Soil Acidity

Crop/Soil Interactions

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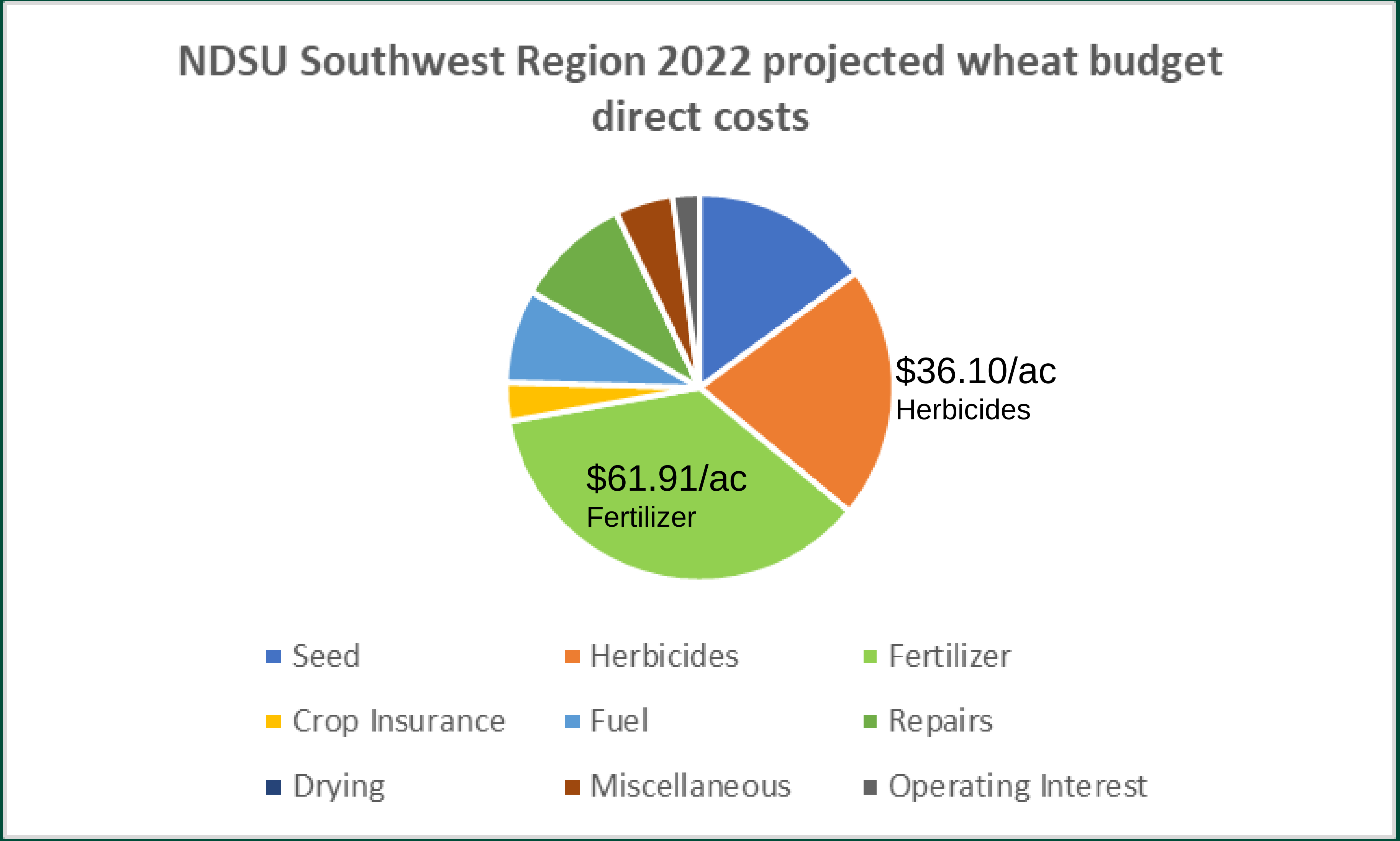
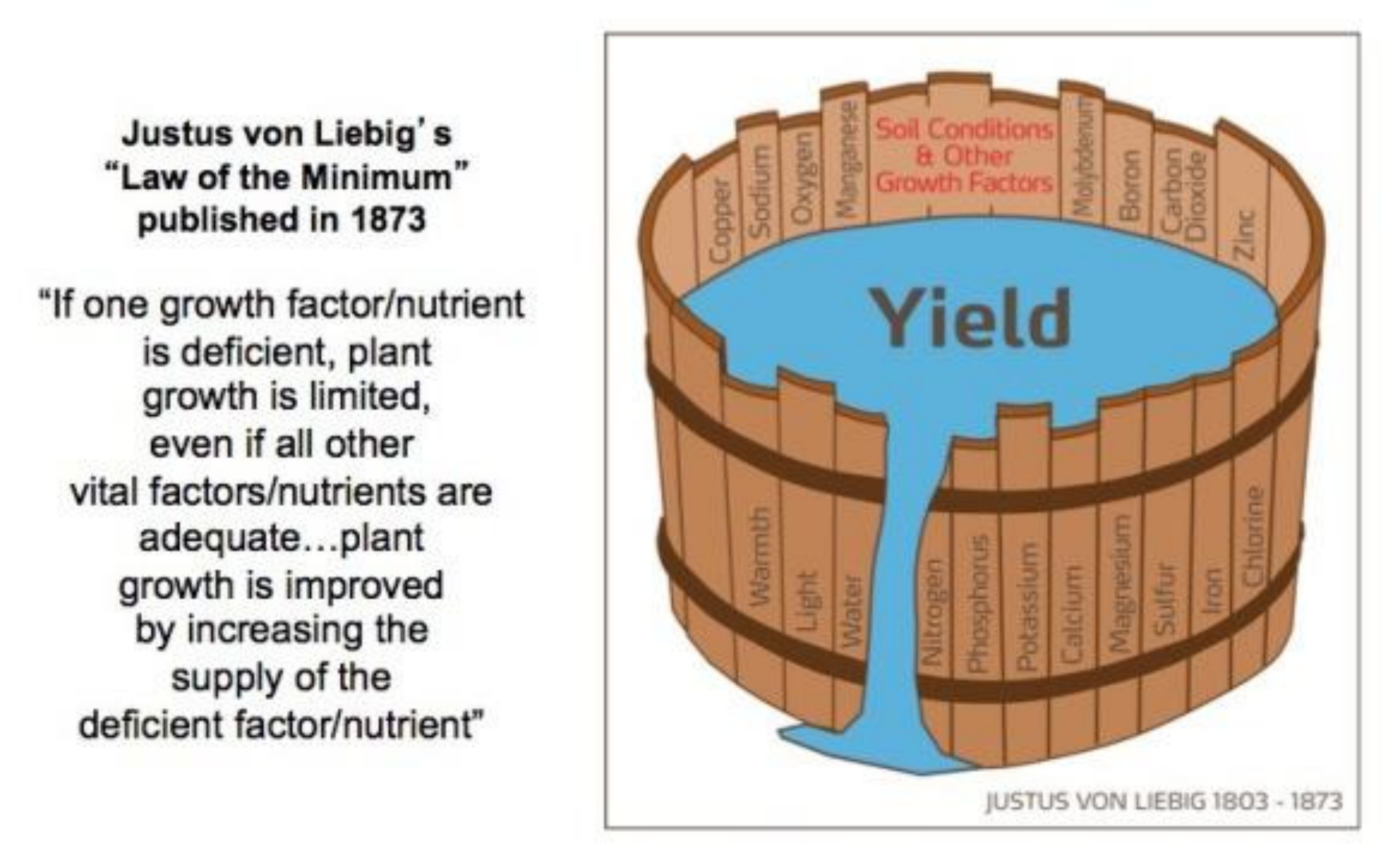
Input use efficiency



Why do we need nutrients for our crops?



https://earthwiseagriculture.net/grower-s-toolbox/law-of-minimums/

- Soil Fertility and Fertilizers (Havlin et al)

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Causes of low soil pH

- Parent materials
  - Granite and volcanic ash are acidic
  - Limestone and ocean sediments (shale) are alkaline
- Rainfall and leaching of base cations (sandy soils)
- Harvest of grain and biomass
  - Increasing yields means increasing removal of cations
  - Grain contains less than leaves and stems (baling straw/forage)

Causes of low soil pH

- Nitrogen fertilizers and manure
  - Nitrification (NH4+ → NO3-) produces acidity (H+)

$$2NH_4^+ \quad + \quad 3O_2 \quad \rightarrow \quad 2NO_3^- \quad + \quad 2H_2O \quad + \quad 4H+$$

ammonium oxygen nitrate water hydrogen ion

- Elemental sulfur fertilizers
  - Sulfur oxidation (S0 → SO42-) produces acidity (2H+)
  - Elemental S-containing P fertilizers
  - Plant residues: decomposition → organic acids

Table 1. Lime quantity required to neutralize the soil acidity produced by different N sources if all of the ammonium-N is converted to nitrate-N.

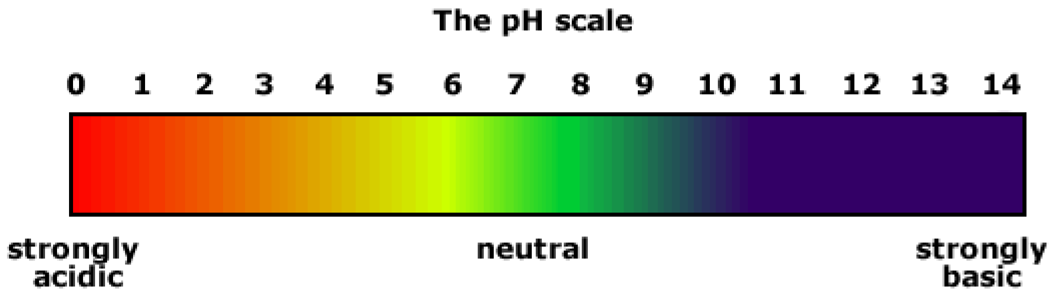
Nitrogen Source	Fertilizer Analysis	Lime Required (lb $CaCO_3$/lb N)
Anhydrous ammonia	82-0-0	1.8
Urea	46-0-0	1.8
Ammonium nitrate	34-0-0	1.8
Ammonium sulfate	21-0-0-24	5.4*
Monoammonium phosphate	11-52-0	5.4
Diammonium phosphate	18-46-0	3.6
Urea-ammonium nitrate solutions	28 to 32-0-0	1.8

From Wortmann et al. (2015) as adapted from Havlin et al., 2005.

*The estimate for ammonium sulfate may be 50% too high (Chien et al., 2010).

What is pH?

- Measure of hydrogen ion (H^+) activity in solution
- Controls availability, solubility, and reactivity of countless chemical and biological reactions in natural systems (e.g., animals, plants, soils, water)
- pH is a logarithmic (log) scale, 10-fold increase for each pH-unit



Soil pH: What is it?

Relative level	pH (1:1 method)	Interpretation
Very acidic	**<5.5**	**Aluminum toxicity, liming important**
Acidic	**5.5-6.5**	**Liming may be necessary, crop choice**
Neutral	6.5-7.5	
Alkaline	7.5-8.5	Band P fertilizer, maybe Zn?
Very alkaline	>8.5	Sodium problem, gypsum may be required

- pH controls soil chemical and biological reactions
- Herbicide breakdown affected in low or high pH soils

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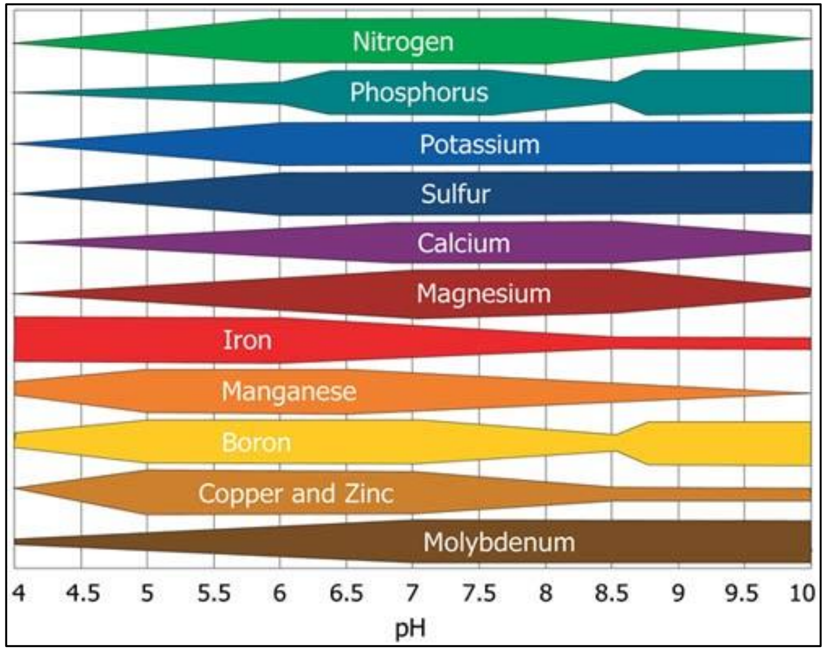
Why are acid soils problematic?

Reduced nutrient availability



Aluminum toxicity

Photo: Gene Hettel/CIMMYT. https://flic.kr/p/8Ke1Jr

Aluminum toxicity on wheat seedlings

High Al^{3+}

No Al^{3+}

Photo: S. Carr. https://www.agric.wa.gov.au/soil-acidity/effects-soil-acidity

Soybean plants and their root systems grown under field conditions where soil pH decreases (soil acidity increases) from pH 5.1 on the left to pH 4.5 on the right (H. Weiser, Natural Resources Conservation Service).

