Dr. Goos' Greatest Hits….or… An overview of my research over the past 40 years

R. Jay Goos

North Dakota State University

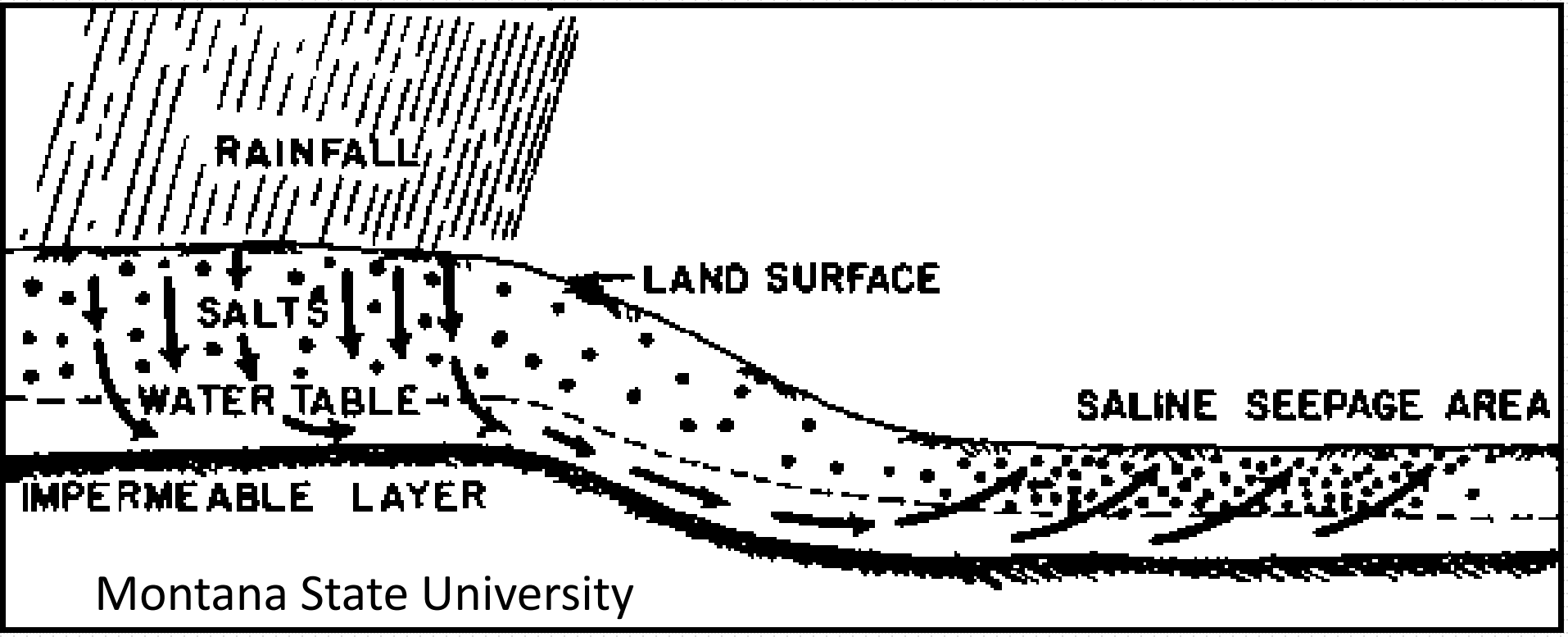
- 1980….
  - A peanut farmer was President, you could still buy a Ford Pinto…..and I arrived on the NDSU campus

So, a lot has changed

- So, looking back at the last 40 years, what were some of the things I studied?
- “Recrop”
- Chloride
- Tillers
- Inhibitors
- Ureides
- IDC

- “Recrop”
- What was the #2 “crop” in North Dakota in 1980?

- 1980…..saline seeps were of great concern in western ND and eastern MT



- Objective, come up with nitrogen and water management recommendations for farmers transitioning away from spring wheat-fallow rotation in western ND

- Water-based decision tools
- Nitrogen management

If 20 bu/A was the criterion for ‘success’, < 2.5“ SSW at planting, you should fallow, ≥ 4” SSW you should recrop

But remember….these were dry years, also pre-notill

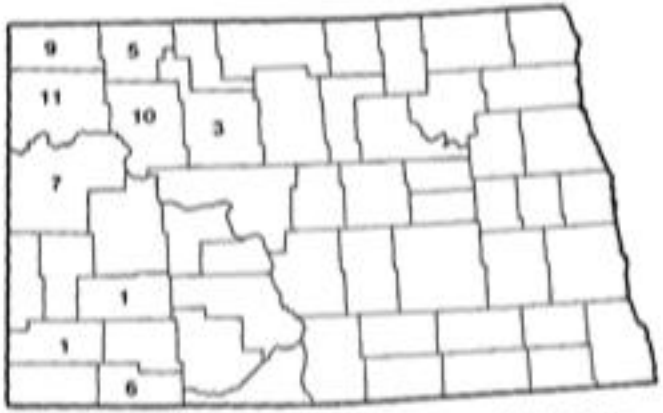


Fig. 1—Distribution of experimental sites by county, North Dakota.

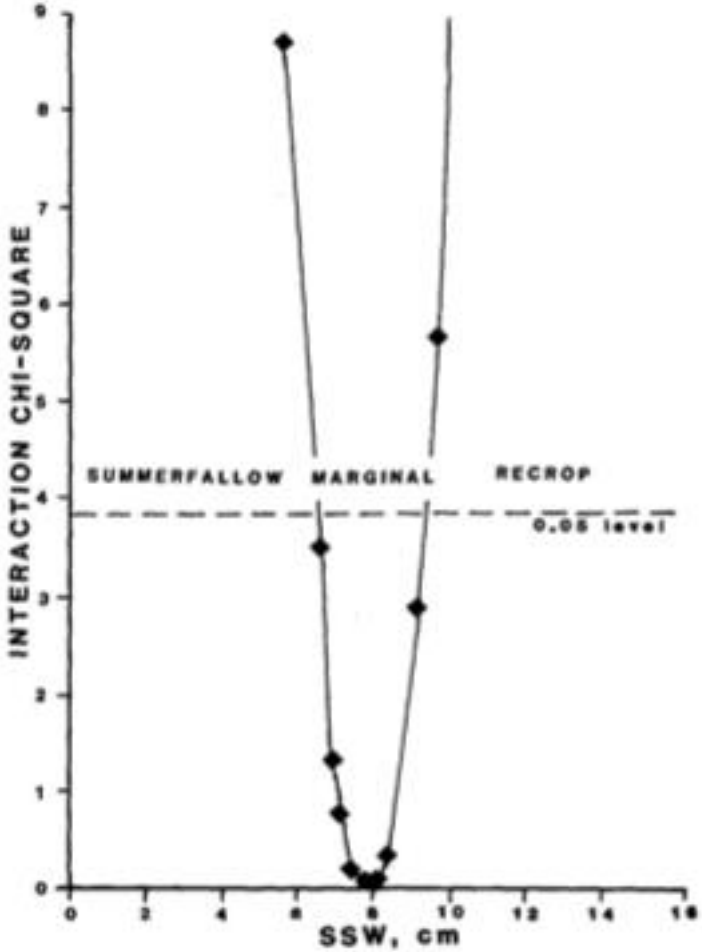


Fig. 5—Interaction chi-square plot used to define soil water and re-cropping guidelines, using a yield of 1350 kg/ha (20 bu/A) as the criteria for success or failure.

- Nitrogen management
- What was the ”N factor”, at the desirable point on the response curve?

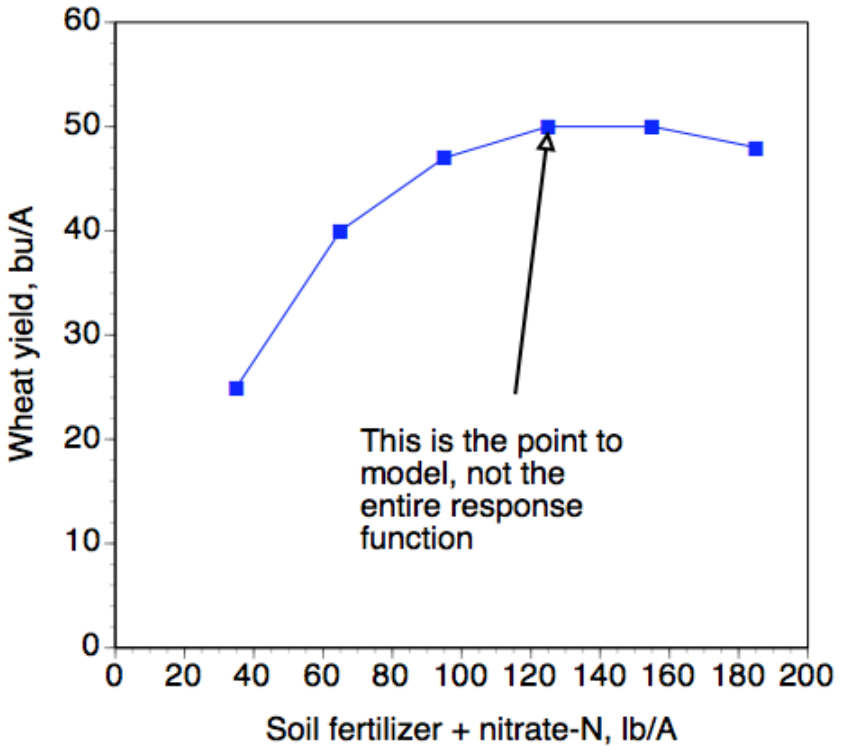


Table 2. Soil plus fertilizer N needs for spring wheat, western ND, 1981-82.

Site	Maximum yield	Minimum soil + fertilizer N needed for maximum yield*	lb N/bu
	bu/A	lb/A	lb N/bu
1982			
Bowbells	17	43	2.5
Fortuna	35	69	2.0
Minot	34	98	2.9
Rawson	35	48	1.4
Stanley	31	95	3.1
Williston E	18	54	3.0
1981			
Stanley	43	104	2.4
Fortuna	18	51	2.8
New Town	26	93	3.5
Dickinson	13	55	4.2
Williston	33	75	2.2
Minot	37	23	0.6
Minot	35	42	1.2
Williston	32	75	2.4
Battleview	35	106	3.0
Average and 95% confidence interval			2.5 ± 0.5

*Initial nitrate-N in top two feet of soil plus fertilizer N. Researchers: Goos, Johnson, Sobolik.

