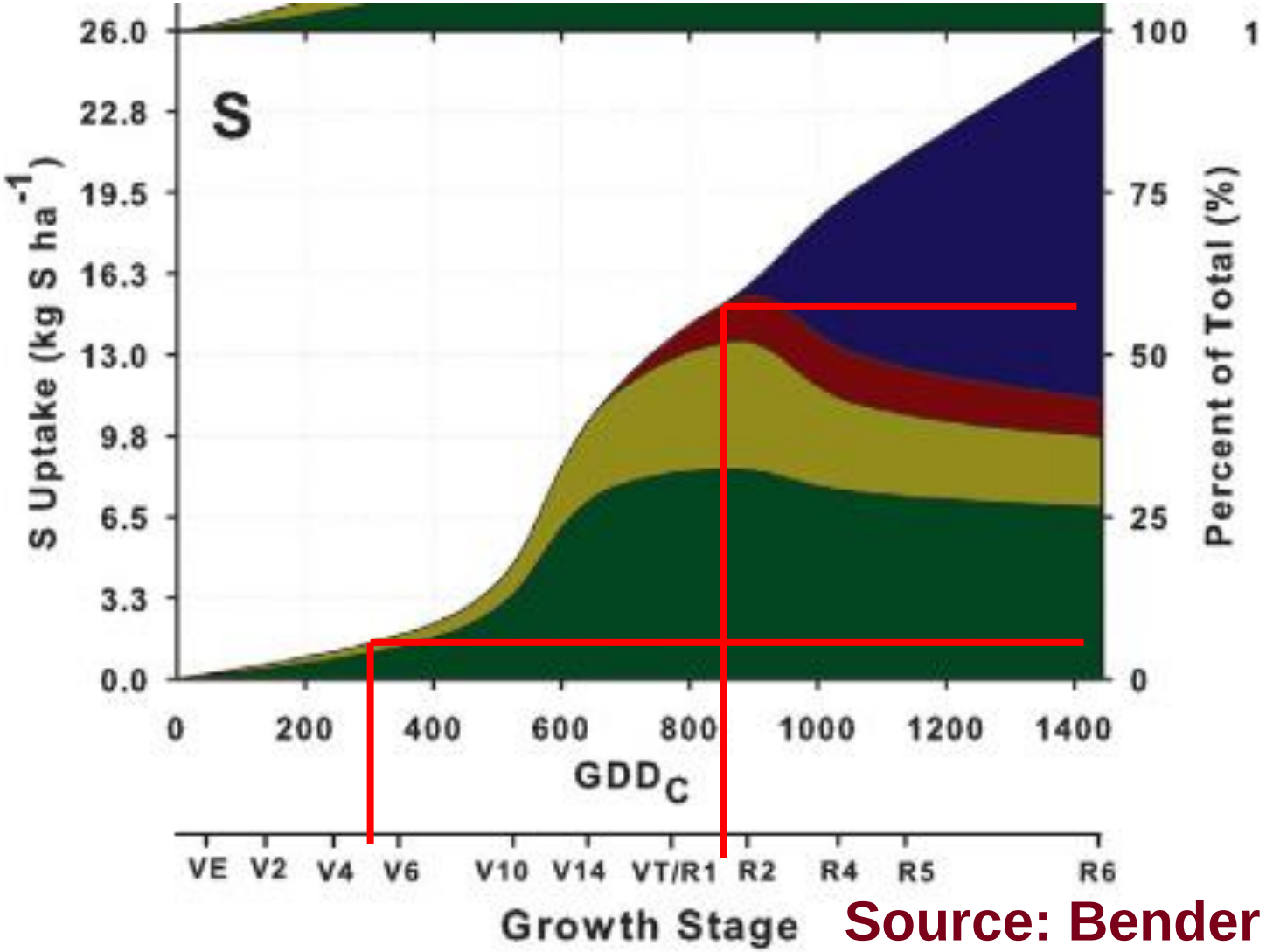
WRAPPING UP

- The more MAP or DAP applied the less likely you need to be worried about applying high rates of sulfur
  - Removal rates of P will likely apply around 5 lbs of S due to S impurities
- Elemental sulfur as Tiger 90 will likely be less effective for high clay soils
  - Even long-term I doubt you will see much more than 25-33% of the product oxidized
- The co-granulated products seem to be a good choice if a grower wants to use elemental S, but at what cost?
  - Stick to the lower end of the suggested S application rate window (~10 lbs)
- ATS is a good option as well
- The good news is there are several options when applying S!

Key Growth Stages for Sulfur Uptake in Corn



~40%
Of total
uptake

~50%
Of total
uptake

~10%
Of total
uptake

Source: Bender et al., 2013

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http://z.umn.edu/nutrientmgmt