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Severe aluminum toxicity in southwest North Dakota

- Safflower: small plants, poor germination
- Pattern follows landscape

Photo: Shawn Sanford, CHS Southwest Grain.

Soil pH and sunflower stand in southwest North Dakota

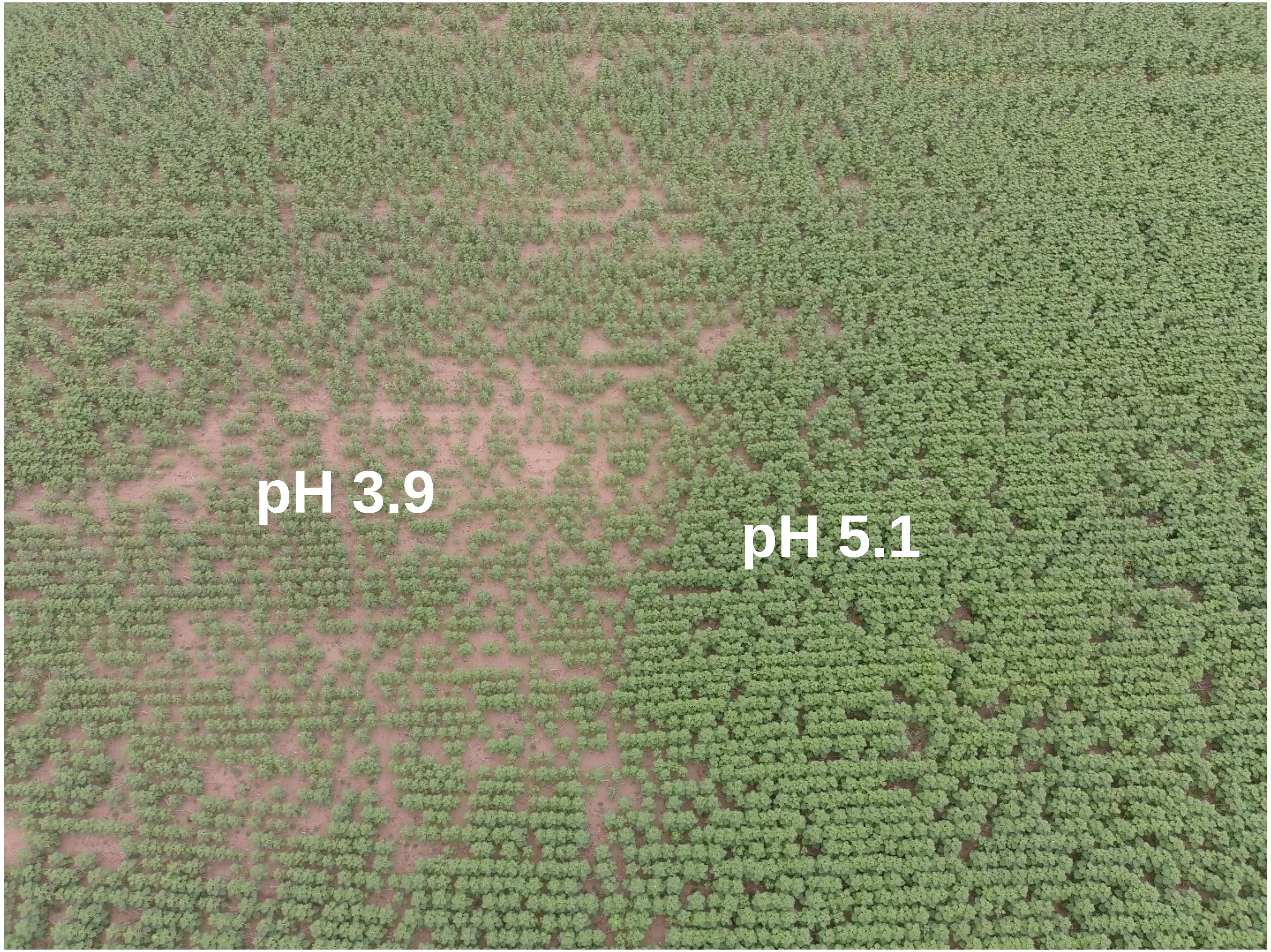

Photo: Ryan Buetow, NDSU Extension, Dickinson, ND.

Aluminum toxicity can take crop stand and yield to zero

Cullars Rotation
Auburn University, Alabama

No lime since 1911
Soil pH 4.7 in 2004

Photo: J.S. Breker, August 2015.

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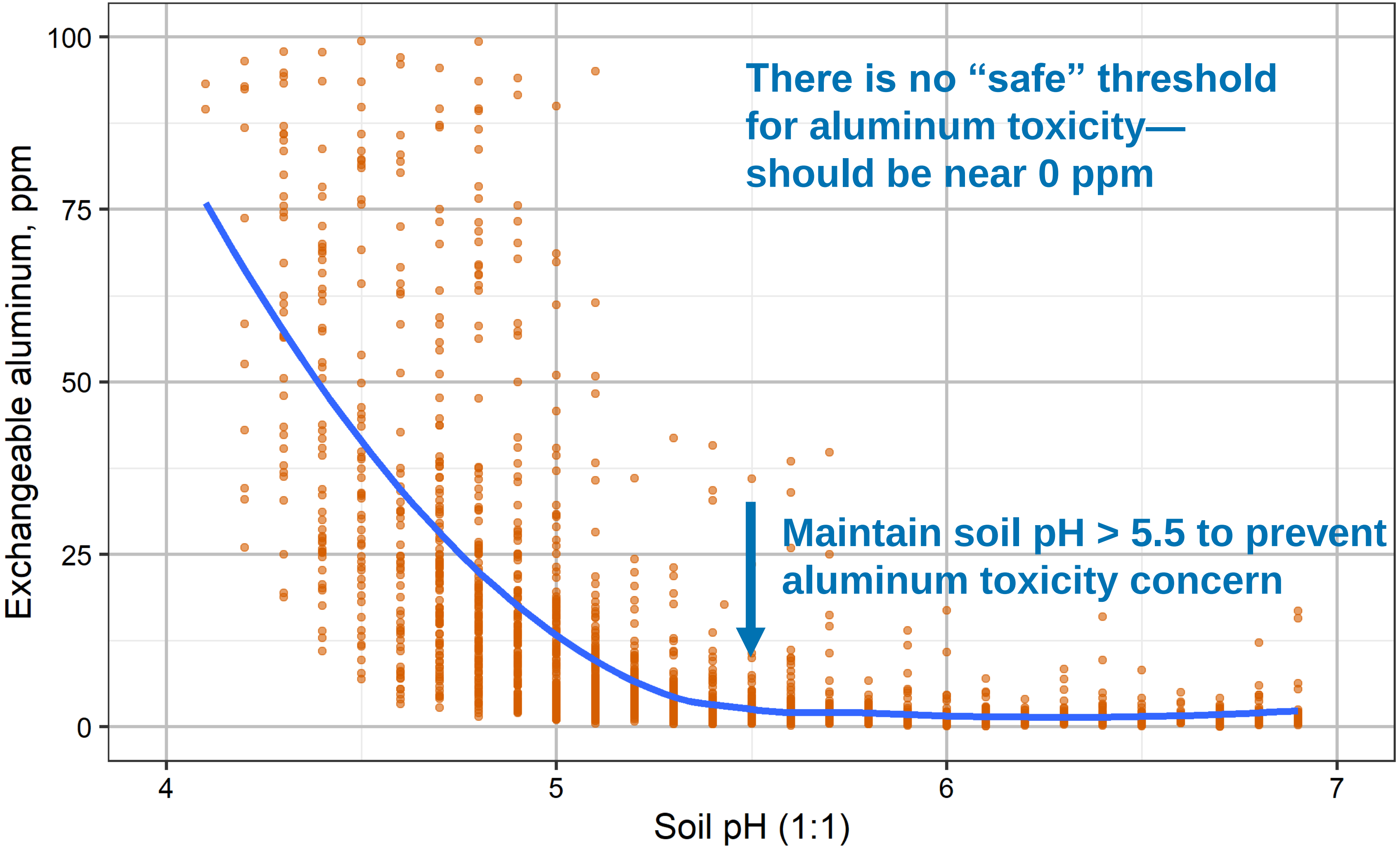
Soil pH controls aluminum availability



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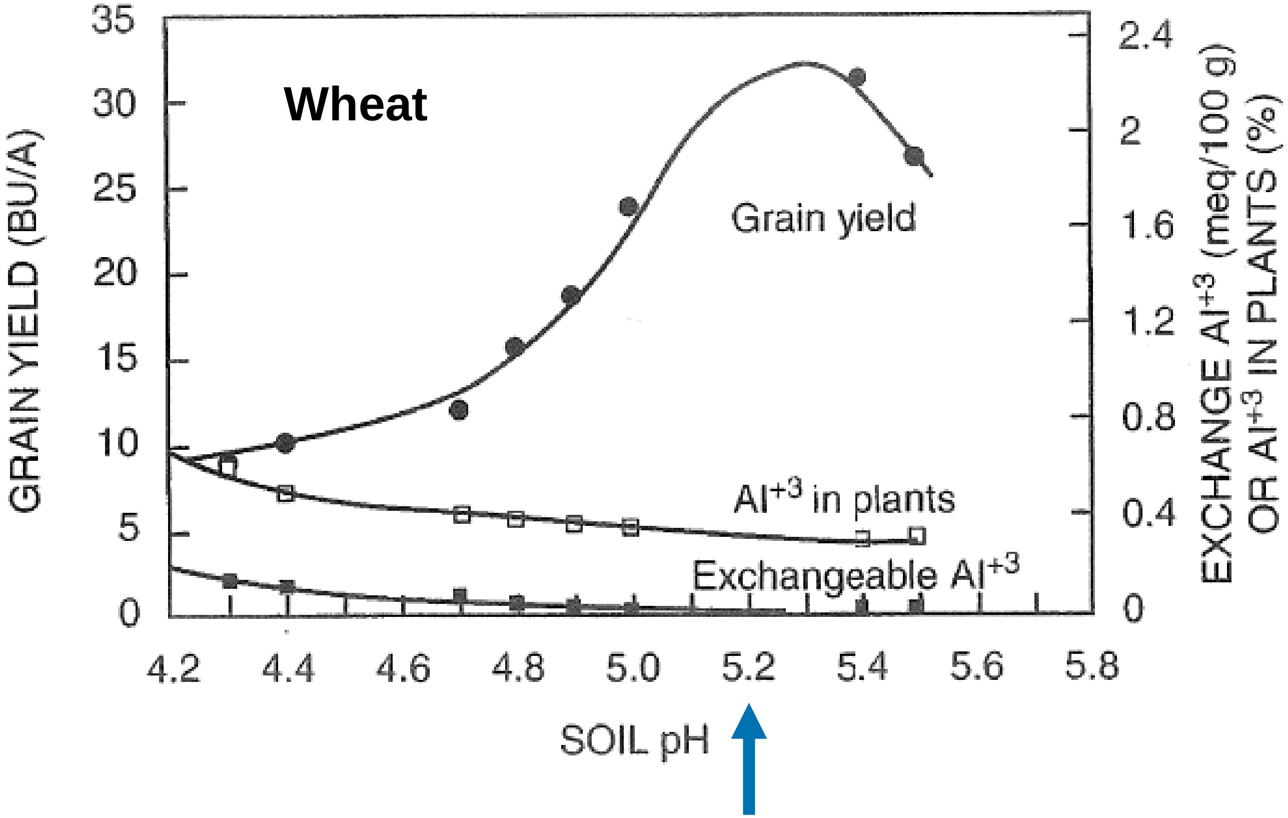
Low pH increases Al^{3+}
More Al^{3+} reduces grain yield



Aluminum toxicity starts near pH 5.0-5.2

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Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 2005. Soil Fertility and Fertilizers: An Introduction to Nutrient Management. 7th ed. Pearson Prentice Hall, Upper Saddle River, NJ.
Patiram, R.N. Rai, and R.N. Prasad. 1990. Effect of liming on aluminum and yield of wheat in acidic soils. J. Indian Soc. Soil Sci. 38(4):719-722.

Herbicides

- Sulfonylureas (Group 2) and Triazines (Group 5)
  - –High pH->Longer herbicide persistence
  - –Low pH->Shorter herbicide persistence
- Imi's (Group 2)
  - –High pH->Shorter herbicide persistence
  - –Low pH->Longer herbicide persistence
- Spartan (Group 14) and Metribuzin (Group 5)
  - –High pH->More active, more crop injury
  - –Low pH->Less active, less crop injury

Weed Control Guide

- Pg 100
- In low pH, residues of Imi herbicides can injure sensitive plants for many years

Site of Action	Common Name	Herbicide Trade name	Premix or Co-pack Trade names
ALS Inhibitor (2) Imidazolinone "Imi"	imazamethabenz imazamox imazapic imazapyr imazethapyr	Assert. Beyond = Clearcast = Raptor. Cadre = Impose = Plateau. Arsenal = Habitat. Pursuit = Thunder.	- Varisto Journey. Sahara. Authority Assist, Extreme=Thunder Master, Lightning, Matador, Pummel, Torment, Zidua Pro.

Weed Contr

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Y2. Breakdown of Imidazolinone (Imi), TPS Herbicides, and some HPPD herbicides (Callisto).