- Using protein as a post-harvest indicator of N sufficiency in HRSW

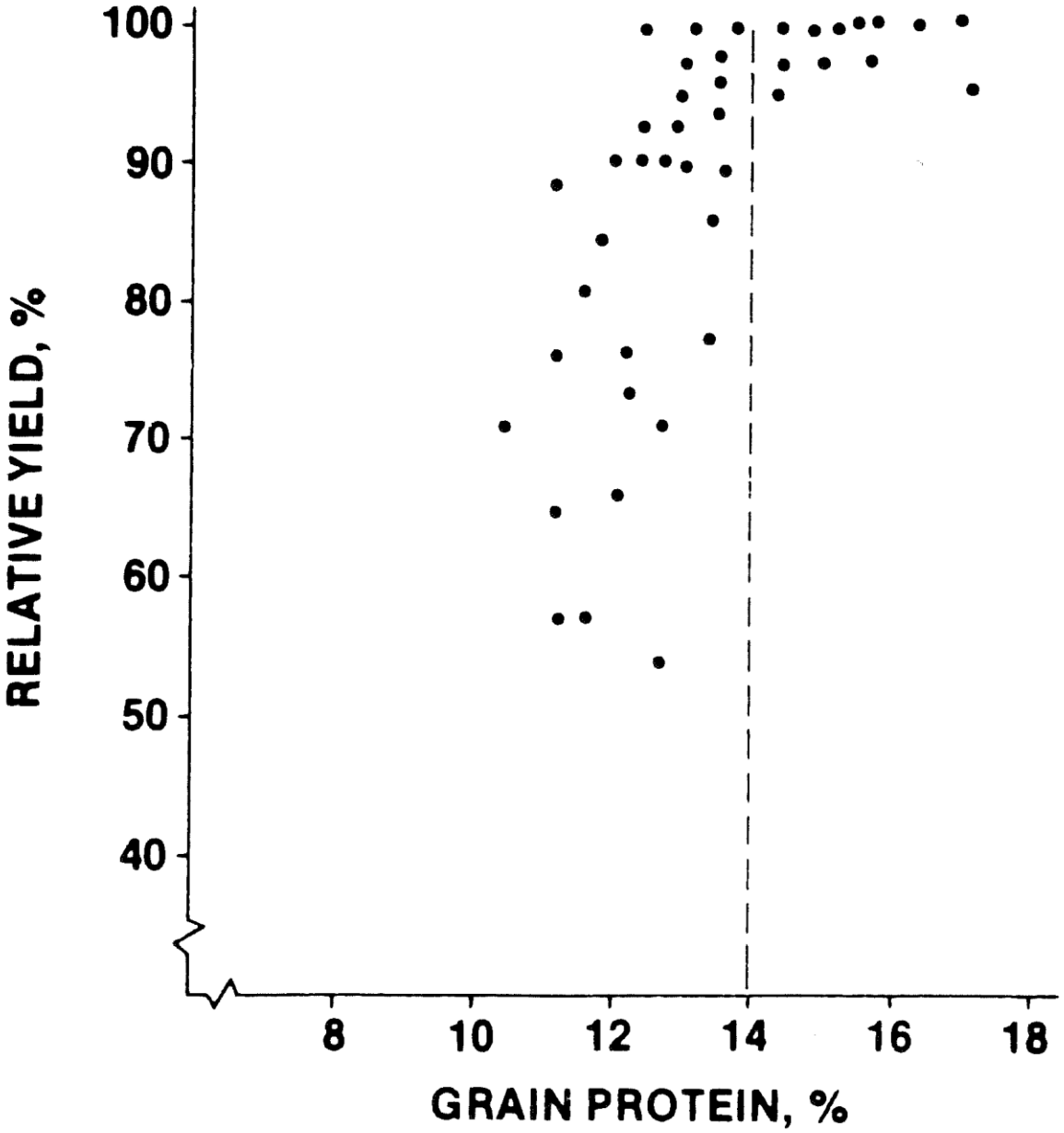
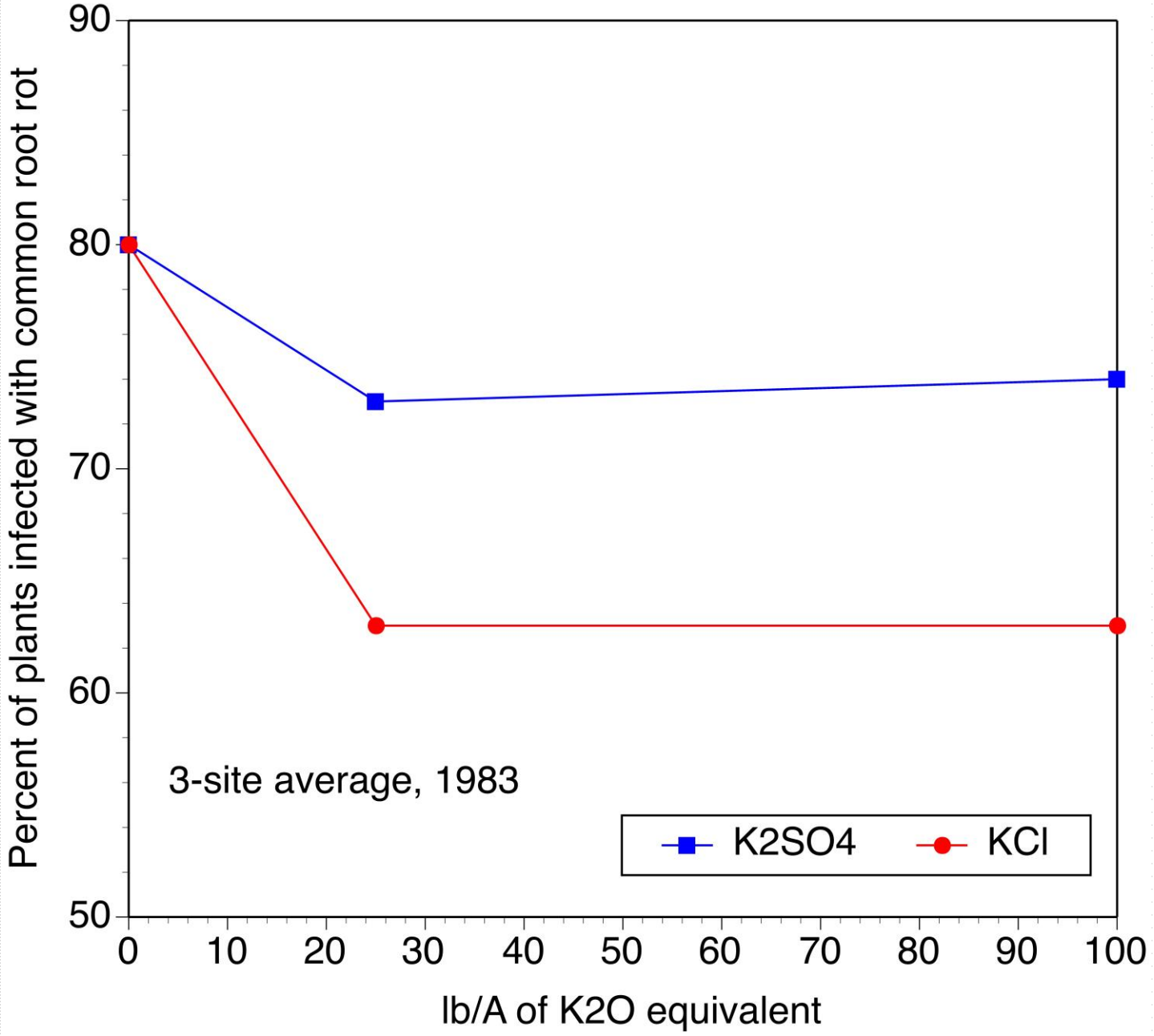
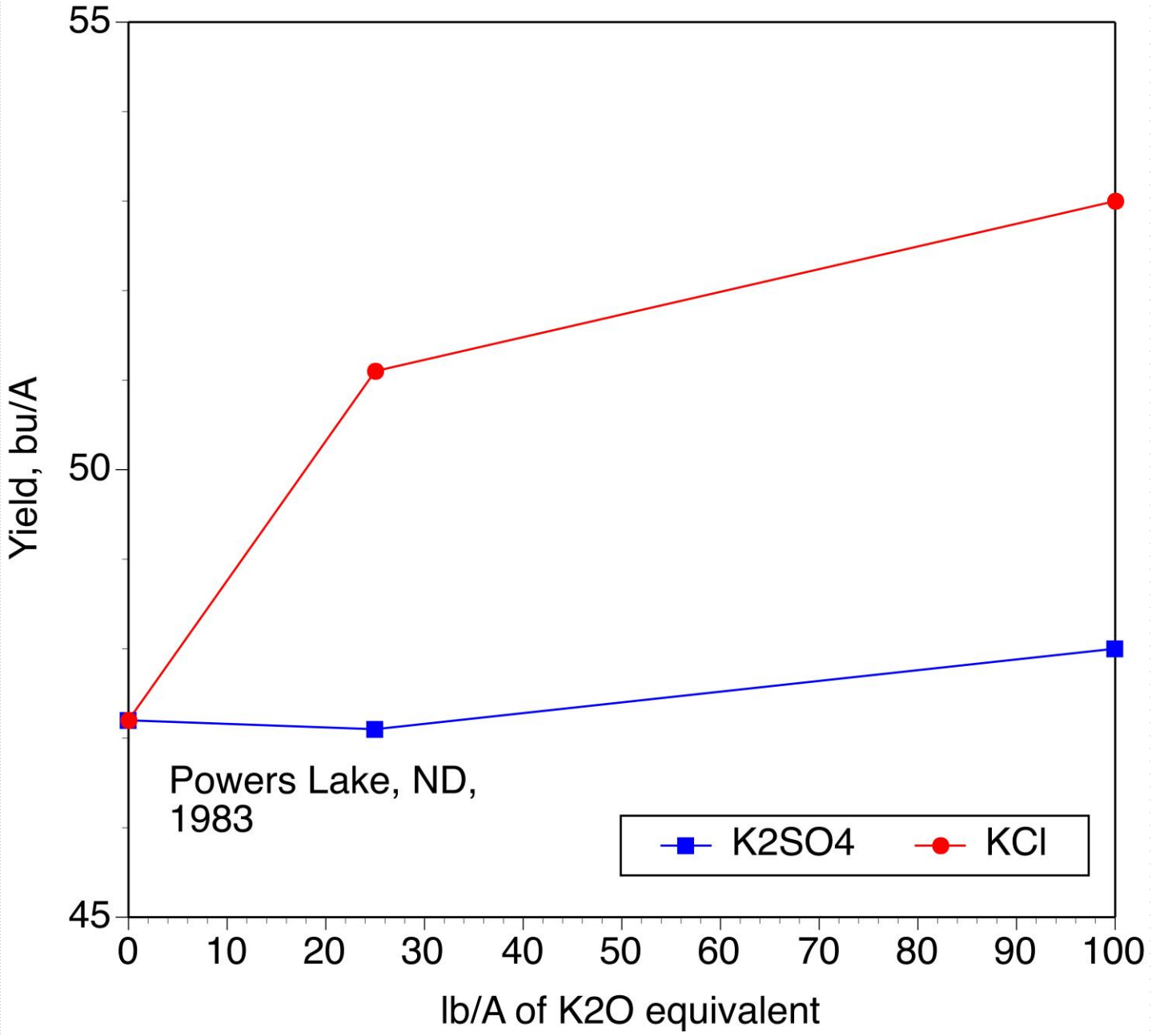


Fig. 2. Relative yields of 'Len' hard red spring wheat as related to grain protein content. North Dakota, 1981–1982.

- Chapter 1…Recrop
- Chapter 2…Chloride
  - North Dakota has a long history of documented “potash” response in barley, on soils high in available K
  - Researchers in PNW, showed chloride responses in winter wheat, especially when infected with take-all root disease
  - Seemed logical to me that our historic “potash” responses in barley were chloride responses, and perhaps there were effects on root diseases

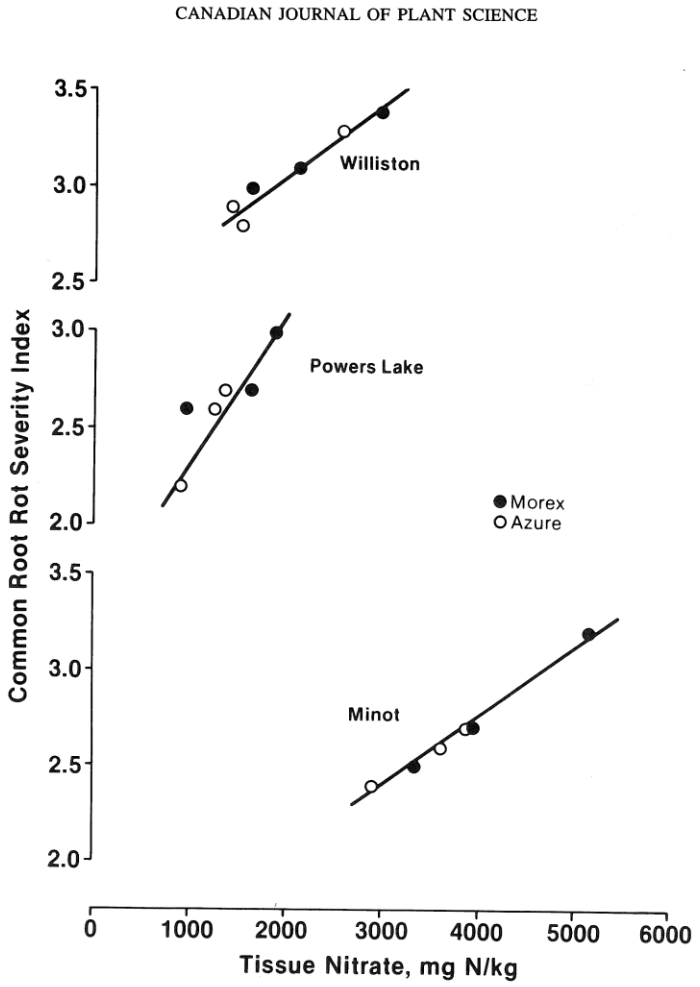
- 1983, three rates of K (0, 25, 100 lb K_2O/A), KCl vs K_2SO_4
- Measured common root rot, grain yield


Percent of plants infected with common root rot
90
80
70
60
50
0
10
20
30
40
50
60
70
80
90
100
lb/A of K2O equivalent
3-site average, 1983
K2SO4
KCl


55
50
45
Yield, bu/A
0
10
20
30
40
50
60
70
80
90
100
lb/A of K2O equivalent
Powers Lake, ND,
1983
K2SO4
KCl

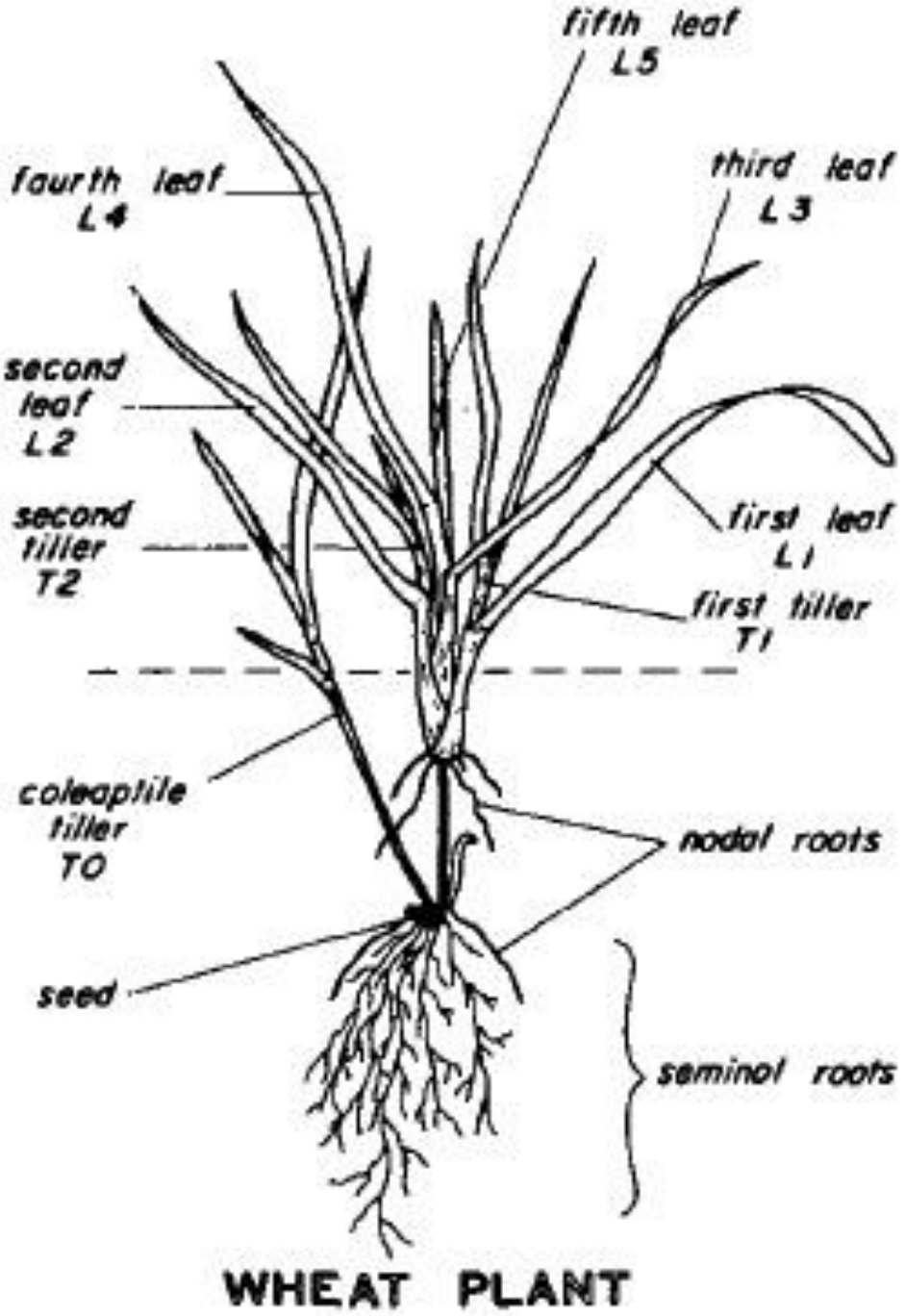
- Subsequent chloride studies
- KCl rates x 2 barley varieties differing in CRR resistance
- KCl vs. seed-applied fungicide for reducing CRR severity in barley
- In both studies, KCl application reduced CRR

- KCl x 2 barley varieties differing in CRR resistance
  - CRR strongly correlated to nitrate content of stems



- Chloride fertilization is accepted now, but it wasn’t at the time

- Chapter 3. Tillers
- In 1985, NDSU flew 5 scientists to the USDA station at Pendleton, OR, to learn from Dr. Betty Klepper



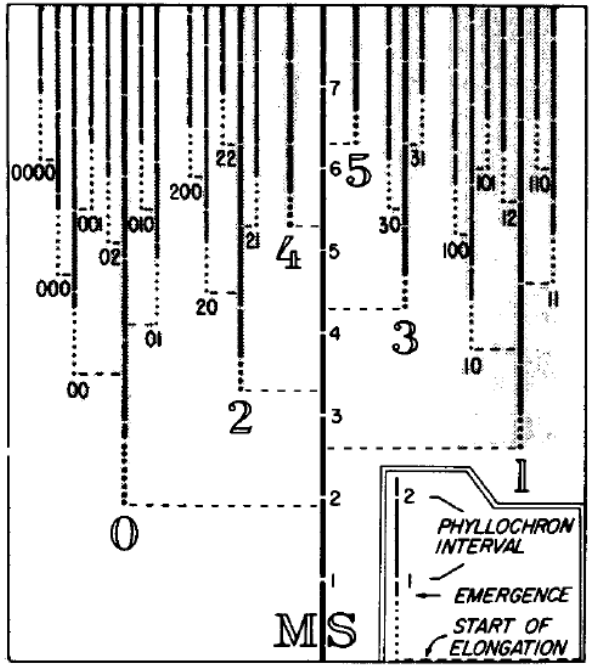
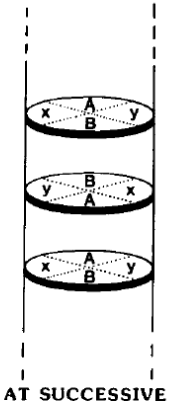


Fig. 2. Relationships of leaf and tiller production in winter wheat based on data for 'Stephens' wheat. The passage of phenological time is measured in elapsed phyllochrons which are numerically equivalent to the main stem Haun stage.

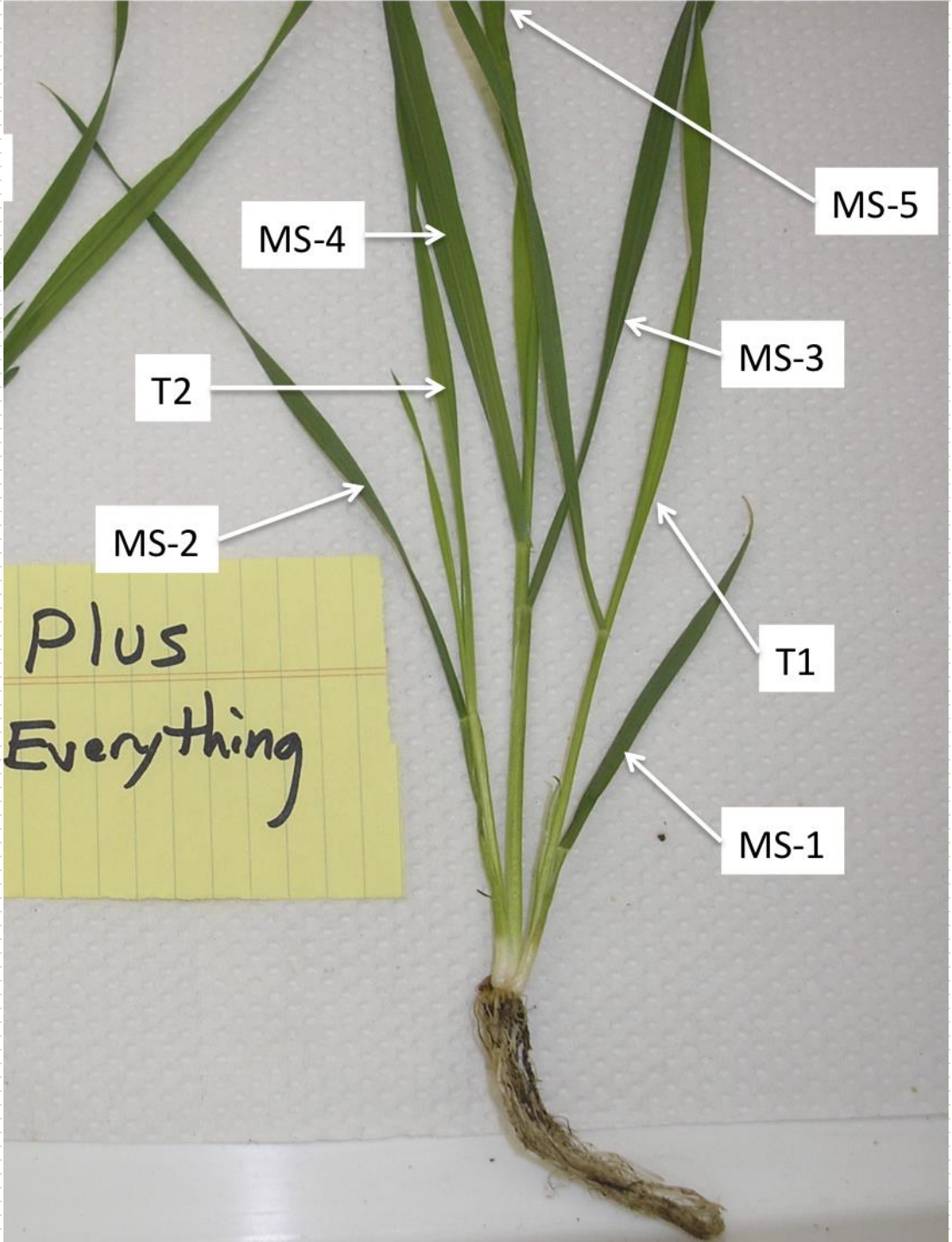


ROOTS AT SUCCESSIVE NODES

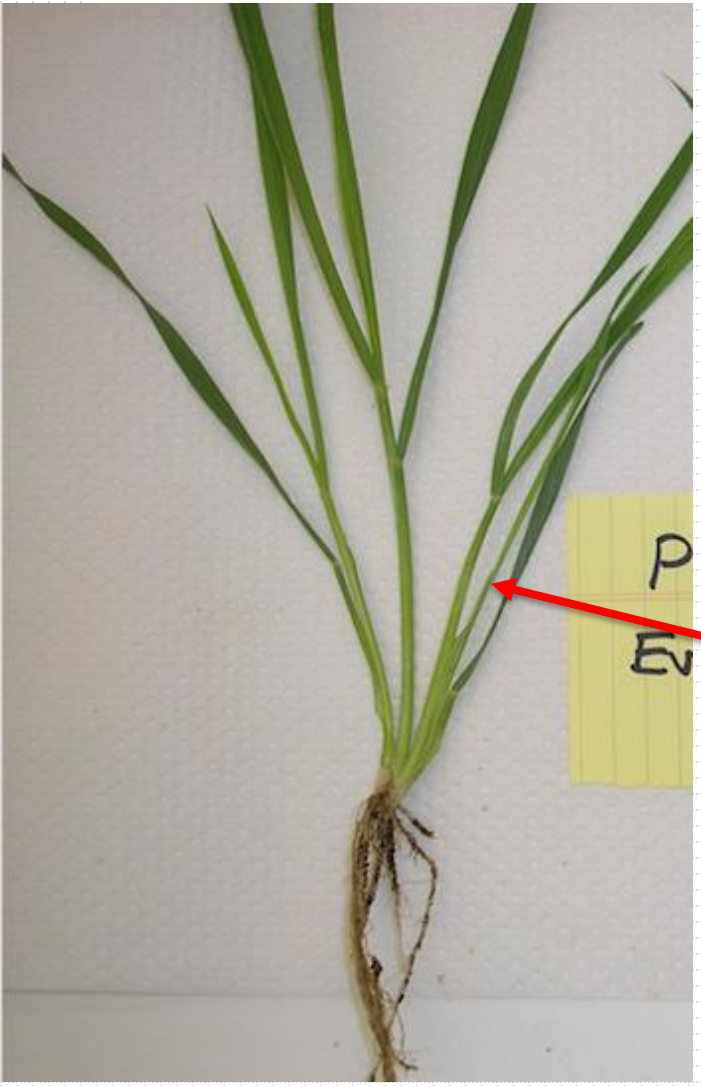
Fig. 1. Orientation of naming quadrants at successive nodes on a plant.

- Since then, use of the Klepper/Haun method of describing plant development has been part of all of my studies with wheat
- Phosphorus studies
  - Starter fertilizers containing P and S
  - Seed inoculation with “PB-50” (JumpStart)
- Nitrogen studies
  - Fall nitrogen/overwinter losses
  - Response to slow-nitrifying fertilizers

- Where does the yield of wheat come from?
- Wheat plants can produce many tillers, which ones really contribute to yield?
- Answer: Main stem, T1, T2 tillers account for 90-100% of yield
- A sub-tiller, T10, sometimes contributes
- T0 tillers not common with most of our varieties, and seldom vigorous


MS-5
MS-4
MS-3
T2
MS-2
Plus
Everything
T1
MS-1

- T10, probably the only sub-tiller that can contribute to final yield…sometimes



T10 tiller, from the base of Leaf 1, analogous to the T0 tiller on the main stem

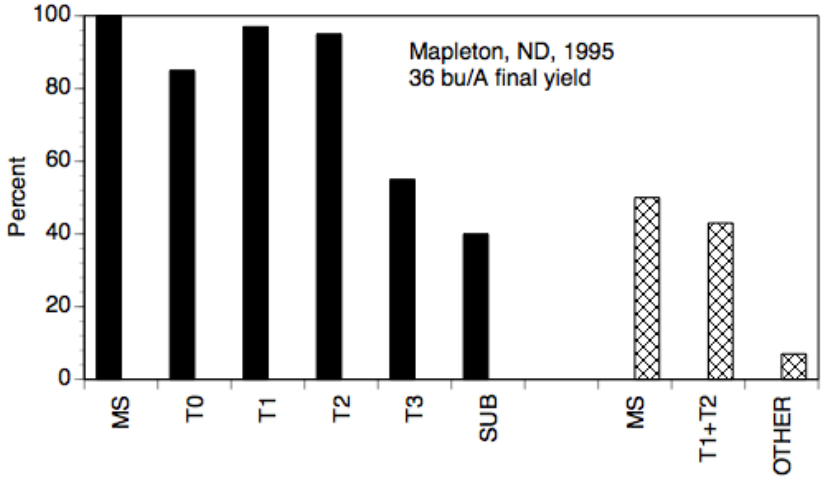
- For yields up to 70 bu/A or so, 90-100% of the yield comes from the combined contribution of the main stem, T1 and T2 tillers
- Following pictures are from a 2017 study in Minot, from wheat plants in the 70 bu/A range
  - I only observed 4 kinds of plants