In general, breakdown occurs by soil microbes and **breakdown occurs more rapidly and herbicide activity increases as soil pH increases.** Rate of breakdown decreases in dry conditions. Imi and TPS herbicides are:

1. Broken down by microbes - not broken down by hydrolysis.
2. Not degraded in anaerobic (waterlogged soil) conditions.
3. Not volatile, not photodegraded, not leached beyond 12 inches.
4. Weakly bound to soil but strongly bound to OM.
5. Adsorbed more strongly as soil dries and through time.

Imi herbicides molecules adsorb to OM in dry soil but can desorb and go into soil solution in wet/moist soil allowing molecules to become free for plant uptake and microbial breakdown. For sensitive crops like sugarbeet, the adsorption and desorption process may occur over several years causing crop injury from herbicide residues that become available after moisture events.

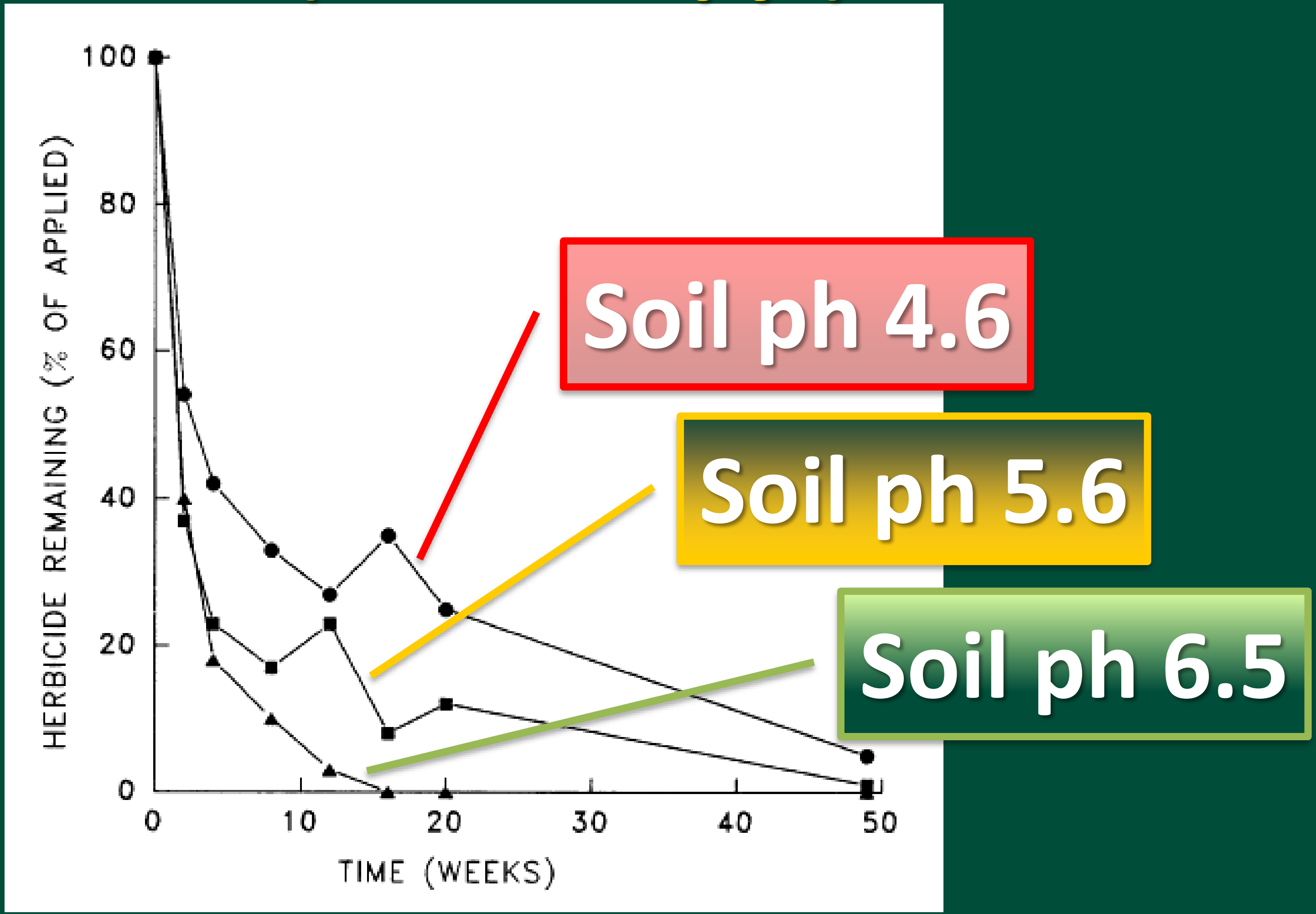
6. Negatively (-) charged, not adsorbed, and free for plant uptake and microbial degradation at soil pH >6.5 for Imi herbicides and pH >7 for TPS herbicides.
7. Strongly bound to OM at pH <6.5 for Imi herbicides and pH <7 for TPS herbicides. For Imi herbicides: Amount adsorbed changes little from 6.5 to 8. At soil pH <6.5, pH reduction as small as 0.2 pH units can **DOUBLE** the amount adsorbed.

Large variation in pH can exist in the same field. In low pH, residues of Imi herbicides can injure sensitive plants for many years.

In summary, activity and degradation of Imi and TPS herbicides increase as soil pH increases. Herbicide adsorption increases as OM matter increases and as soil pH decreases. All factors increasing microbial activity also increase herbicide degradation (warm, moist soils). Degradation increases in soils with pH above 6.5 (Imi) or 7 (TPS) because herbicide molecules are not adsorbed and are in soil solution for plant uptake and microbial breakdown.

IMIs are more persistent at *lower* soil pH

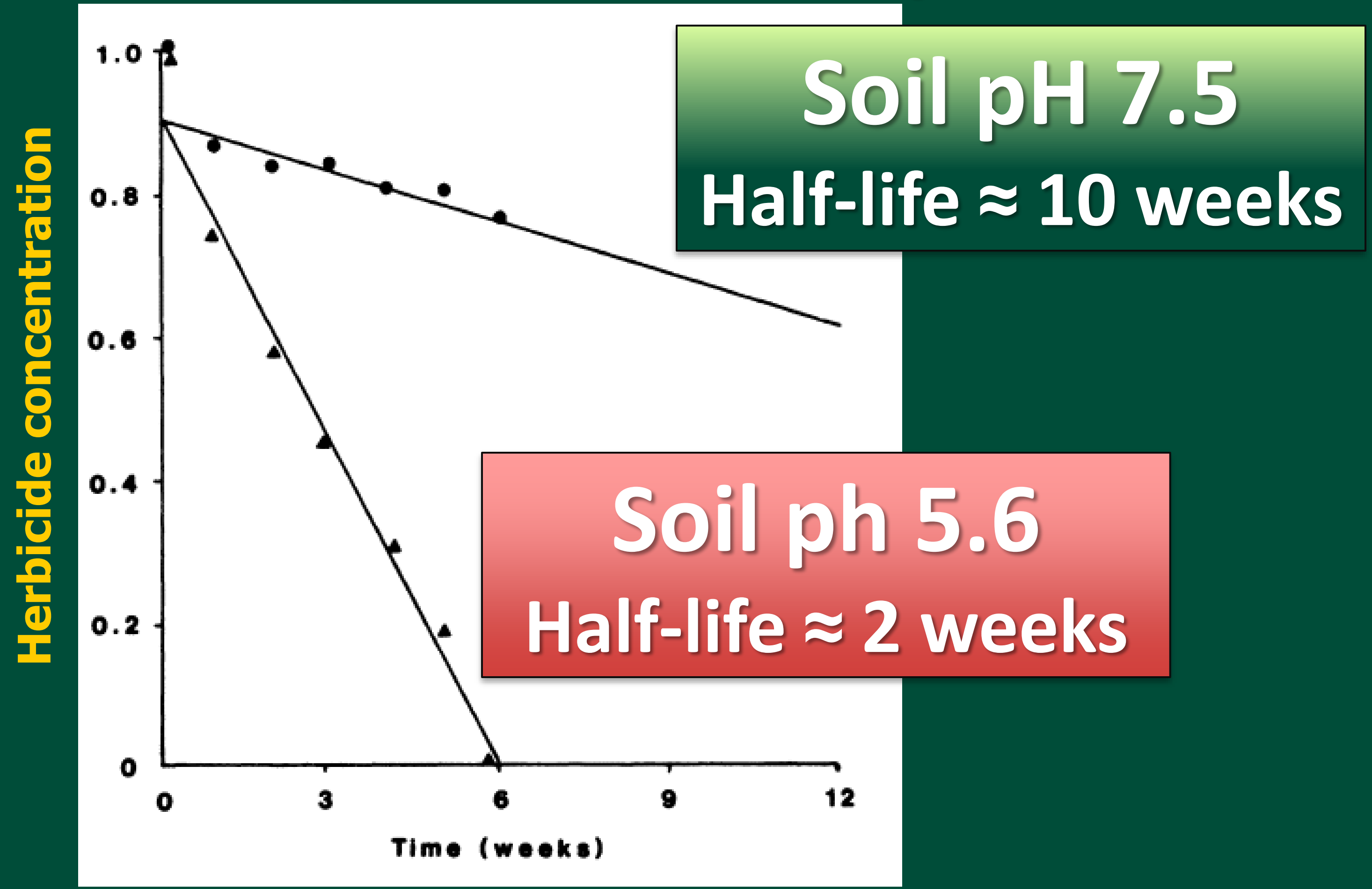
Pursuit (imazethapyr)



Loux and Reese. Weed Tech. 7:452-458

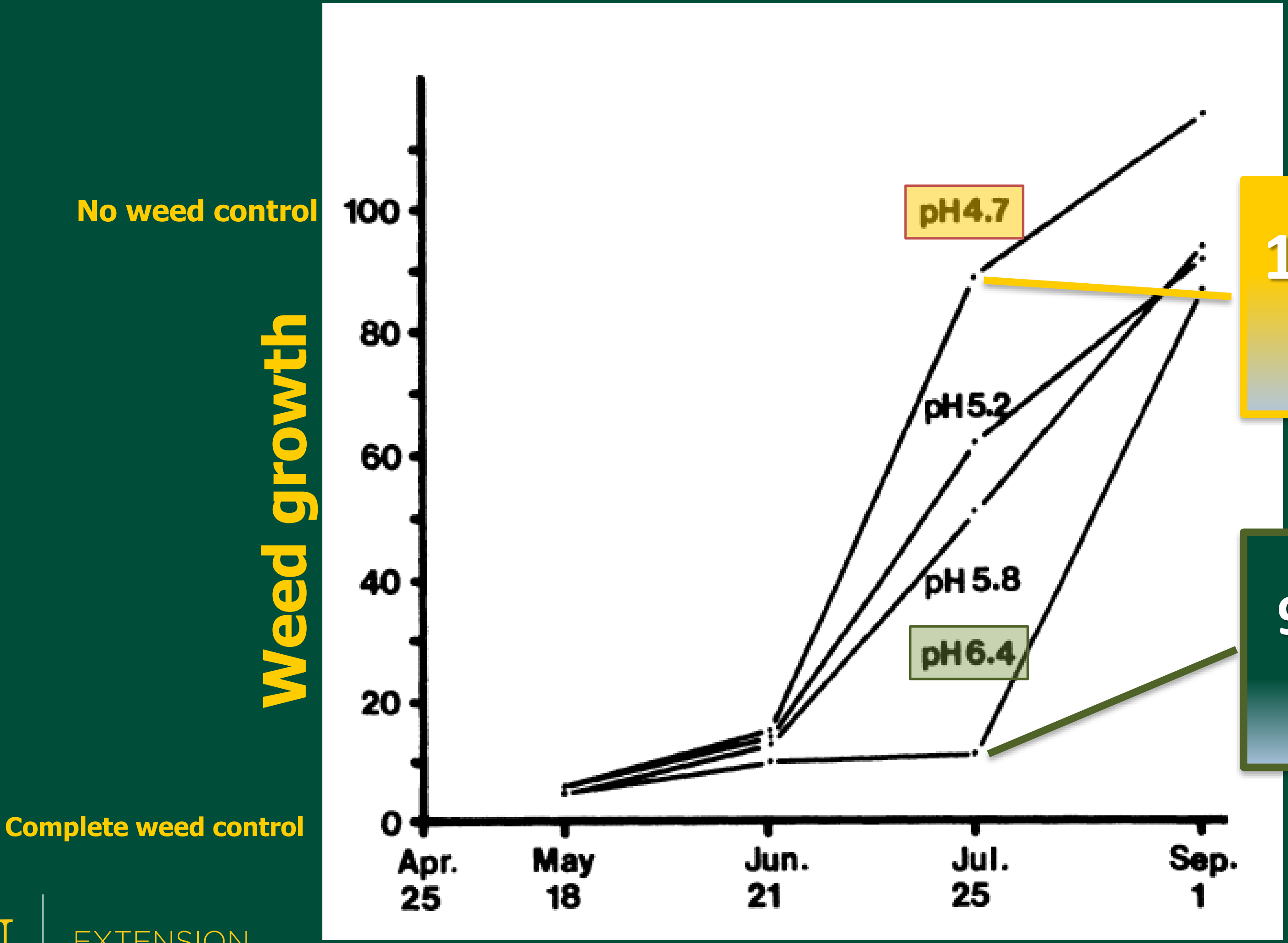
SUs are more persistent at *higher* soil pH

Glean (chlorsulfuron)