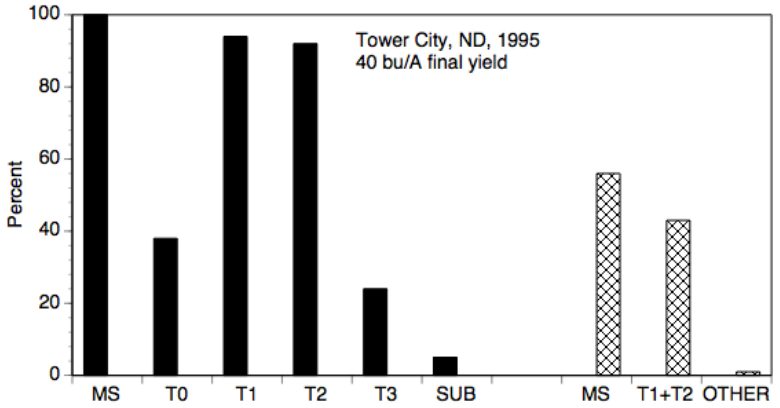
Just main stems

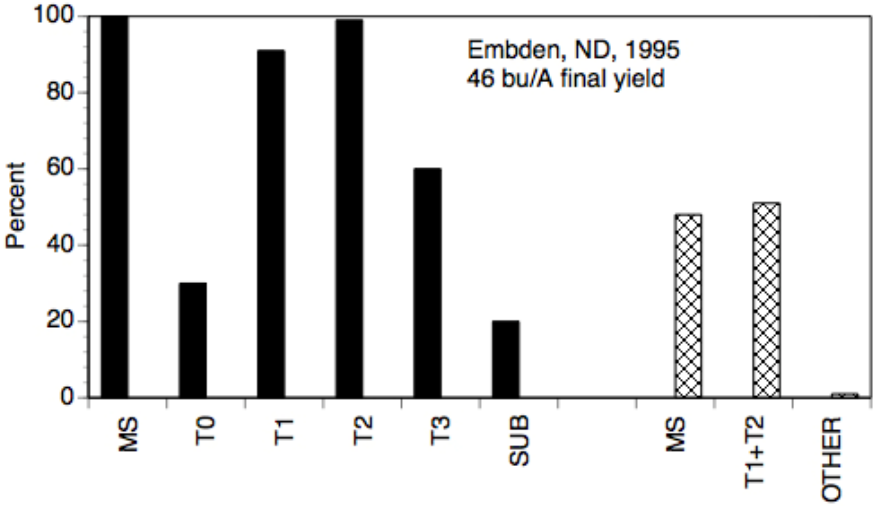
Main stem plus a T1 or a T2

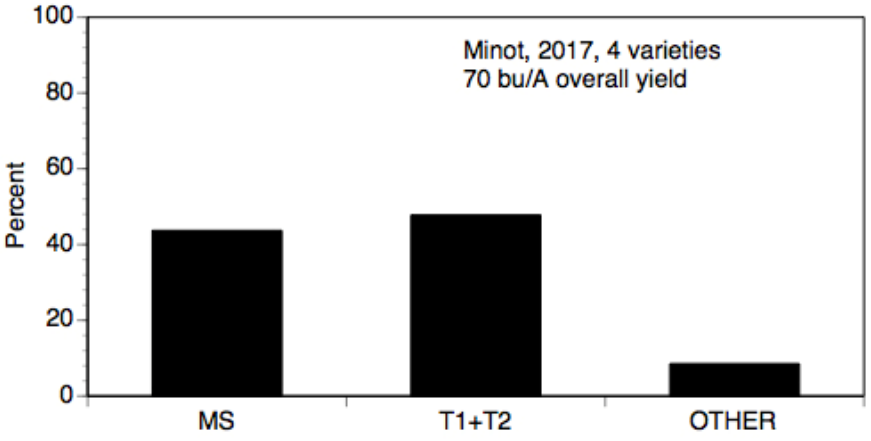
Main stem plus a T1 and a T2

Main stem plus a T1, T2, and a sub-tiller

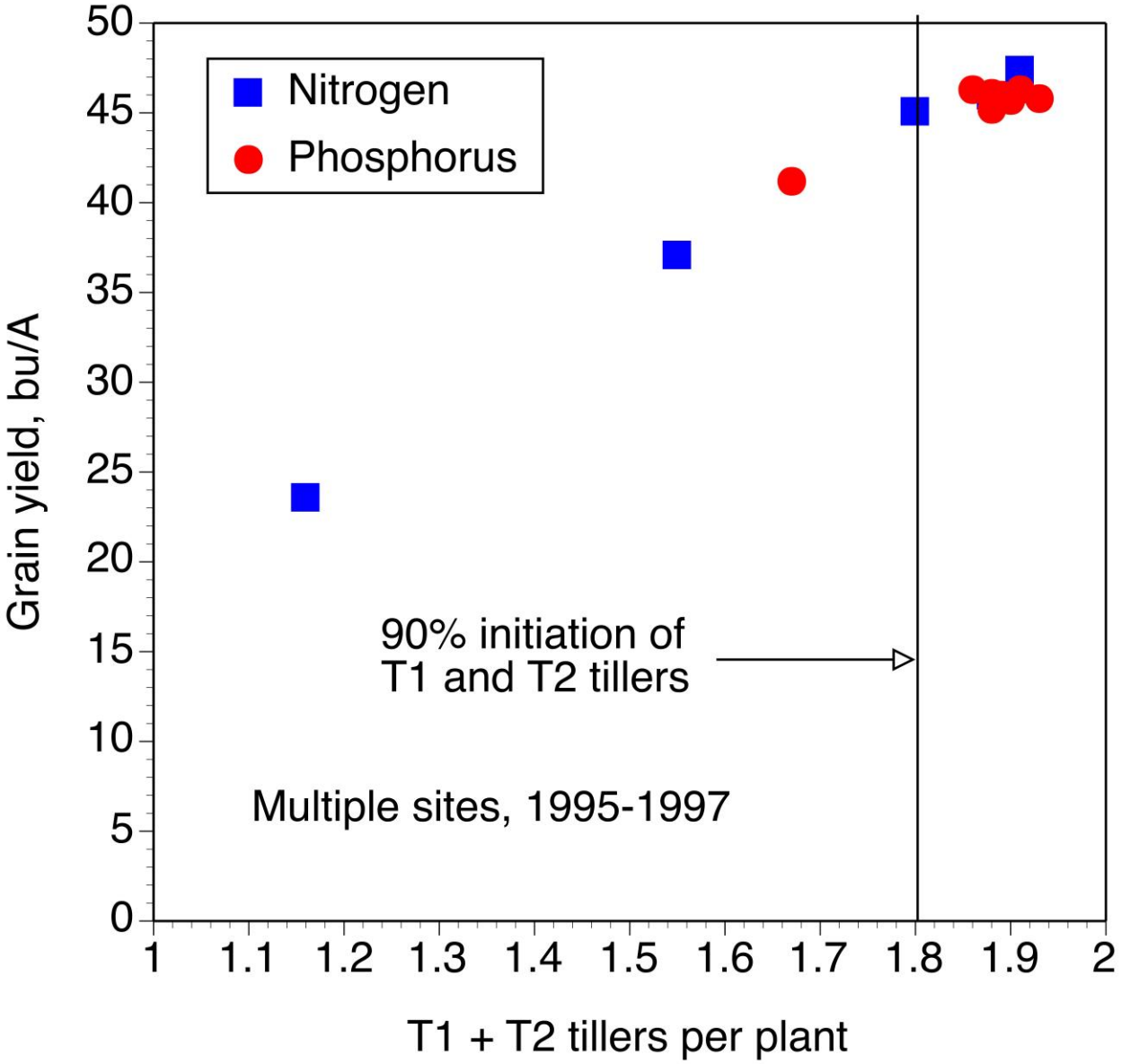

Mapleton, ND, 1995
36 bu/A final yield
Percent
100
80
60
40
20
0
MS
T0
T1
T2
T3
SUB
MS
T1+T2
OTHER

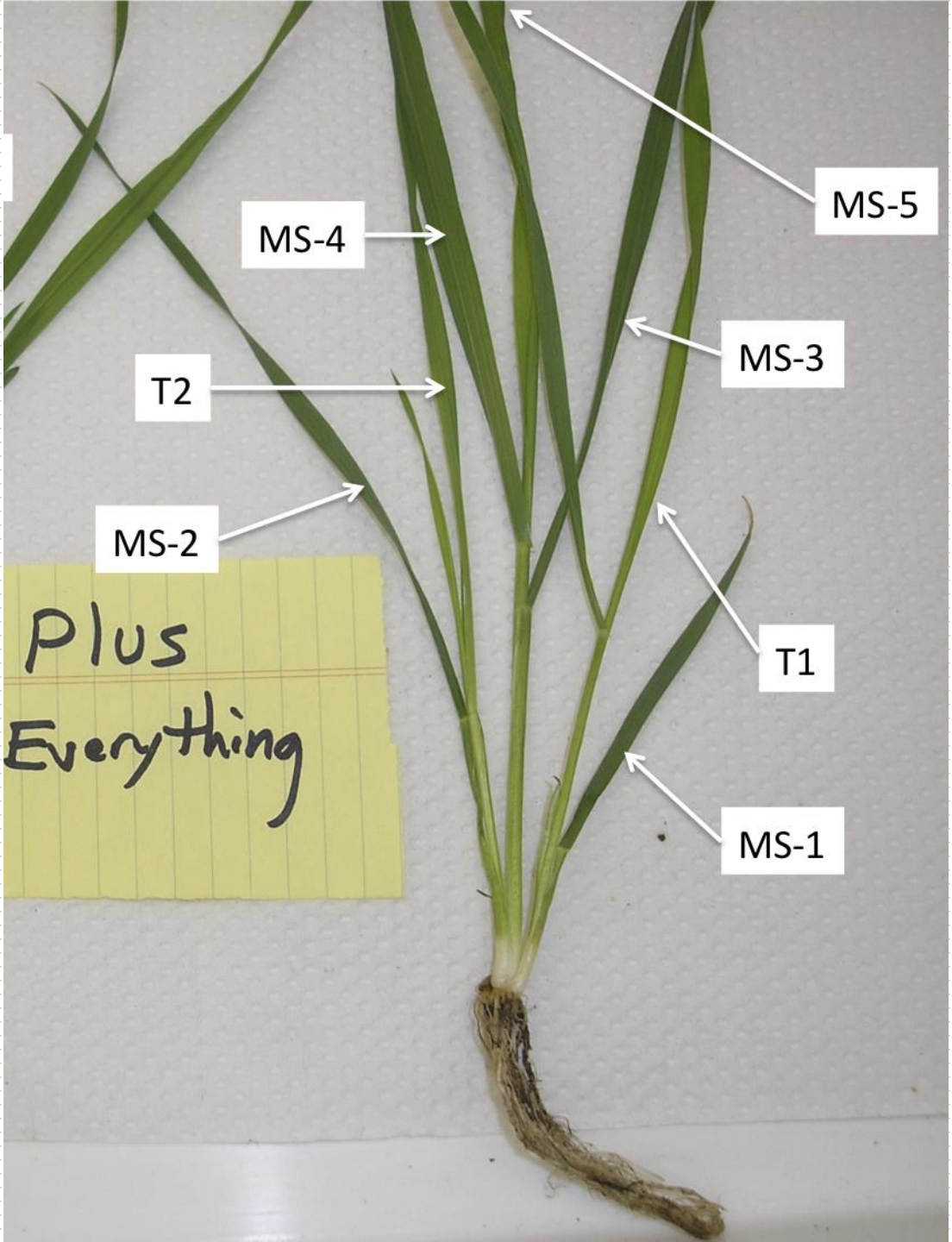

Tower City, ND, 1995
40 bu/A final yield
Percent
100
80
60
40
20
0
MS
T0
T1
T2
T3
SUB
MS
T1+T2
OTHER


Embden, ND, 1995
46 bu/A final yield
Percent
100
80
60
40
20
0
MS
T0
T1
T2
T3
SUB
MS
T1+T2
OTHER


Minot, 2017, 4 varieties
70 bu/A overall yield
Percent
100
80
60
40
20
0
MS
T1+T2
OTHER

In a series of N or P trials, maximum yield was associated with 90% initiation of T1 and T2 tillers

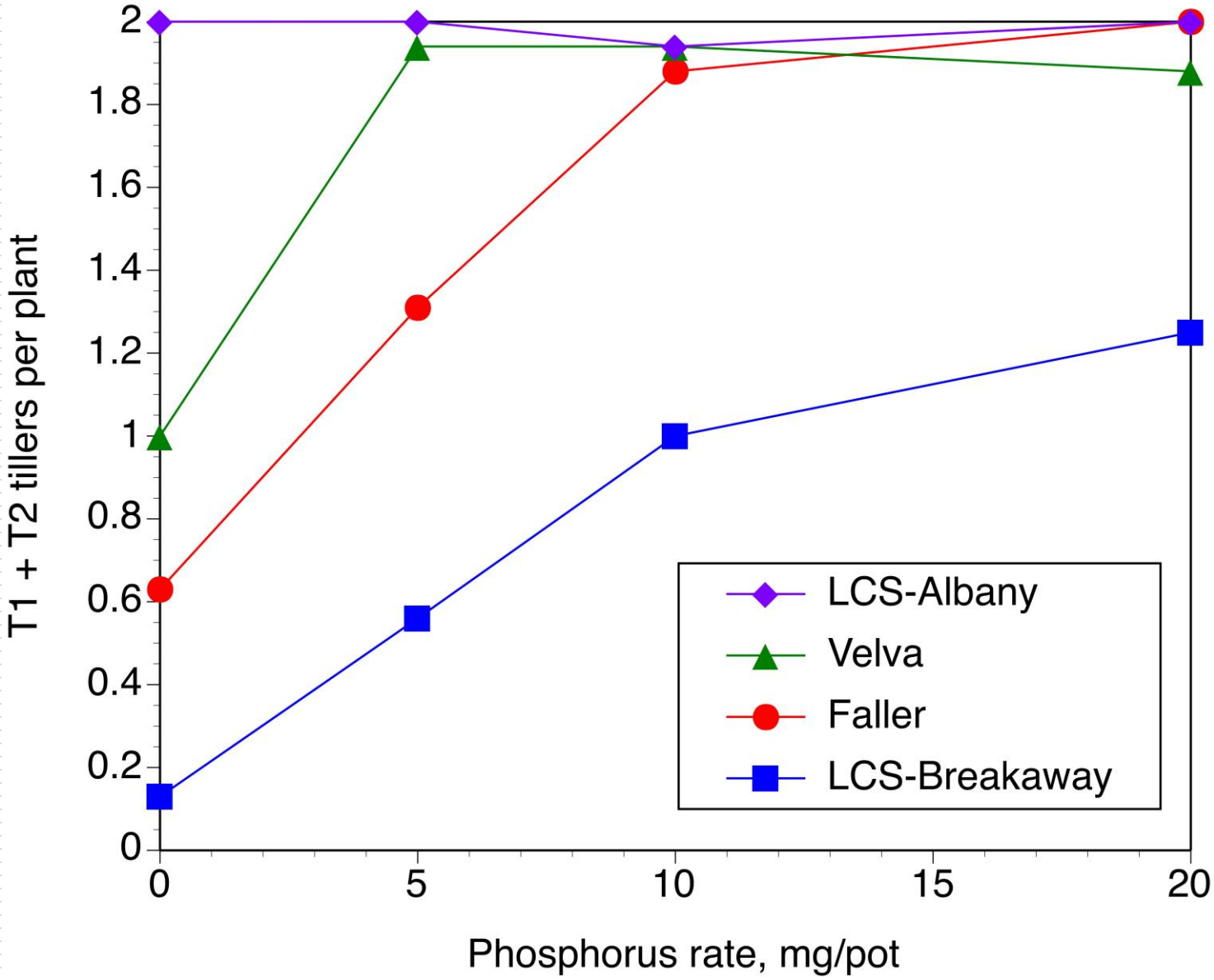



MS-5
MS-4
MS-3
T2
MS-2
Plus
Everything
T1
MS-1

- Recently, >80 historic and current wheat varieties were screened for P requirements for adequate T1 and T2 tillering