Frederickson and Shea, Weed Sci. 34:328-332

Atrazine is more persistent at *higher* soil pH

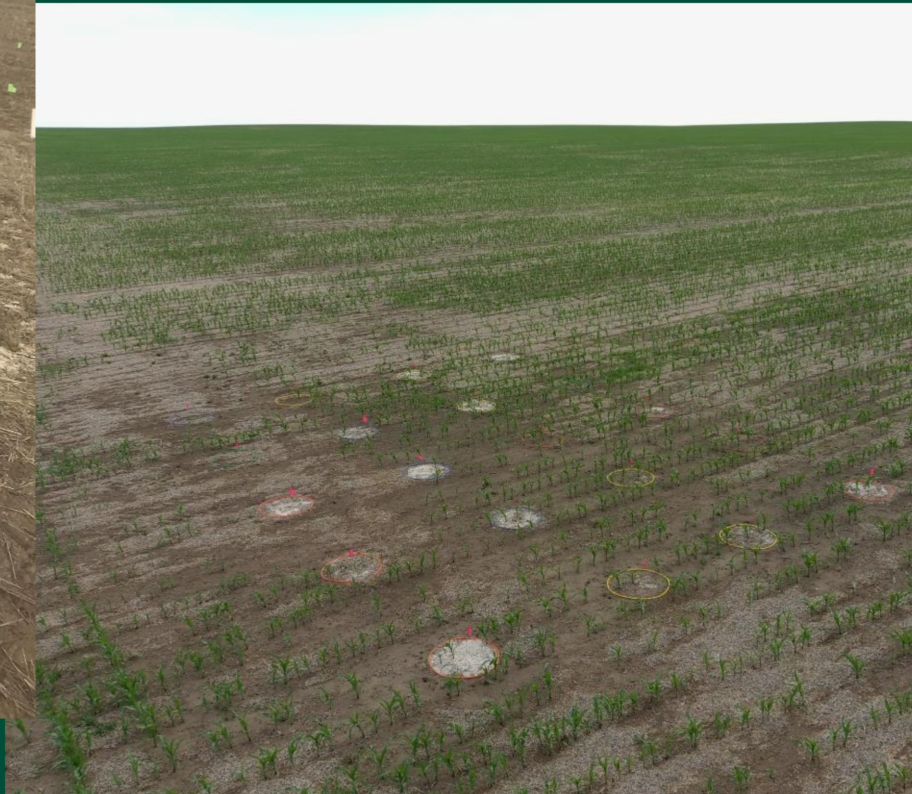


10% control after 2 months

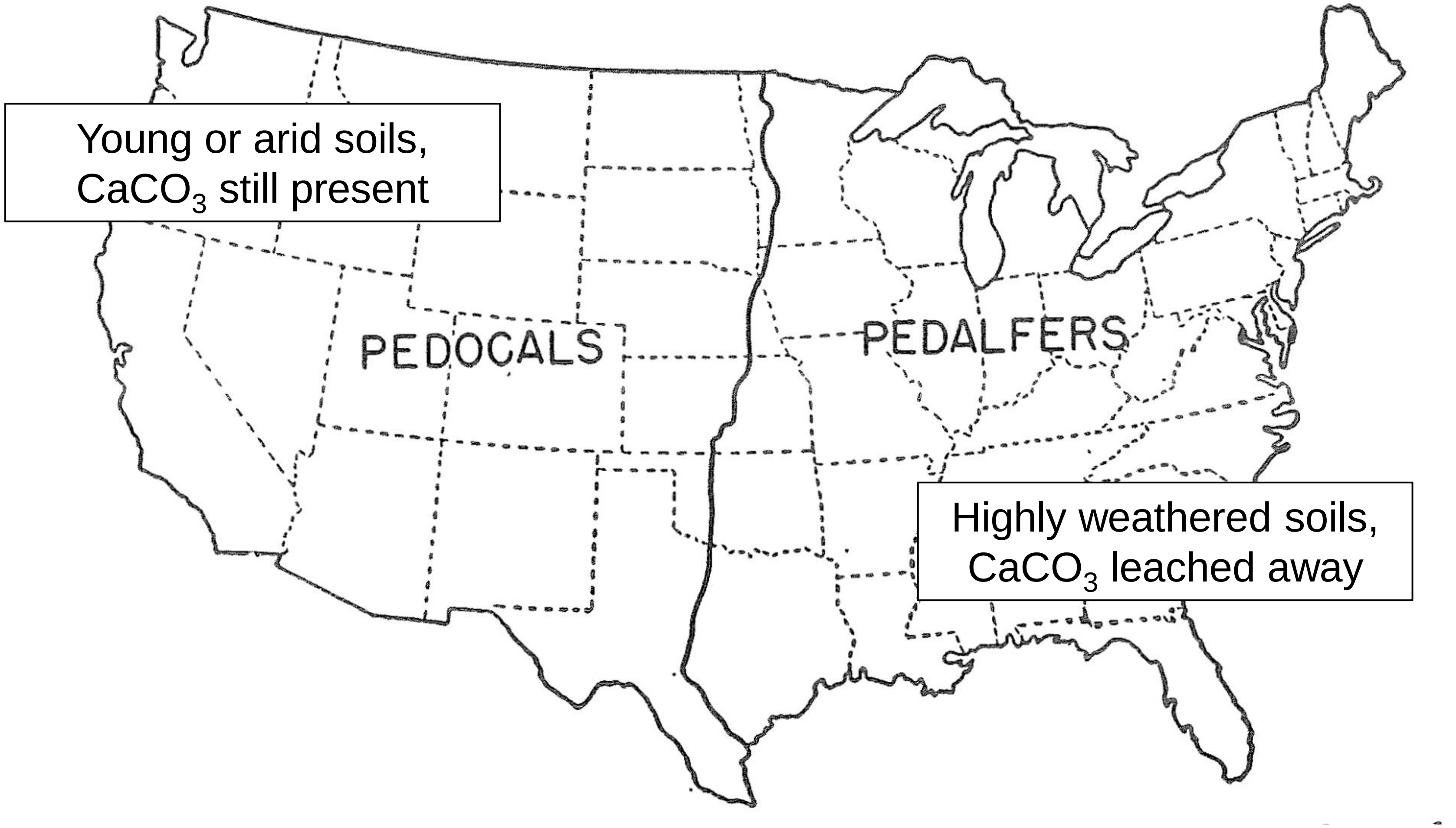
90% control after 2 months

Hiltbold and Buchanan, Weed Sci. 25:515-520

Lime!

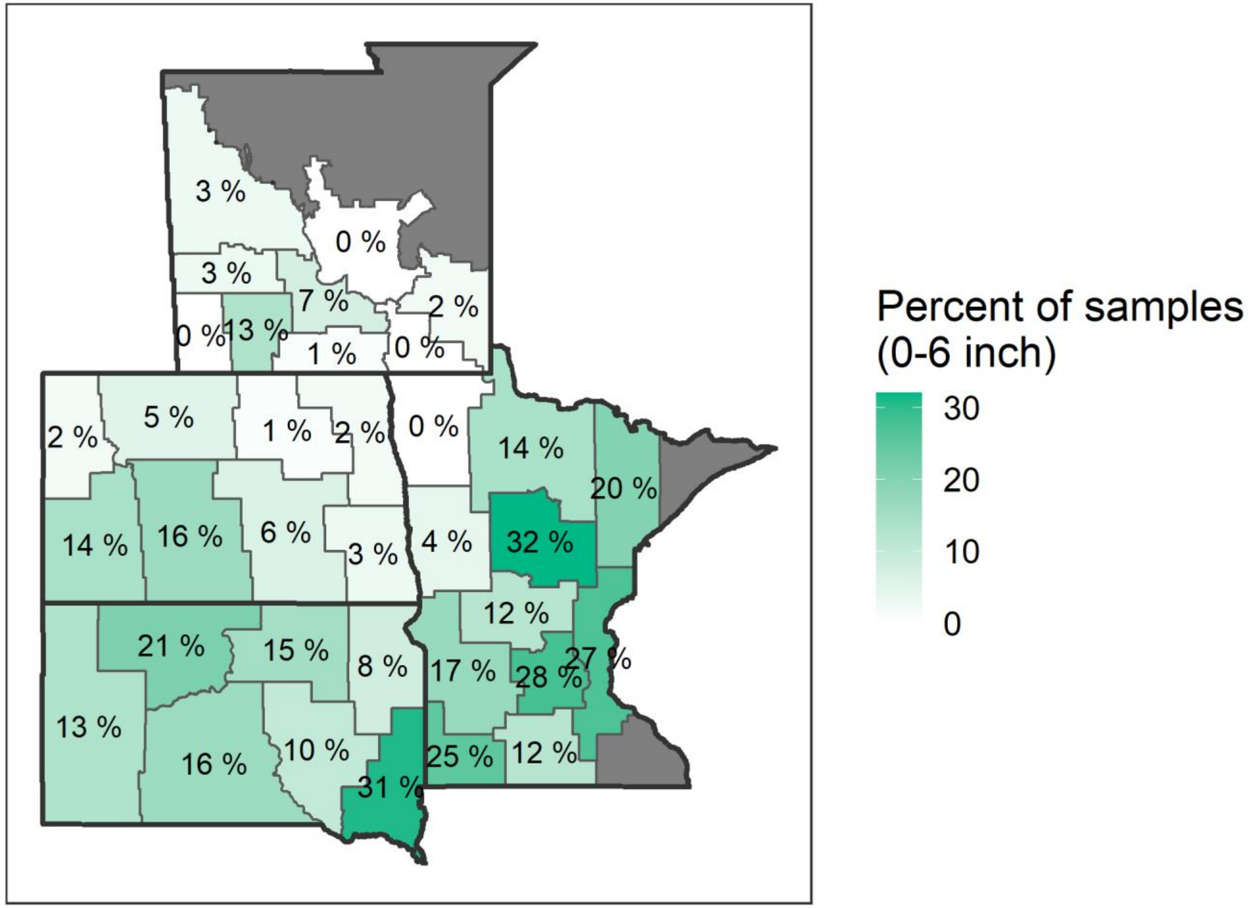


What regions traditionally apply lime?



Jenny, H. 1941. Factors of soil formation. McGraw-Hill Book Company, New York, NY.

Soil samples with soil pH below 6.0 in 2022



Data not shown where n< 100
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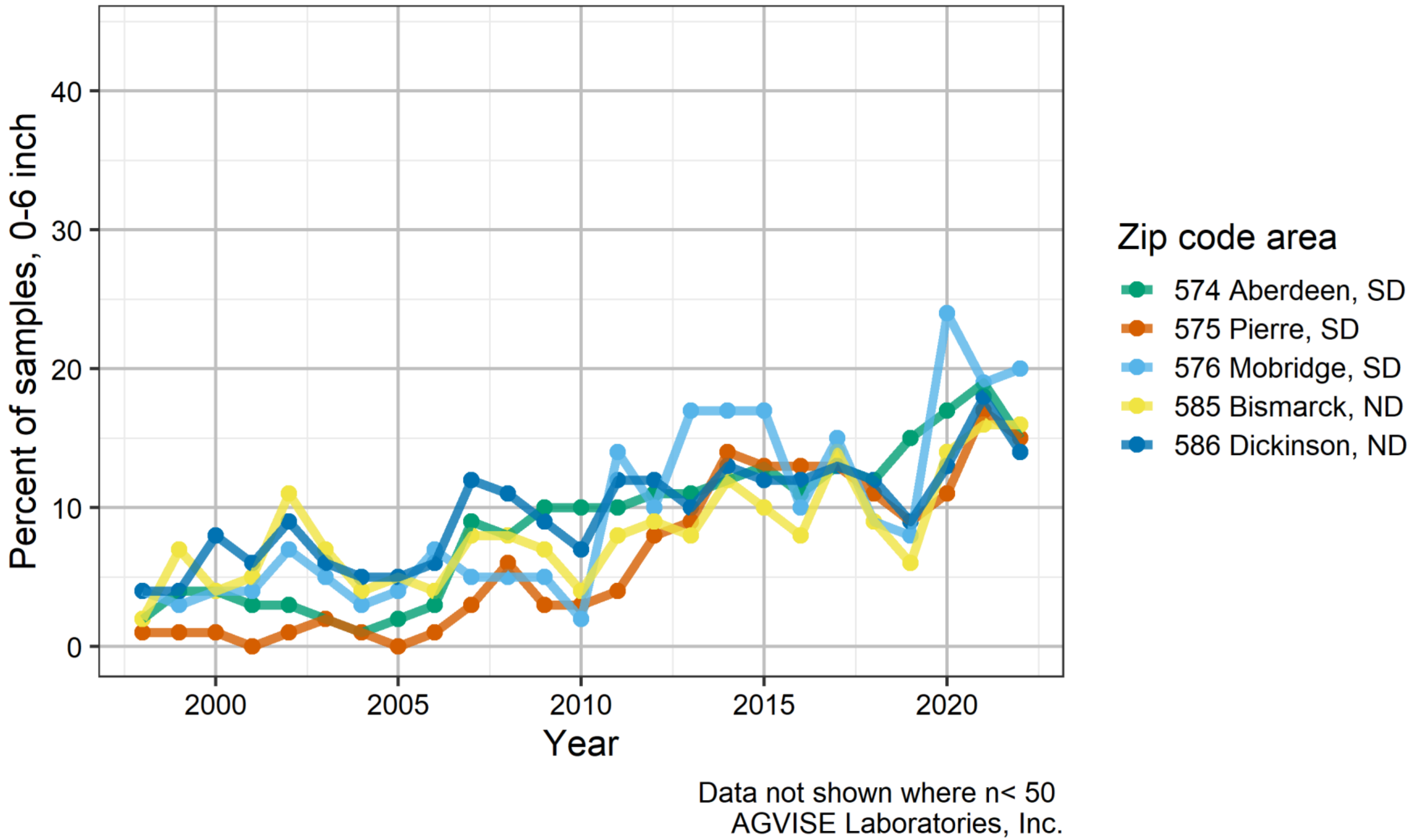
Soil pH trend (pH < 6 1:1) across the northern Great Plains