WS 1812 2375

And…big differences DO exist



- Chapter 4….inhibitors
- Urease and nitrification inhibitors….situation 40 years ago
- N-Serve (nitrapyrin) introduced in 1976, and was used only with anhydrous ammonia
- Agrotain (NBPT) would not be introduced until 1995
- DCD was only used in Europe
- Nothing was available for liquid fertilizers

- Ammonium thiosulfate (ATS, 12-0-0-26S) is the main sulfur fertilizer used with UAN
- 1984, I thought the thiosulfate ion ($S_2O_3^{2-}$) might have activity as a urease or nitrification inhibitor
- And, certainly it does, especially when applied in concentrated bands, or surface “dribble” application
- Between 1985-2013, nine papers on ATS

DIVISION S-8—FERTILIZER TECHNOLOGY AND USE

Identification of Ammonium Thiosulfate as a Nitrification and Urease Inhibitor[1]

R. J. Goos[2]

Urea Hydrolysis and Ammonia Volatilization Characteristics of Liquid Fertilizer Mixtures. I. Laboratory Studies[1]

R. J. Goos[2]

Urea Hydrolysis and Ammonia Volatilization Characteristics of Liquid Fertilizer Mixtures II. Studies Under Modified Field Conditions[1]

T. E. Fairlie and R. J. Goos[2]

Effect of Ammonium Thiosulfate and Liquid Fertilizer Droplet Size on Urea Hydrolysis

R. J. GOOS* AND T. E. FAIRLIE

EFFECT OF AMMONIUM THIOSULFATE AND DICYANDIAMIDE ON RESIDUAL AMMONIUM IN FERTILIZER BANDS[1]

R. J. Goos and B. E. Johnson

Department of Soil Science, North Dakota State University, Fargo, ND 58105

THIOSULFATE OXIDATION BY THREE SOILS AS INFLUENCED BY TEMPERATURE

R. J. Goos* and B. E. Johnson

SOILS

Ammonium Thiosulfate Effect on Herbicide Longevity in Soil

R. J. Goos* and W. H. Ahrens

But, I'll just summarize the last two

NOTES & UNIQUE PHENOMENA

Performance of Two Nitrification Inhibitors Over a Winter with Exceptionally Heavy Snowfall

R. Jay Goos* and Brian E. Johnson

Effects of Fertilizer Additives on Ammonia Loss after Surface Application of Urea–Ammonium Nitrate Fertilizer

R. JAY GOOS

Department of Soil Science, North Dakota State University, Fargo, North Dakota, USA

- Performance of Two Nitrification Inhibitors Over a Winter with Exceptionally Heavy Snowfall. Agron. J. 1999. 44:1046-1049

- October 1996, aqua ammonia was knifed into the soil, with and without N-Serve and ATS
  - 75 lb N, 15 lb S, 1 x and 3 x N-Serve label rate
- Then, the winter of 96-97 happened
- It was a “worst case scenario” for over-winter loss of nitrogen

- Band samples taken in the spring, how much mineral N (ammonium + nitrite + nitrate-N) made it through such an awful winter?????

	Site 1	Site 2	Average
Control	3	4	4
Aqua	7	9	8
Aqua + NP	22	31	27
Aqua + 3X NP	37	41	39
Aqua + ATS	29	36	33

- Site 2 was planted to wheat.

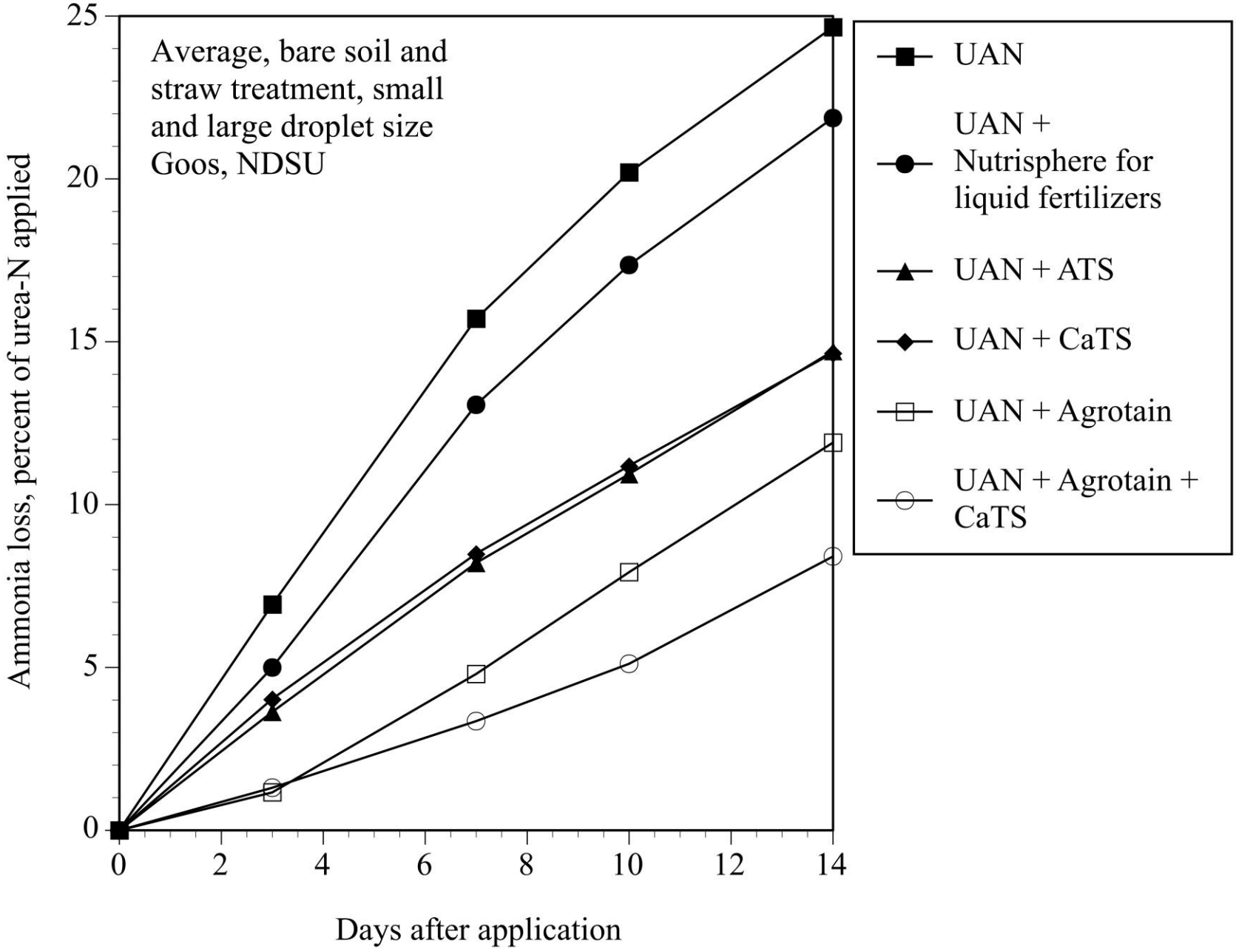
Goos and Johnson, 1999

- Yield and NUE data...

Treatment	Grain yield	Total N uptake in grain + straw	Nitrogen fert. use efficiency
	bu/A	lb/A	%
Control	23.4	34.6	--
Aqua	37.0	52.9	24
Aqua + NP	45.0	72.2	50
Aqua + 3X NP	45.9	72.5	50
Aqua + ATS	47.3	77.0	56

Goos and Johnson, 1999

- So, when banded, ATS can slow nitrification
- What about ammonia volatilization?
- Effects of Fertilizer Additives on Ammonia Loss after Surface Application of Urea-Ammonium Nitrate Fertilizer. 2013. Comm. Soil Sci. Plant Anal. 44:1909-1917.


Average, bare soil and straw treatment, small and large droplet size
Goos, NDSU
Ammonia loss, percent of urea-N applied
Days after application
0
5
10
15
20
25
0
2
4
6
8
10
12
14
UAN
UAN + Nutrisphere for liquid fertilizers
UAN + ATS
UAN + CaTS
UAN + Agrotain
UAN + Agrotain + CaTS

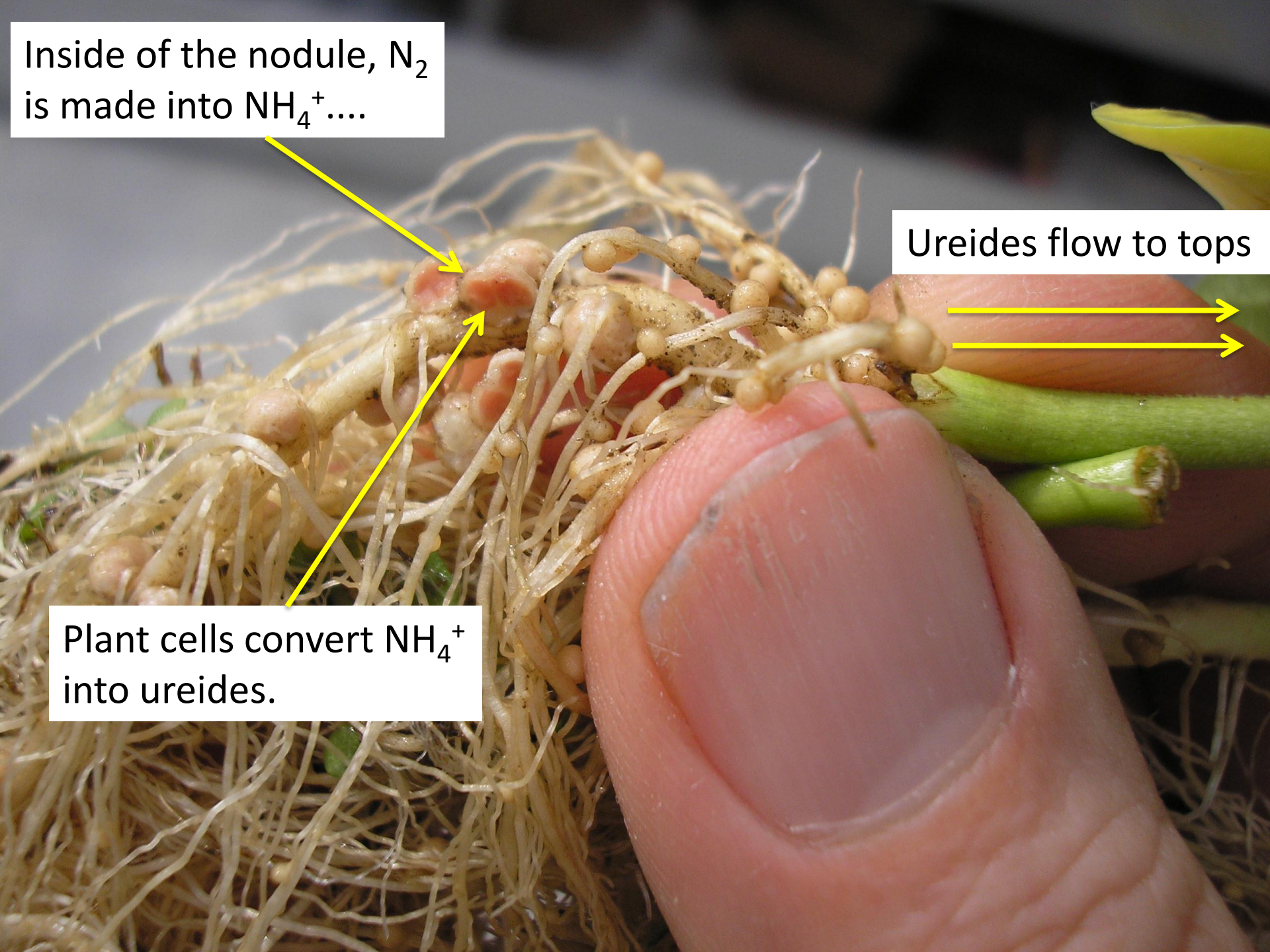
- So, ATS can slow ammonia loss, but isn't as effective as Agrotain

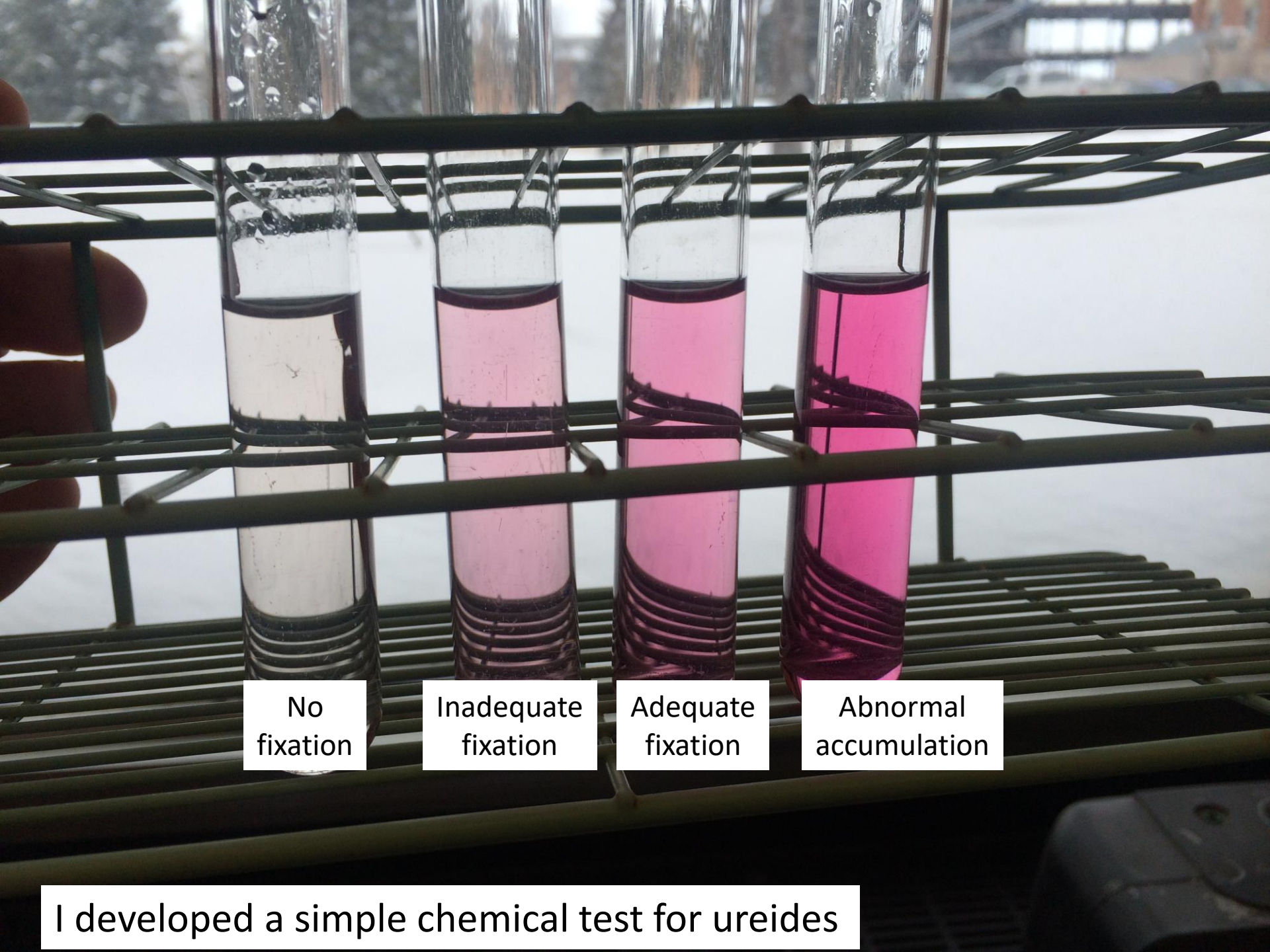
- General conclusion about ATS…if you are using UAN, and need S, you may also get some nitrogen conservation benefit from using ATS

- Other studies….
- Larger urea granules plus DCD can achieve very slow nitrification
- Recent papers, evaluating new products
  - Nutrisphere-N, NZone

- Chapter 5. Ureides.
- Nitrogen flows from soybean roots to the tops, almost entirely in two forms:
  - Nitrate from the soil solution
  - "Ureides" from the nodules

NO_3^- Ureides


Inside of the nodule, N_2 is made into NH_4^+....
Ureides flow to tops
Plant cells convert NH_4^+ into ureides.

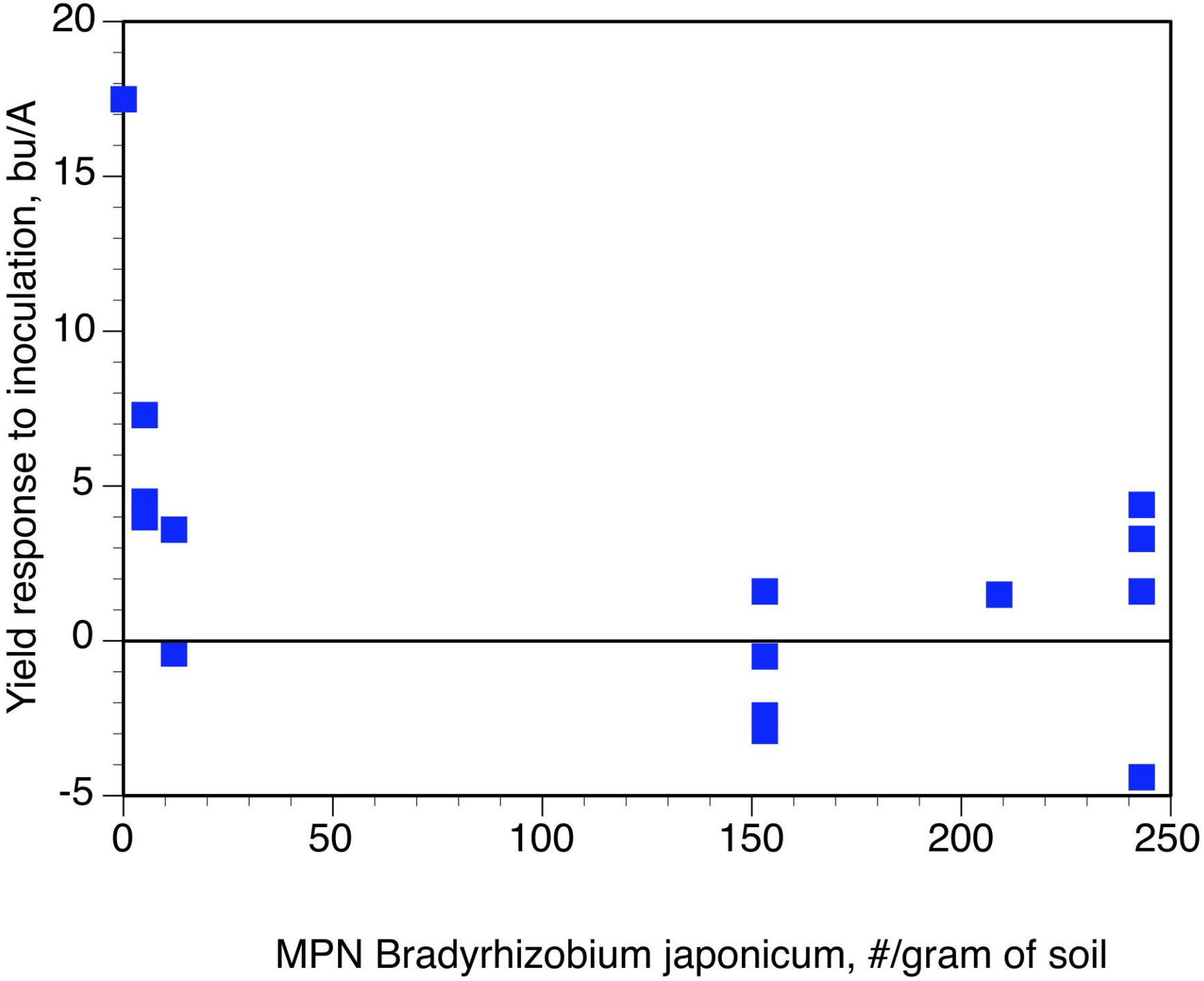


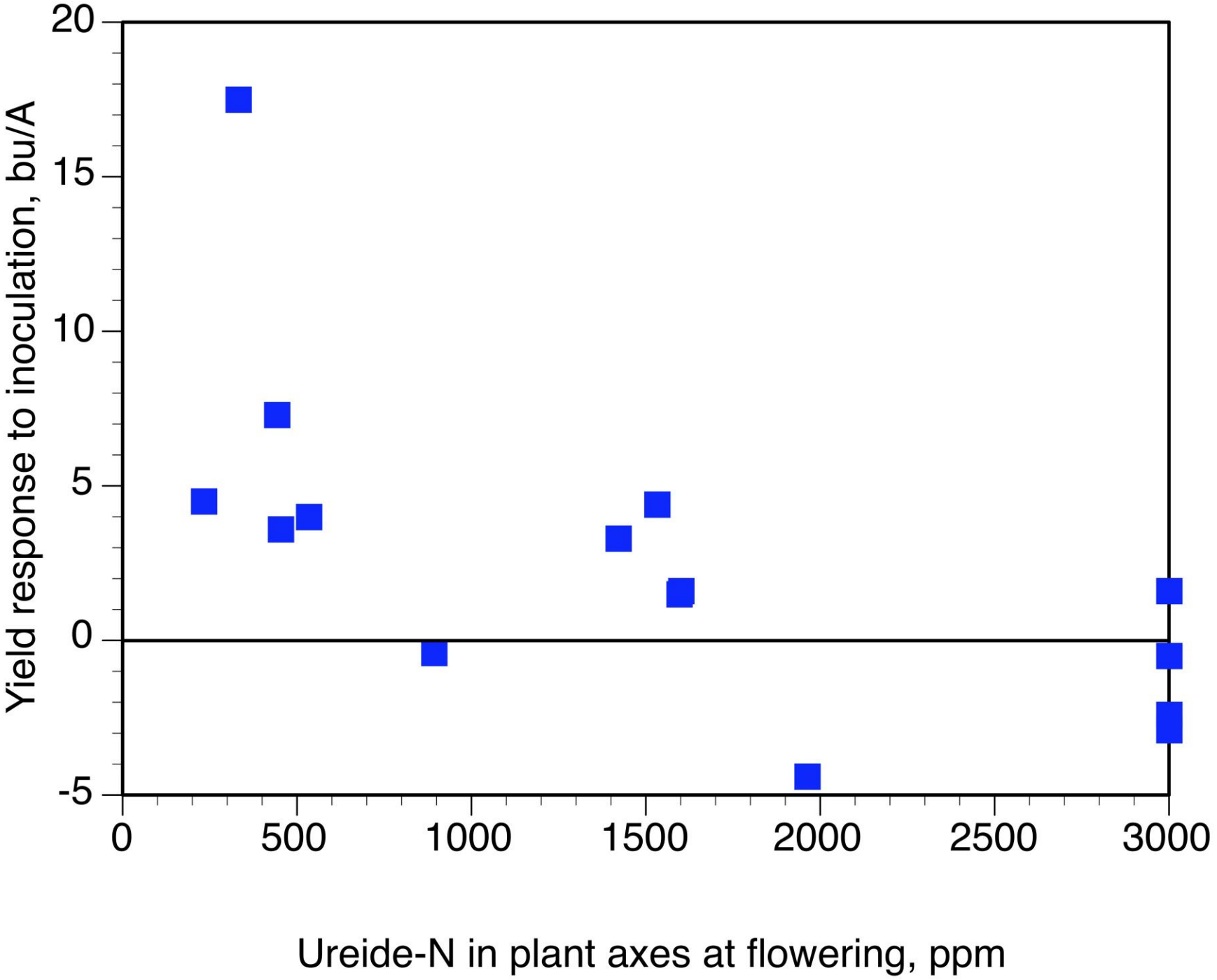
I developed a simple chemical test for ureides

- Inoculation studies performed at Carrington and Minot on “virgin” ground, or sites where soybeans had only been grown once before

- Correlate crop response to inoculation to the number of B. japonicum at planting time, and also the ureide-N concentration in the plant stems

- MPN of *Bradyrhizobium japonicum* per gram of soil at planting:
- Carrington, 2007a*..... 5
- Carrington, 2007b*....12
- Carrington, 2015..... 153
- Carrington, 2016..... 243
- Carrington, 2017.... 209
- Minot, 2015*..... 5
- Minot, 2016*..... 0
- *No history of soybean


Yield response to inoculation, bu/A
20
15
10
5
0
-5
0
50
100
150
200
250
MPN Bradyrhizobium japonicum, #/gram of soil


Yield response to inoculation, bu/A
20
15
10
5
0
-5
0
500
1000
1500
2000
2500
3000
Ureide-N in plant axes at flowering, ppm