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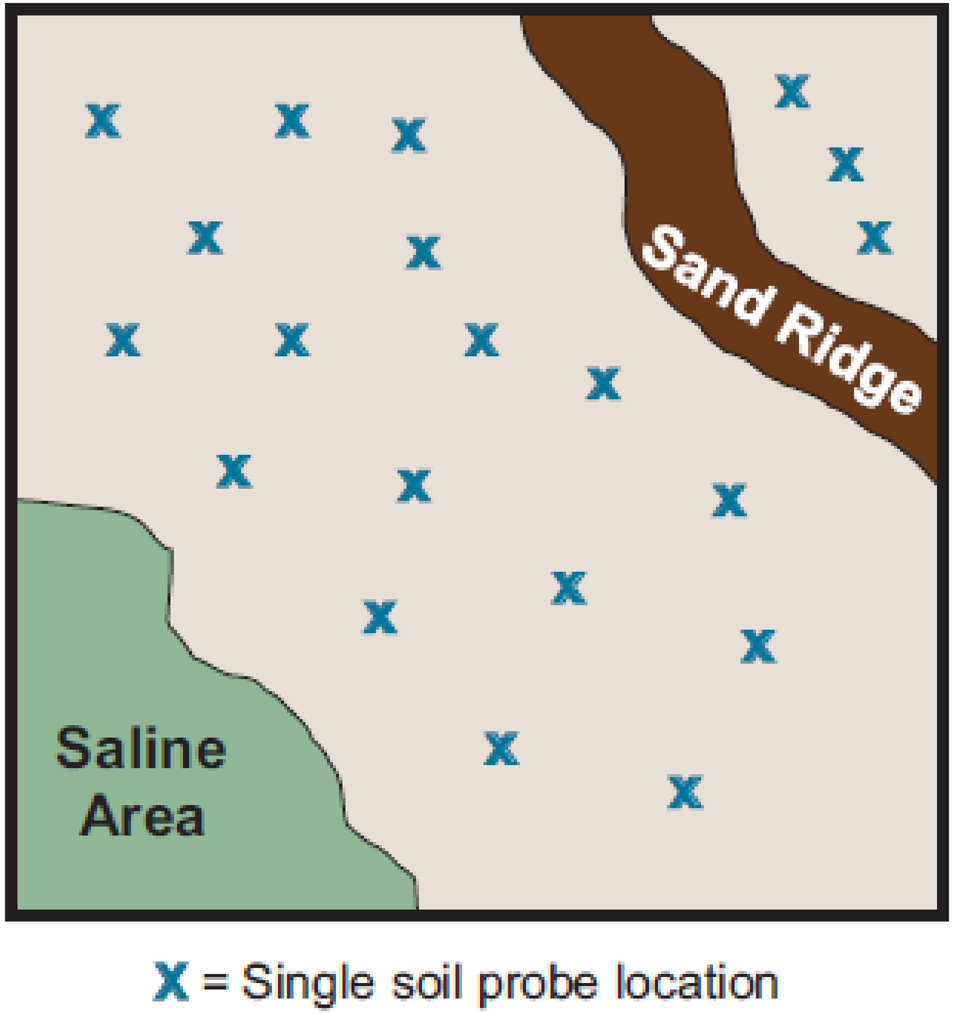
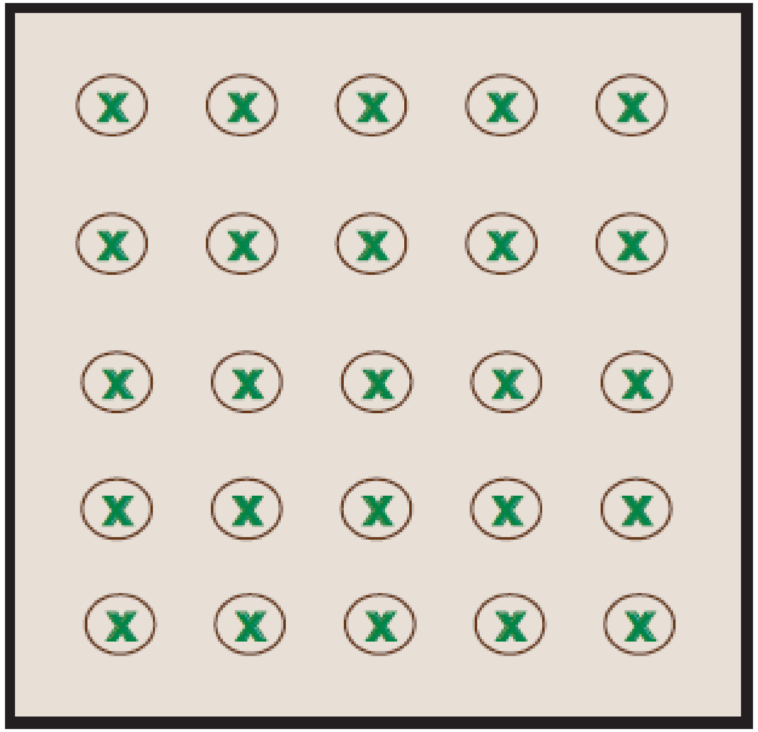
Composite Field Sampling



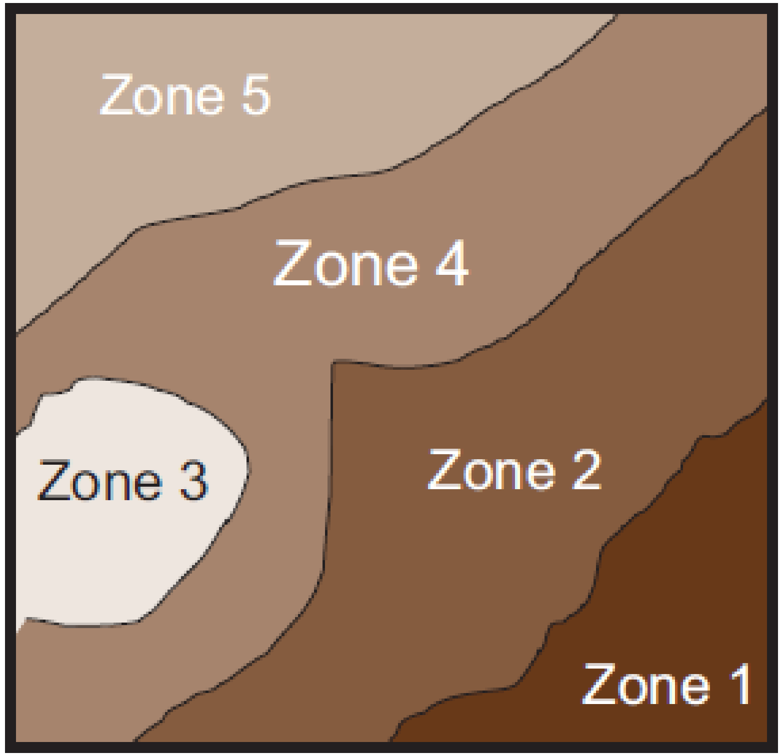
20-25 soil cores collected across entire field
Avoid nonrepresentative areas

Grid Sampling Example



(x) = 8-10 Probe Sites per grid point

Productivity Zone Sampling Example



10-15 Probe Sites per zone area

Zone soil sampling reveals field variability

	Average soil test range within a field (high zone – low zone)					
Number of zones per field	**Nitrate-N lb/acre, 0-24 inch**	**Olsen P ppm**	**K ppm**	**pH**	**EC(1:1) dS/m**	**SOM (%)**
3	31	9	93	0.6	0.8	1.1
4	39	14	118	0.8	0.9	1.2
5	47	17	143	0.9	1.1	1.9
6	63	21	175	1.1	1.4	1.8
7	69	23	185	1.2	1.5	1.6
8	66	28	196	1.4	1.3	2.0

Summary of 26,000 precision soil sampled fields from Manitoba, Minnesota, North Dakota, South Dakota; AGVISE Laboratories, 2022.

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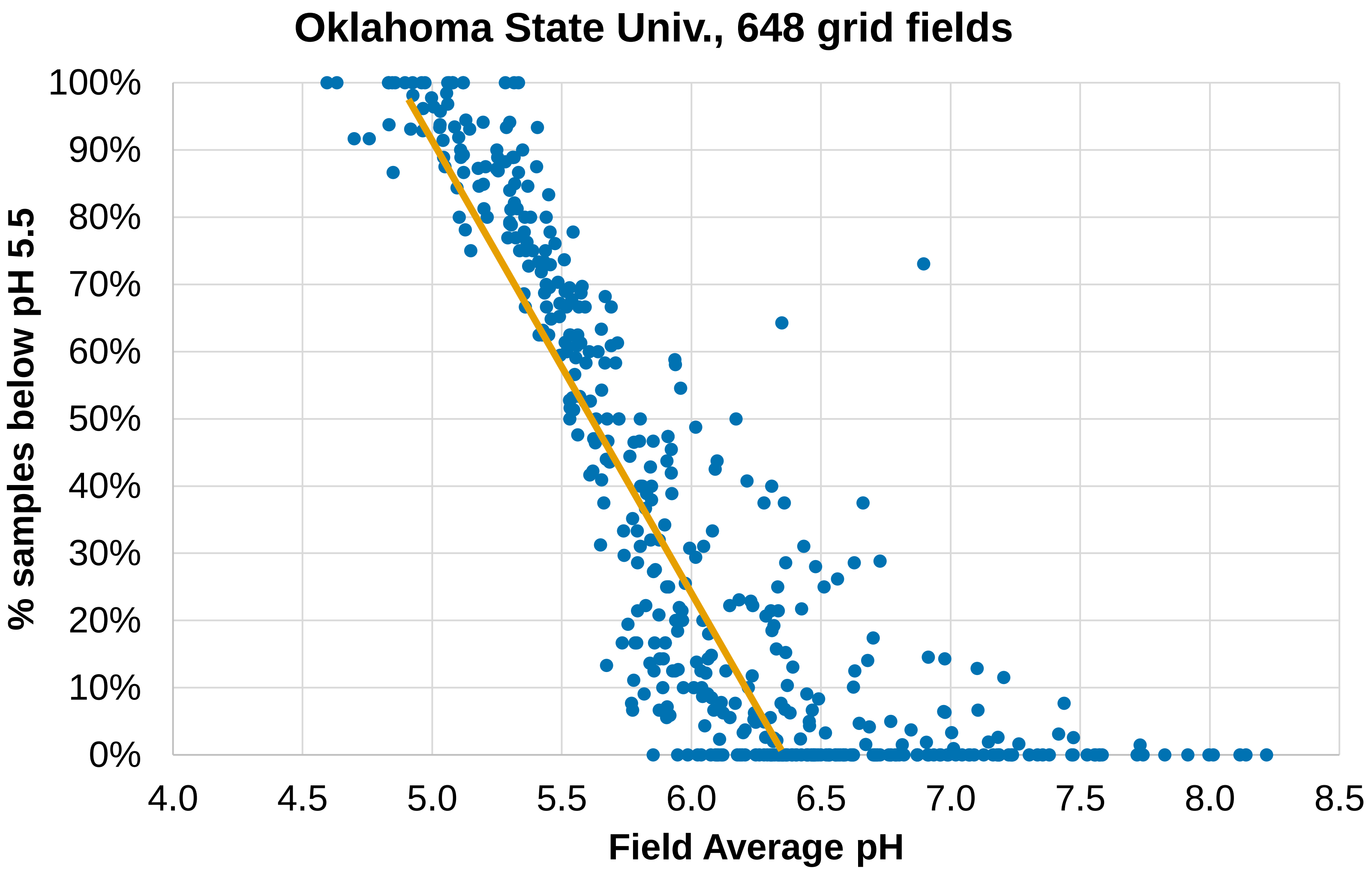
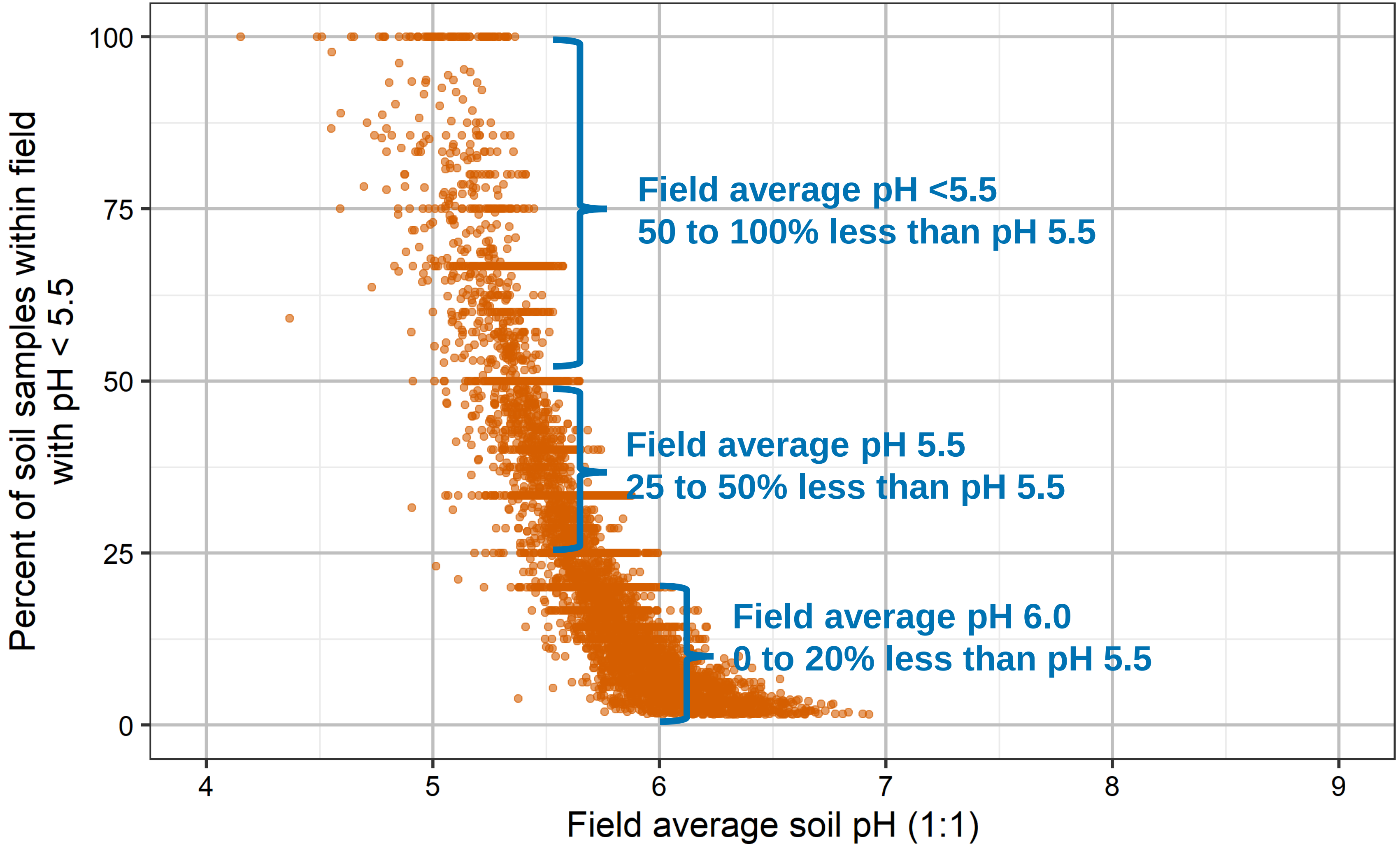
pH variability is hidden in the average