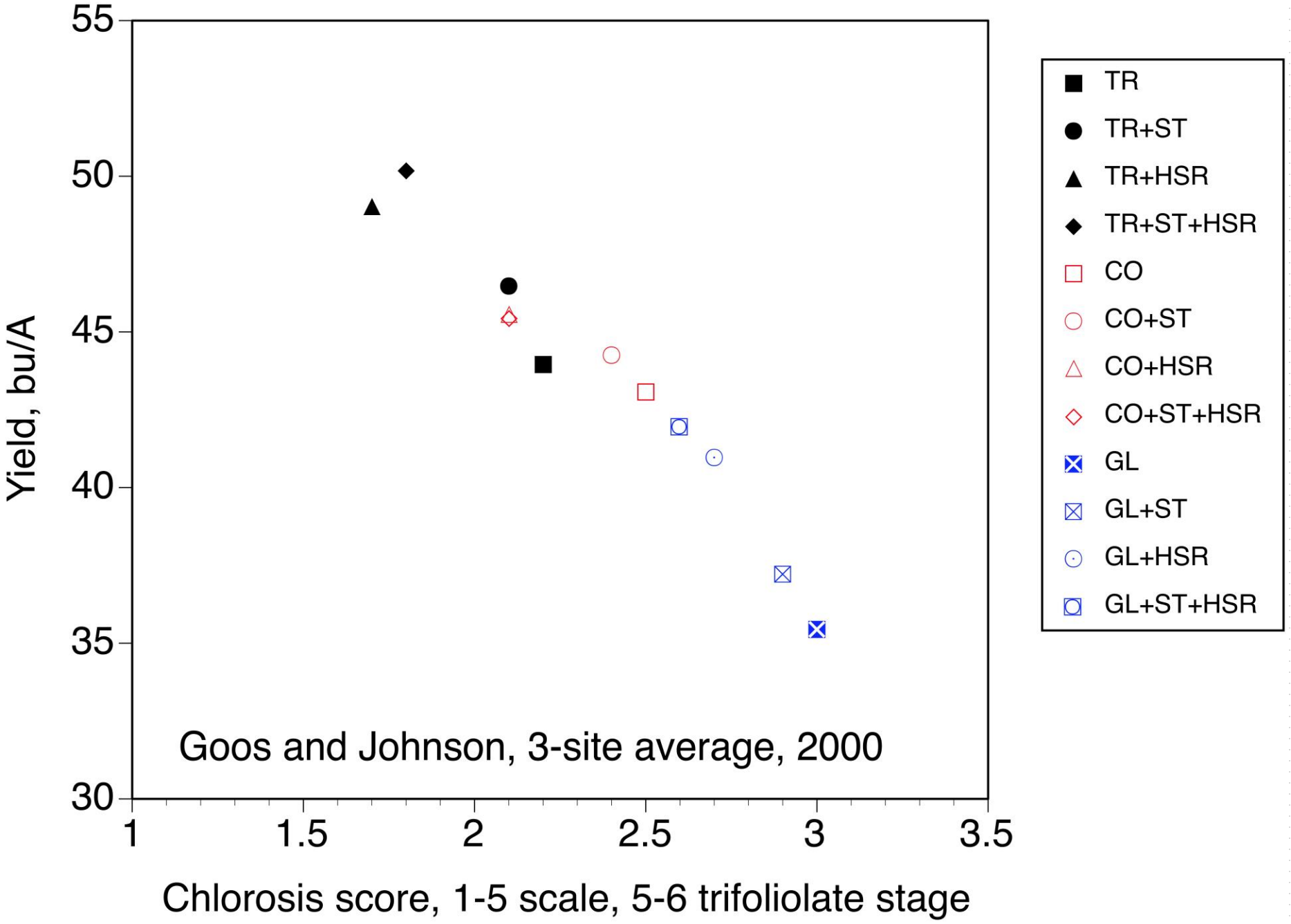
- You only need ~50 *B. japonicum* per gram of soil for adequate nodulation
  - Typical number in the soil, ***in the thousands***, after soybeans grown several times
  - Bad news for the inoculum industry
- The ureide test is a useful tool

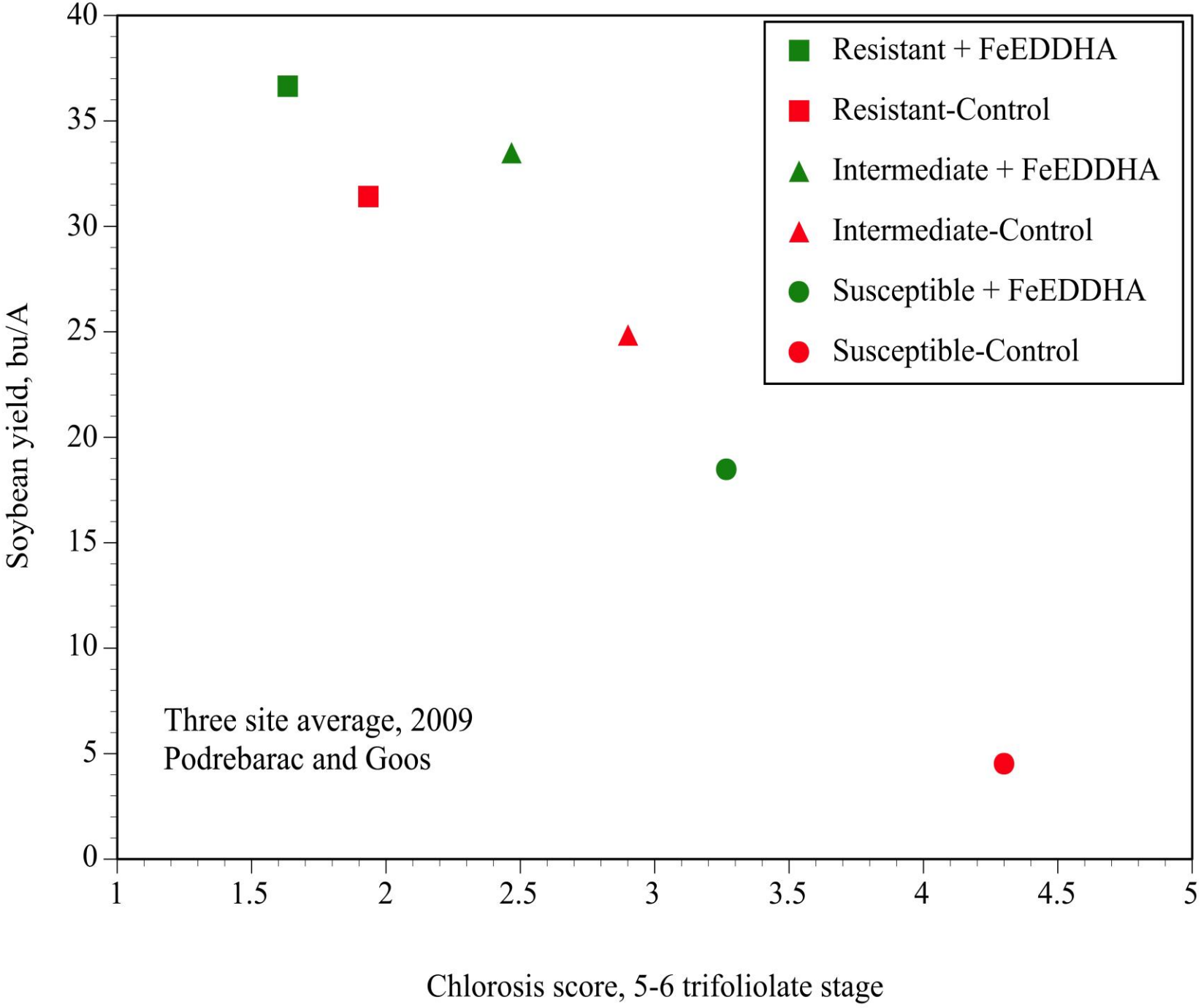
- Chapter 6….wait for it…


• Chapter 6….IDC

- Major findings over the years
- Variety is the most effective control measure
  - Seven major DNA associations
- Control measures are “stackable” with a resistant variety
  - FeEDDHA, wider rows, heavier seeding rates
- Excess nitrate makes things worse
- Foliar sprays, just don’t translocate
- Watch out for “The Lake Woebegon Effect”
- Hanky-panky in the fertilizer trade

- Variety is the most effective control measure, but control measures are “stackable”


55
50
45
40
35
30
Yield, bu/A
1
1.5
2
2.5
3
3.5
Chlorosis score, 1-5 scale, 5-6 trifoliolate stage
Goos and Johnson, 3-site average, 2000
TR
TR+ST
TR+HSR
TR+ST+HSR
CO
CO+ST
CO+HSR
CO+ST+HSR
GL
GL+ST
GL+HSR
GL+ST+HSR


Resistant + FeEDDHA
Resistant-Control
Intermediate + FeEDDHA
Intermediate-Control
Susceptible + FeEDDHA
Susceptible-Control
Three site average, 2009
Podrebarac and Goos
Soybean yield, bu/A
Chlorosis score, 5-6 trifoliolate stage
0
5
10
15
20
25
30
35
40
1
1.5
2
2.5
3
3.5
4
4.5
5

yellowsoybeans.com

(This page updated annually).

Iron Deficiency Chlorosis in Soybeans

Results of variety screening trials in North Dakota

New!! 2006 Annual Report, chlorosis ratings of 181 varieties!!

2005 Annual Report, chlorosis ratings of 176 varieties!!

2004 Annual Report, chlorosis ratings of 178 varieties!!

2003 Annual Report, chlorosis ratings of 161 varieties!!!

2002 Annual Report, chlorosis ratings of 182 varieties!!!

2001 Annual Report, chlorosis ratings of 181 varieties!!!

The relationship between chlorosis and yield, 1998-2000

- A resistant variety is better at taking up Fe from the soil, and better at translocation and maintaining Fe availability inside of the plant

PLOS ONE

PUBLISH ABOUT BROWSE

OPEN ACCESS PEER-REVIEWED

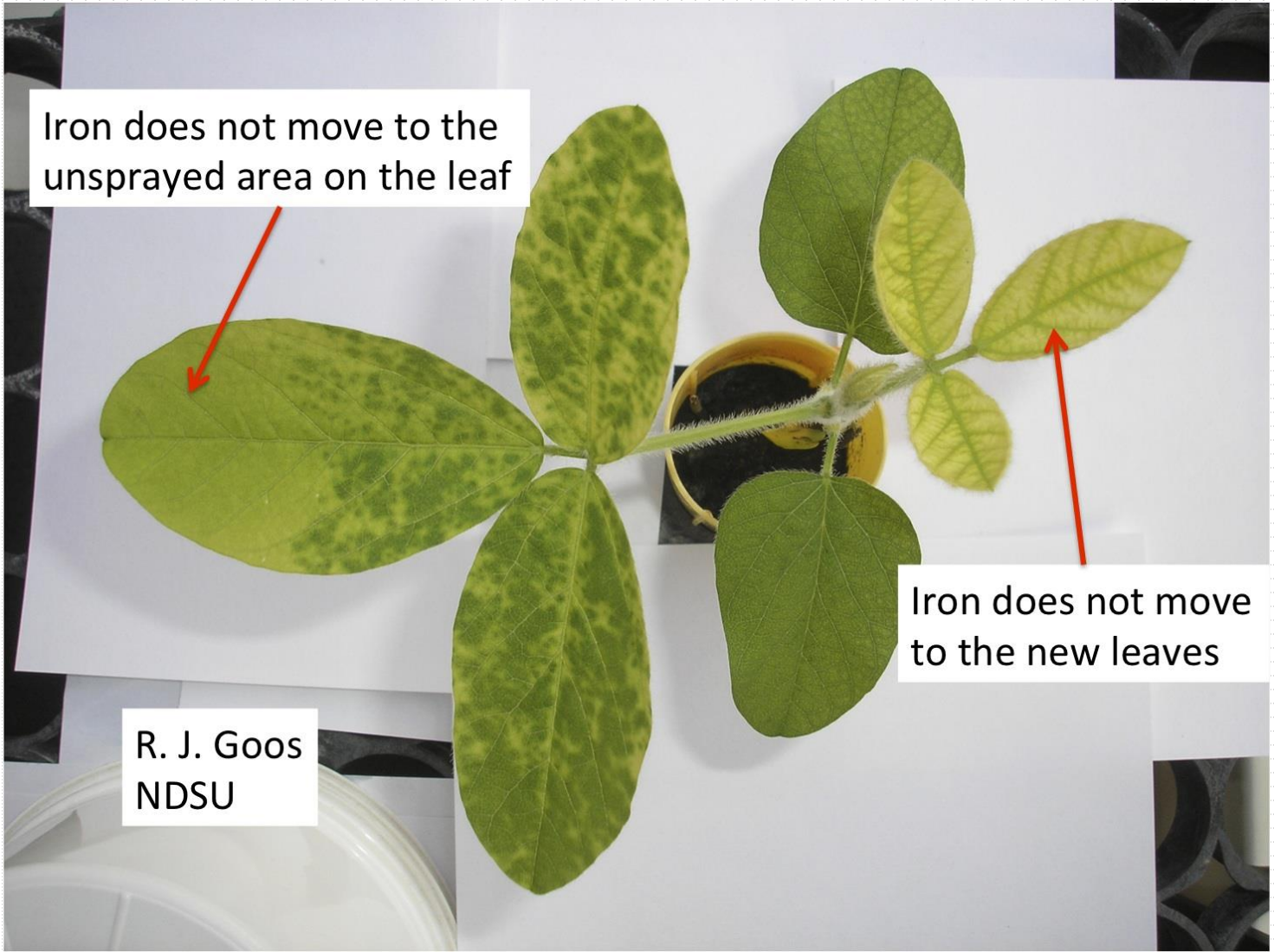
RESEARCH ARTICLE

Genome-Wide Association Studies Identifies Seven Major Regions Responsible for Iron Deficiency Chlorosis in Soybean (*Glycine max*)

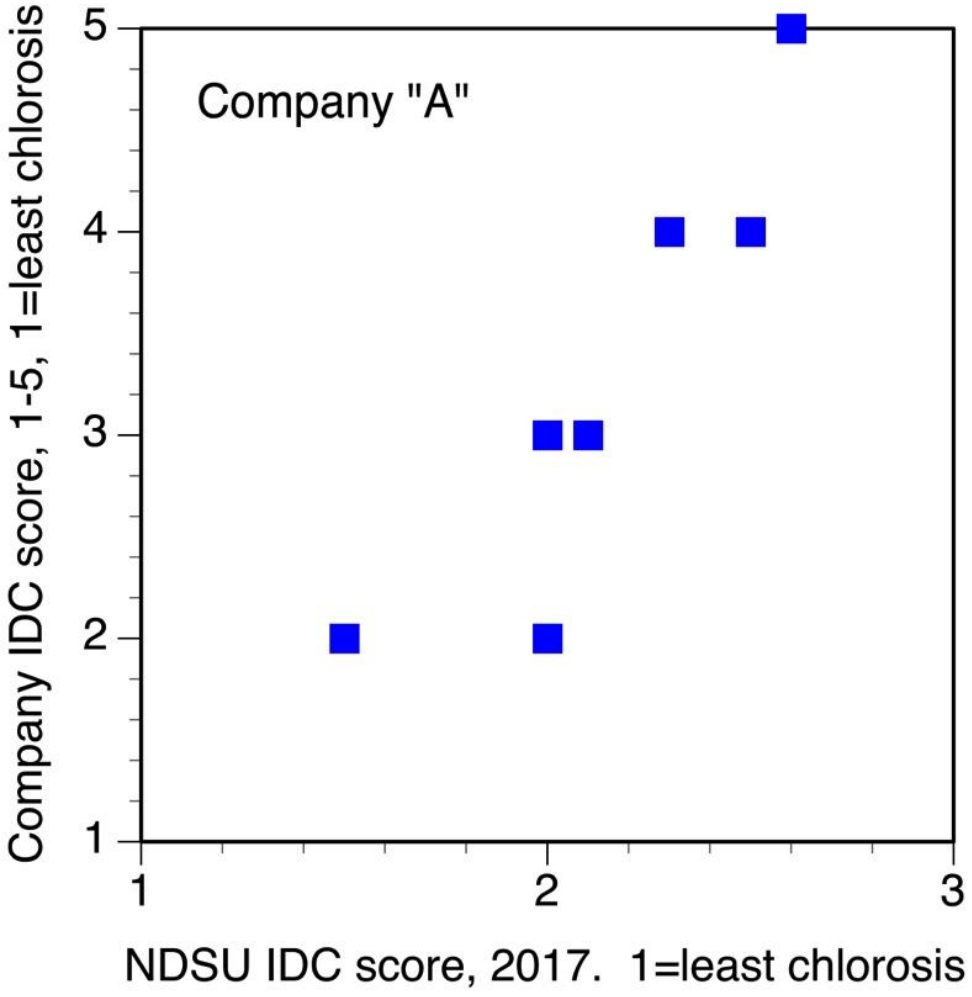
Sujan Mamidi, Rian K. Lee, Jay R. Goos, Phillip E. McClean