Slide courtesy of Brian Arnall, Oklahoma State Univ., Stillwater, OK.

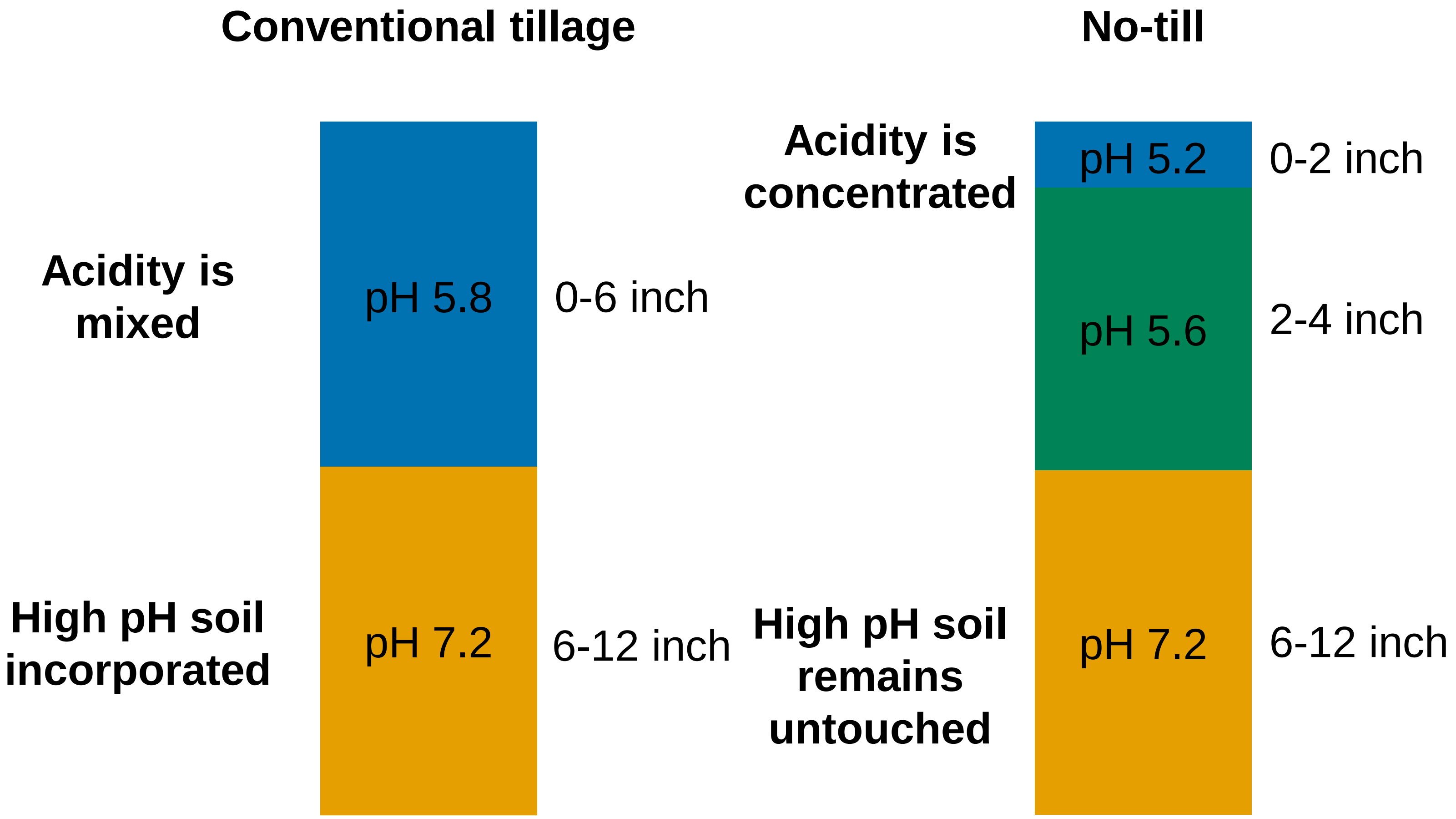
pH variabilty is hidden in the average



AGVISE Laboratories, Inc.

Summary of 58,000 precision soil sampled fields from Manitoba, Minnesota, North Dakota, South Dakota; AGVISE Laboratories, 2021-2022.

Soil pH stratification and tillage



Factors Affecting Lime Effectiveness

- Time/Temperature
- Pureness of lime
- Particle size
  - The finer the lime, the faster it dissolves
- Rainfall
  - Need moisture to dissolve
- Incorporation
  - This increases soil contact. pH improvements observed in true no-till and arid conditions.

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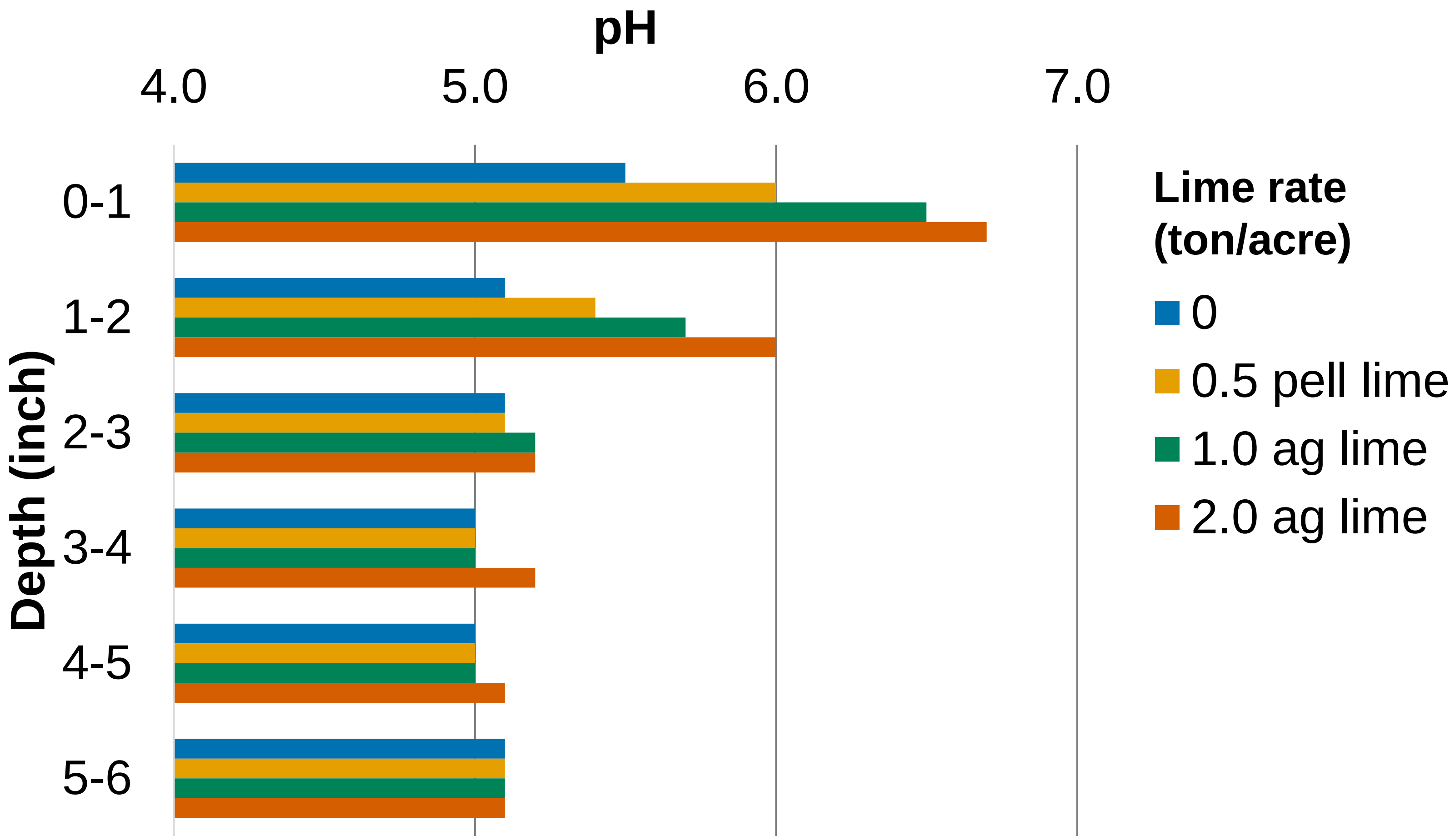
Surface liming on no-till effective in Kansas, after 4 years



Godsey, C.B., G.M. Pierzynski, D.B. Mengel, and R.E. Lamond. 2007. Management of soil acidity in no-till production systems through surface application of lime. Agron. J. 99(3):764–772.

AGVISE Long-term Lime Project

Objective: determine the amount of surface-applied lime required to raise pH and track lime movement

Site: Golden Valley, ND
Grail silty clay loam

Soil pH
- 0-3 inch: 5.2
- 3-6 inch: 5.4

Buffer pH
- 0-3 inch: 6.3
- 3-6 inch: 6.4

Trial initiated: 5 May 2021

Treatments:
0 to 2.5 ton/acre ENP
surface application, no incorporation

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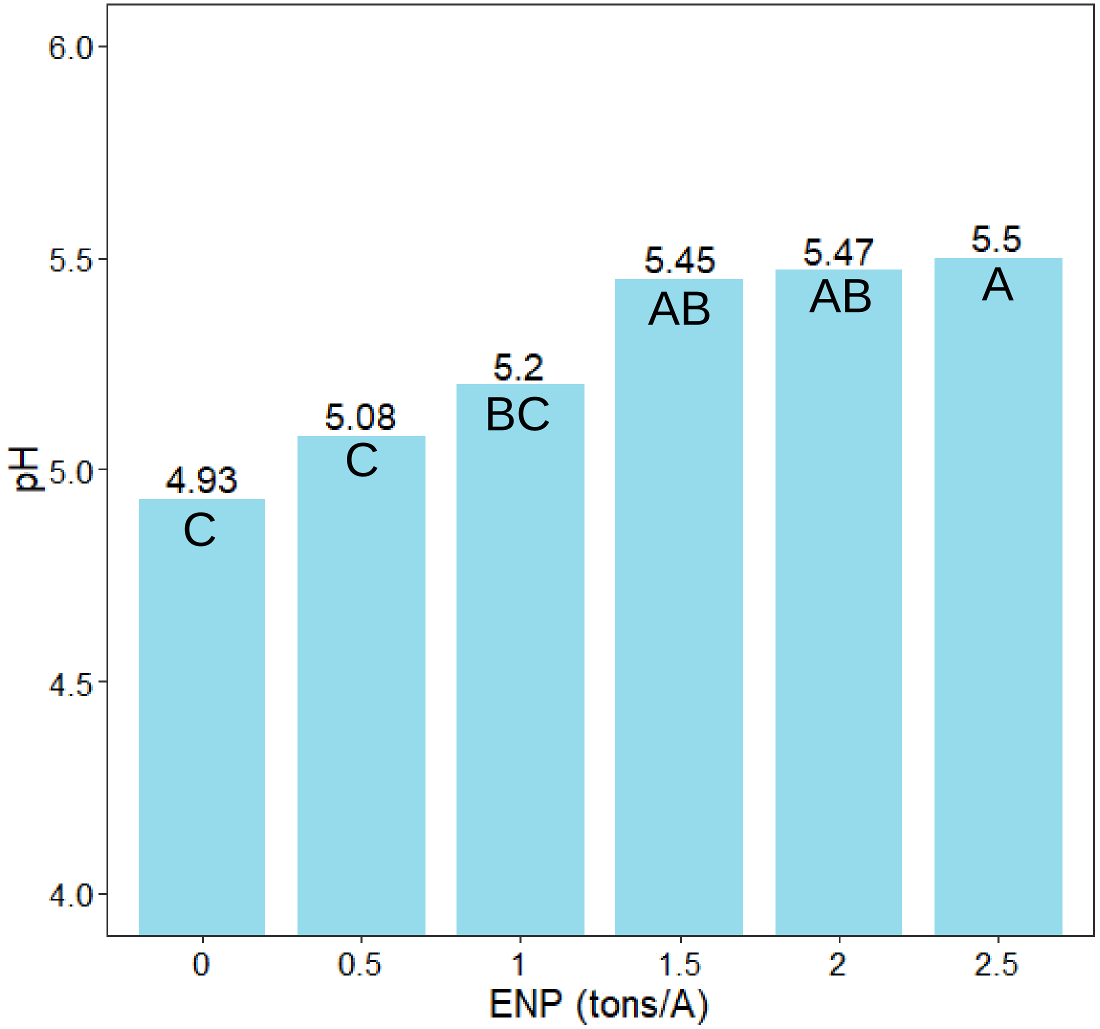
Soil pH change after 1.5 years after lime application, 0-3 inch



No changes in 3-6 inch pH yet

NDSU liming work in progress with Dr. Chris Augustin

Figure 1. Locations of experimental sites in North Dakota (Google LLC, 2022).

- Promising data on surface application
- Still analyzing 2022 data
- Sign up for Dickinson REC newsletter for updates

Table 2. Regression analysis and predicted lime needed to raise soil pH at the 0-3 inch depth.

Buffer pH‡	Desired pH (0-3 in depth)			Equation**	r^2
	5.5	6	6.5		
	Tons of Calcium Carbonate/Acre				
6.2 n=5†	5.6	9.5	14	$y = 1.271x^2 - 6.8828x + 5.0276$	0.99*
6.3 n=7	10	11	8.5	$y = -7.0431x^2 + 82.954x - 233.15$	0.6
6.4 n=20	0.7	3.4	8.6	$y = 5.1047x^2 - 53.374x + 139.86$	0.81*
6.5 n=24	2.7	5.2	8.6	$y = 1.5829x^2 - 13.1x + 26.826$	0.60*
6.6 n=29	2	4.5	8.1	$y = 2.0756x^2 - 18.833x + 26.826$	0.67*
6.7 n=19	1.5	5.5	9.2	$y = -0.6377x^2 + 15.394x - 63.884$	0.57*
6.8 n=27	0.9	2.4	5.1	$y = 2.3551x^2 - 24.025x + 61.806$	0.54*
6.9 n=22	0.1	1.2	3.8	$y = 2.9871x^2 - 32.222x + 86.998$	0.61*
7.0 n=16	-0.1	0.5	2.5	$y = 2.9062x^2 - 32.259x + 89.428$	0.59*
7.1 n=5	1.1	4.2	7.3	$y = -0.1207x^2 + 7.6291x - 37.184$	0.56

*r^2 was significant at the 0.05 level.

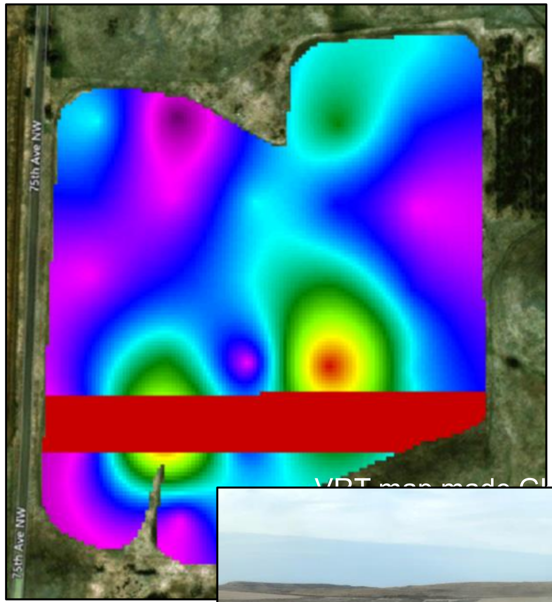
**x variable is desired soil pH at the 0-3 in depth. y variable is tons of lime/ac.

†n is the number of samples from each soil environment.

‡Sikora, 2006.

Real-world liming in western North Dakota

- Approx. $100/acre
  - $0/ton sugar beet from Sidney Sugar
  - $39/ton transportation ~ 136 miles
  - $11.50/acre application + $5.00 per ton/acre
- VRT-based on 1-acre grid (0 to 4 ton/acre lime)
- Lime disked to 3 inch after application



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Raising soil pH

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2O + CO_2(g)\uparrow$$

lime *hydrogen* *calcium* *water* *carbon dioxide*

Carbonate needed to neutralize acidity (H^+) and increase soil pH

Gypsum (calcium sulfate, $CaSO_4 \cdot 2H_2O$) does not contain carbonate

- Not a lime source
- Does not fix the pH, nutrient availability, or herbicide activity problems

Lime sources

Ag lime

Crushed limestone

Cheap, no local sources

Pelleted lime

Crushed limestone, then pelletized

Expensive, no local sources, easy handling

Spent lime

By-product lime from industry or water utilities

Cheap, local sources, difficult handling

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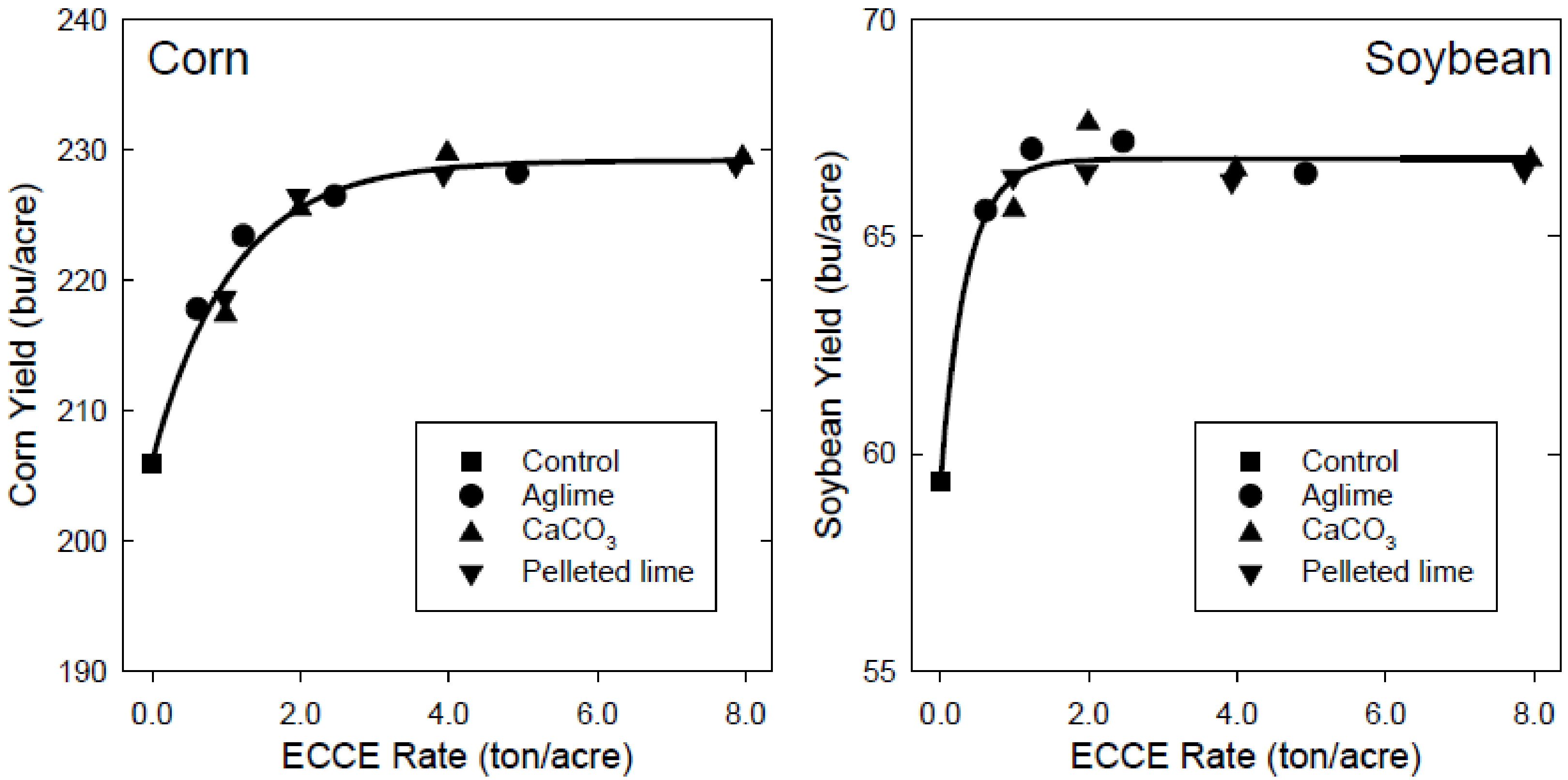
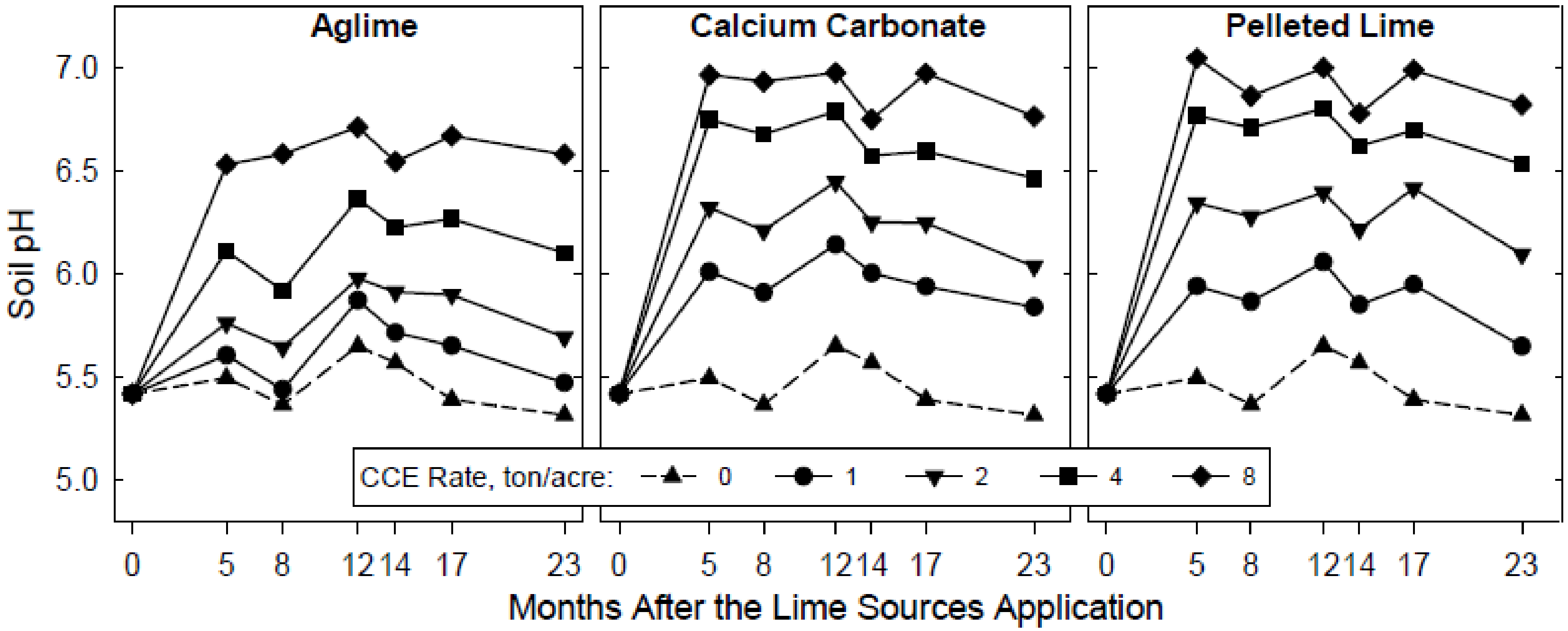
Comparing lime sources



Mallarino, A.P., and M.U. Haq. 2017. Evaluation of agricultural lime and pelleted lime to increase soil pH and crop yield. In: Proceedings of the 47th North Central Extension-Industry Soil Fertility Conference. Des Moines, IA. 15-16 Nov. 2017. Intl. Plant Nutr. Inst., Peachtree Corners, GA. p. 109–117.