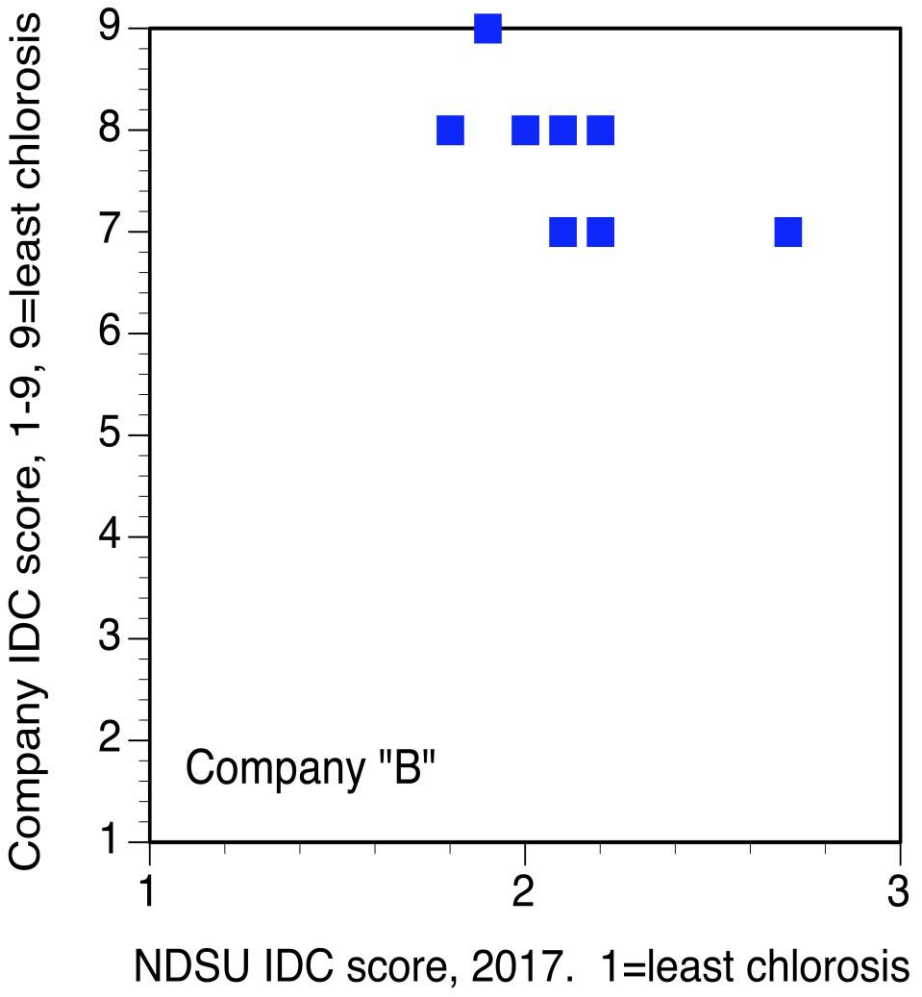
Published: September 16, 2014 • https://doi.org/10.1371/journal.pone.0107469

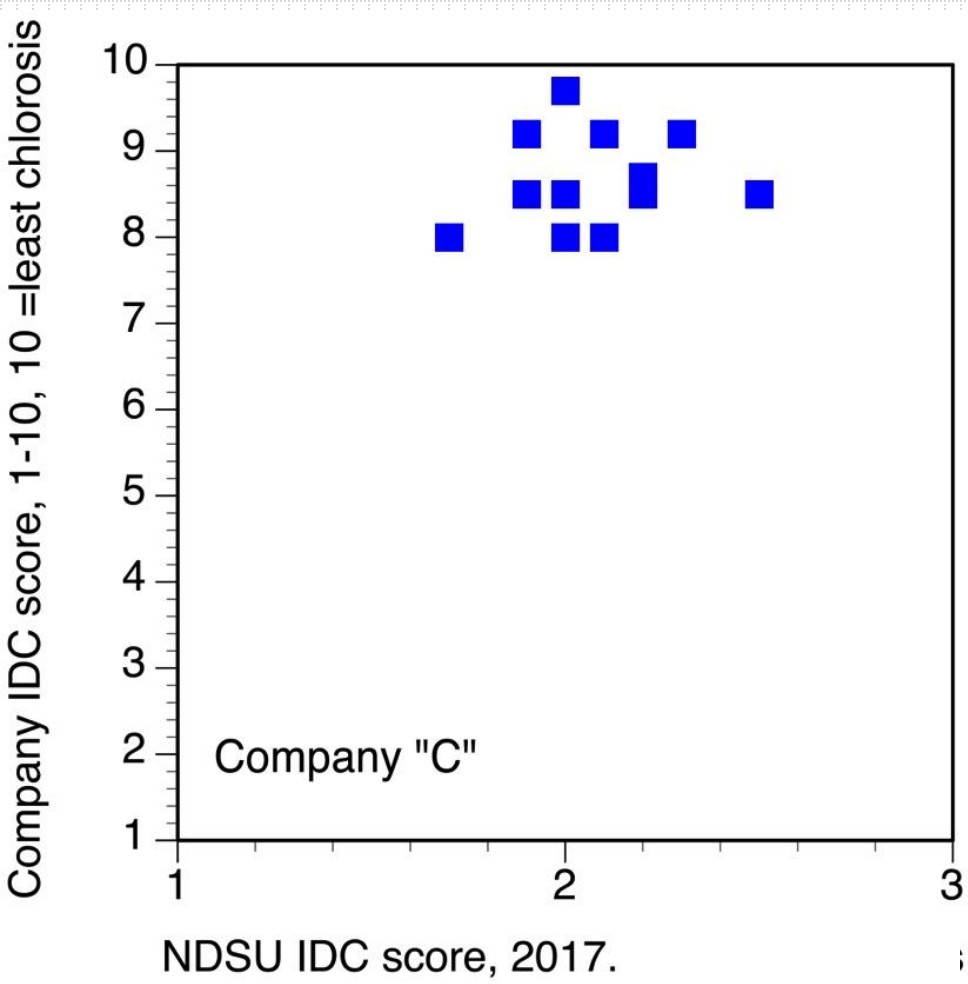
- Foliar sprays….just don’t translocate

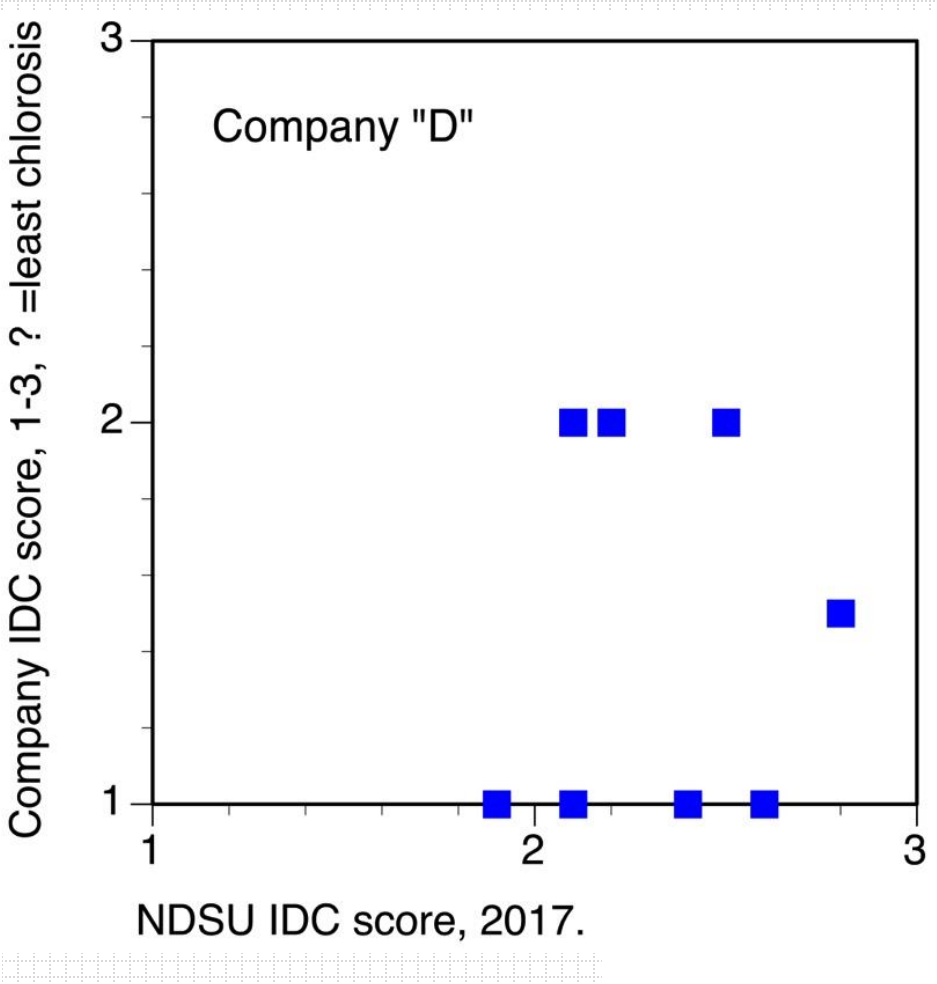


- “Lake Woebegon, where all of the children are above average”



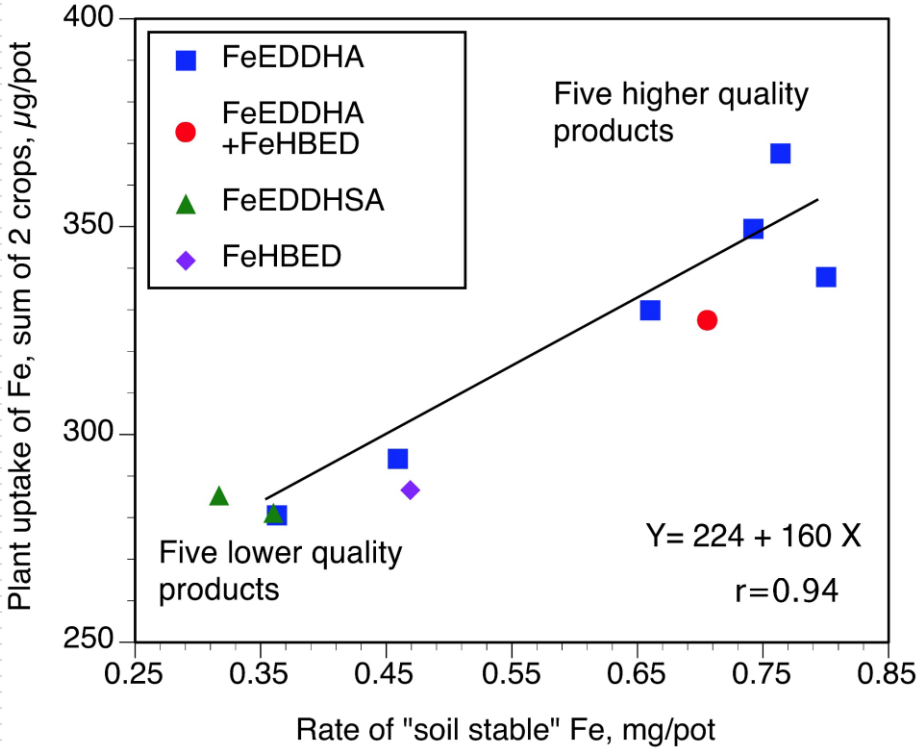






The seed industry needs to do a LOT BETTER with regards to IDC ratings.

- Hanky-panky in the fertilizer trade
- FeEDDHA is a “messy” product to make, commercially, and contains ineffective isomers and condensates
- Quality varies across products



- Current studies on IDC
  - Development of a rapid (~4-week) variety screen
  - Screening seed treatments (FeEDDHA + additives)

- So, that's an overview of my research over the past 40 years. Studies not mentioned:
  - Phosphorus fertilization of alfalfa
  - Fertilization of alfalfa-grass mixtures
  - Nitrate soil test calibration for malting barley in western ND
  - N and P management for buckwheat
  - Pre-establishment of rhizobia by inoculation of wheat
  - Anti-transpirants and water stress of soybeans in western ND

- So, just a blanket ”thank-you” to everyone who helped me over the years, and to numerous grant sponsors, but especially the North Dakota Soybean Council, who has always supported me over the past 20 years