All lime products are effective, but… Low lime rates are not



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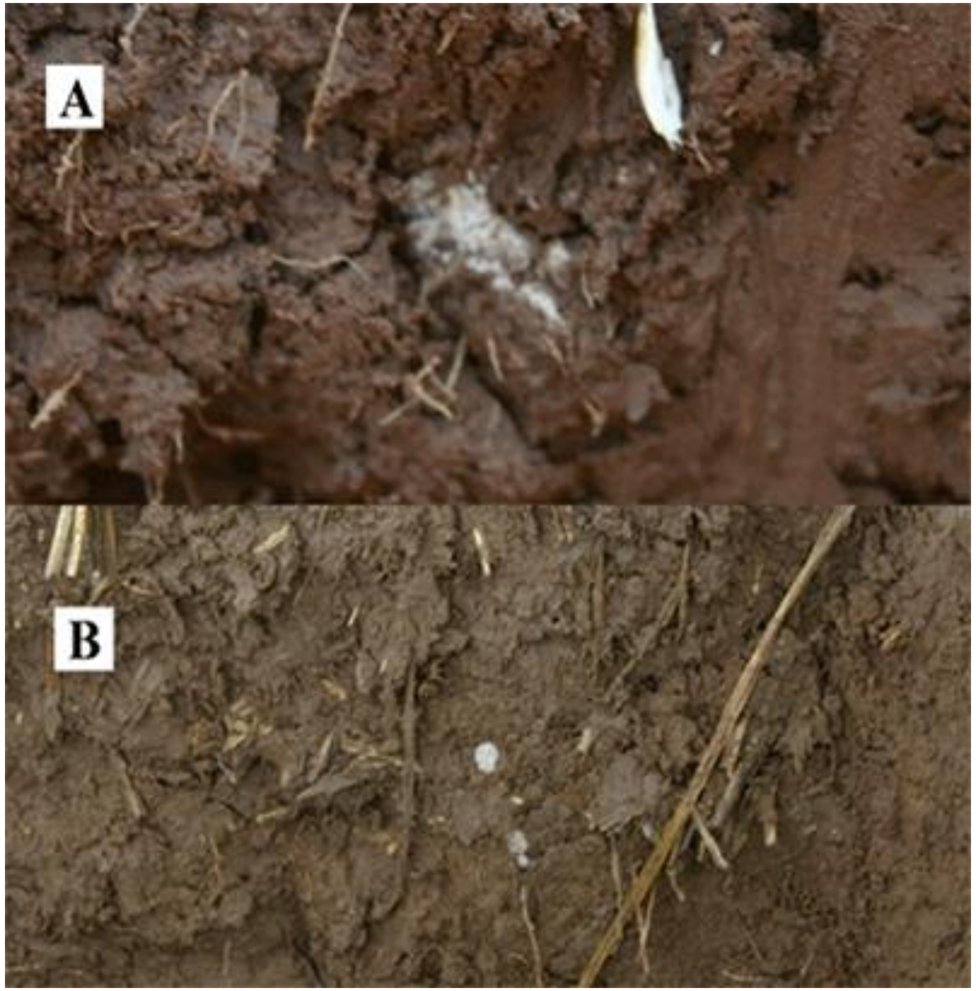
In-furrow pelletized lime disperses poorly (applied ~7 months before)



June 2011

June 2012

Lollato, R.P., J. Edwards, and H. Zhang. 2017. Effectiveness of in-furrow pelletized lime for winter wheat grown in low soil pH. OSU Ext. Circ. PSS-2164. Oklahoma St. Univ., Stillwater, OK. http://factsheets.okstate.edu/documents/pss-2164-effectiveness-of-in-furrow-pelletized-lime-for-winter-wheat-grown-in-low-soil-ph/ (accessed 26 Jan. 2018)

Calcium

Calcium fertilizer yields of HRSW across other treatments, Dickinson 2021 and 2022.

	Yield	
	bu/ac	
Treatment	2021	2022
Control	21.4	54.3
Lime in furrow	20.3	56.3
Gypsum in furrow	20.8	57.4
Calcium nitrate in furrow	N/A	57.8
LSD (0.05)	ns	ns

- Low rates of lime will not have a significant impact on pH or yield
- Tons of lime are needed!

What about rented acres?
What about while waiting for lime to react?

Bandaid management

More like putting a wrap on a broken bone, than a bandaid
If continuing like normal it will get much worse without appropriate treatment

HRSW variety evaluation for acidity tolerance (Dickinson, ND 2018)

More tolerant variety (right) has larger root system and more plant growth

Photo: J.S. Breker, June 2018.

Species Selection

Aluminum tolerance of selected crops. (Soil Fertility and Fertilizer 7th Edition, Havlin et al.)			
Highly Sensitive	Sensitive	Tolerant	Highly Tolerant
Alfalfa	Canola	Ryegrass	Oats
Annual medics	Barley	Orchard grass*	Orchard grass*
Red clover	Wheat*	Wheat*	Triticale
Safflower	Soybean	Lupins	Cereal rye
	Sorghum	Corn	Teff
*Some crops are listed twice because Al tolerance can depend on variety			

Hard Red Spring Wheat management

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Varietal difference in acidity

- TaAl1 gene
- Variety trials conducted from 2018-2022

Wheat variety assessment on acidic soil near Dickinson, ND. Soil test results showed pH of 5.7, 4.5, and 4.2 and 0-2", 2-6", and 6-12" respectively. Trial planted May 9th, 2018.

Variety	Yield	Test Weight	Aluminum	Manganese
	(bu/ac)		Tissue samples collected around early flag leaf	
Soren	39.9c	59.3a	91.7	283.5
Alum	49.4b	56.3b	72.4	209.5
Glenn	50.7b	57.0a	54.0	264.5
Bolles	50.8b	57.8ab	118.2	277.8
Lanning	58.7a	55.5b	88.7	255.8
LSD (0.05)	5.2	2.3	ns	ns

Acid soil HRSW variety trial yield results. All sites averaged below 5.3 pH in top 3" of soil.

Variety	Dickinson 2021	Lefor 2021	Lefor 2022
		bu/ac	
Bolles	18.0	57.3	22.4
CP3099A	**23.0**	-	**27.5**
CP3119A	**22.6**	69.3	23.4
CP3188	21.8	65.4	**31.1**
CP3530	19.9	-	22.5
CP3915	17.4	64.4	21.9
Dagmar	22.6	64.2	-
Duclair	20.2	61.5	-
Glenn	18.6	60.4	19.5
Lanning (tolerant check)	20.5	64.8	21.2
SY Soren (susceptible check)	19.2	61.9	16.7
TCG Heartland	15.8	62.3	-
TCG Spitfire	20.8	**72.6**	22.2
TCG Wildcat			19.3
WB9479	12.7	61.8	-
WB9516	13.1	68.4	-
WB9590	13.2	66.8	-
WB9606	21.4	67.4	14.2
WB9719	11.2	**70.8**	25.6
LSD (0.05)	3.9	4.2	3.9

Varietal difference in acidity

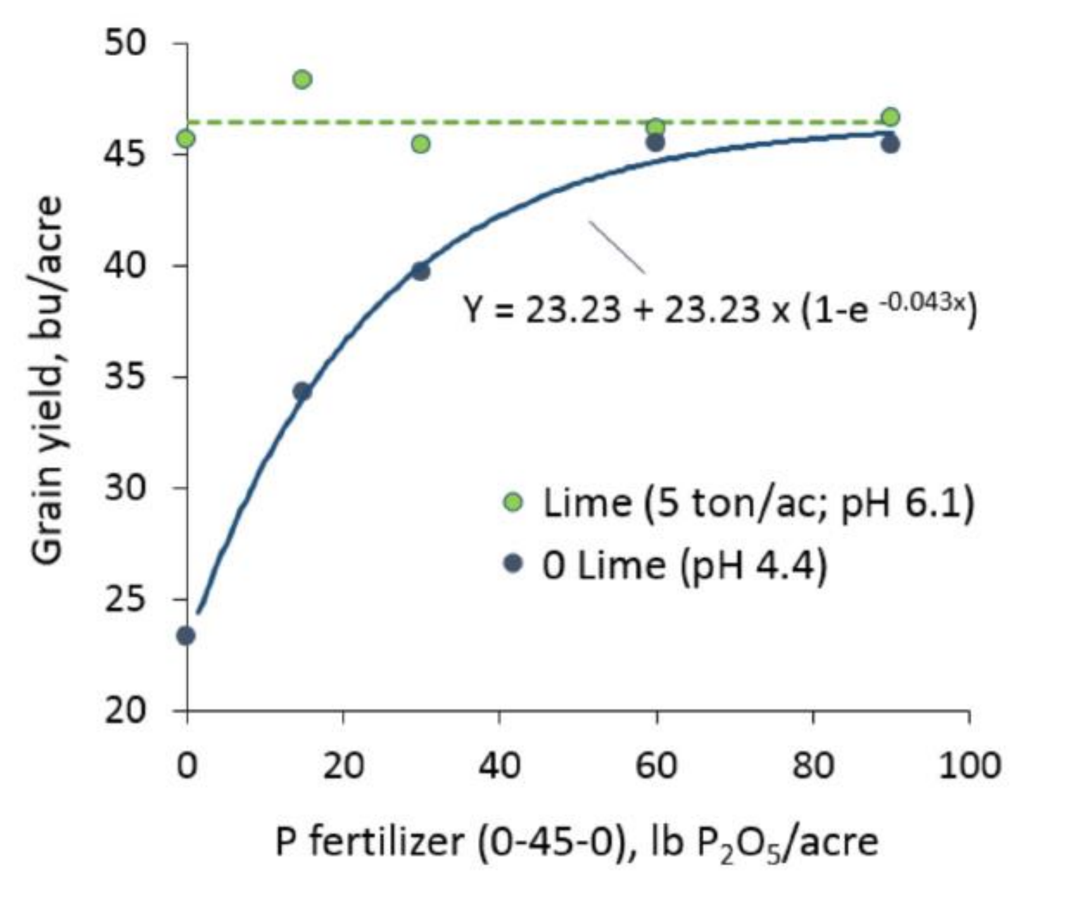
HRSW variety across fertilizer treatments, Dickinson 2021 and 2022.

	Yield	
	bu/ac	
Variety	2021	2022
SY Soren (susceptible)	19.6b	47.5b
Lanning (tolerant)	22.3a	65.4a
LSD (0.05)	1.2	3.2

*Cultivar selection is most economical band-aid, however you are still dealing with issues of nutrient tie up, reduction in microbial activity, and impacts on herbicide efficacy

Montana research in Durum

Fig. 8, right: Durum grain yield increased with seed-placed P_2O_5 (0–45–0) at this field testing high in Olsen P only when soil pH was not corrected with Aglime (Engel, unpublished data).



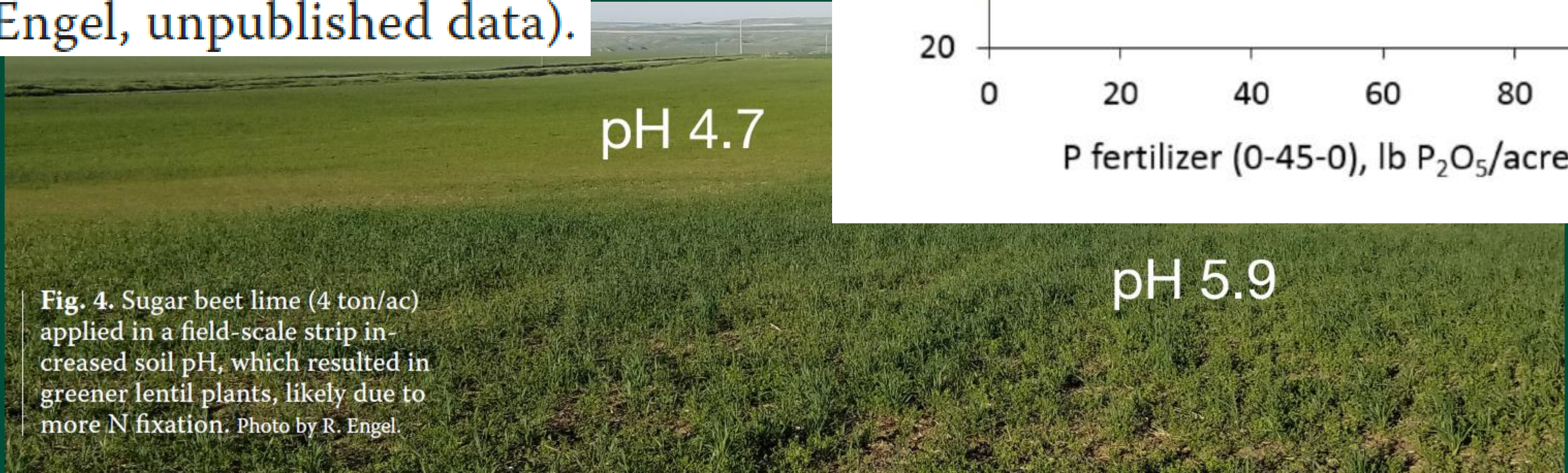


Fig. 4. Sugar beet lime (4 ton/ac) applied in a field-scale strip increased soil pH, which resulted in greener lentil plants, likely due to more N fixation. Photo by R. Engel.

Phosphorus

- Added 130 lbs per acre of TSP in furrow (0-46-0)

P fertilizer across HRSW varieties, Dickinson 2021 and 2022.

	Yield bu/ac	
Treatment	2021	2022
Control	20.1b	51.8b
60 lbs additional P	21.6a	61.1a
LSD (0.05)	1.2	3.2

Other options

- Looked at biologicals, humic acid, PGR's on HRSW
  - No significant difference at 2 locations in 2021

Recommendation for acidity

- Zone/site specific sampling 0-3” and 3-6” for pH
  - Acidity -- if present -- will be near placement of N fertilizer in reduced tillage systems
  - Green foxtail, barnyard grass can be more prevalent in these areas
  - Also look for areas with reduced stands, potential herbicide damage
- Lime if pH is dropping below 6
  - Need more data on surface applications to make no-till recommendations, will vary by soil and starting pH, for many minimum 2 tons needed
    - Low rates of lime, <500 lbs, is an ineffective rate when it comes to major acidity
  - Many different environmental and management variables
  - On-farm testing is best approach to stay ahead of the curve
- Seed-placed P and species/cultivar selection can reduce yield loss in acid soils
- Be aware of surface pH when making herbicide applications

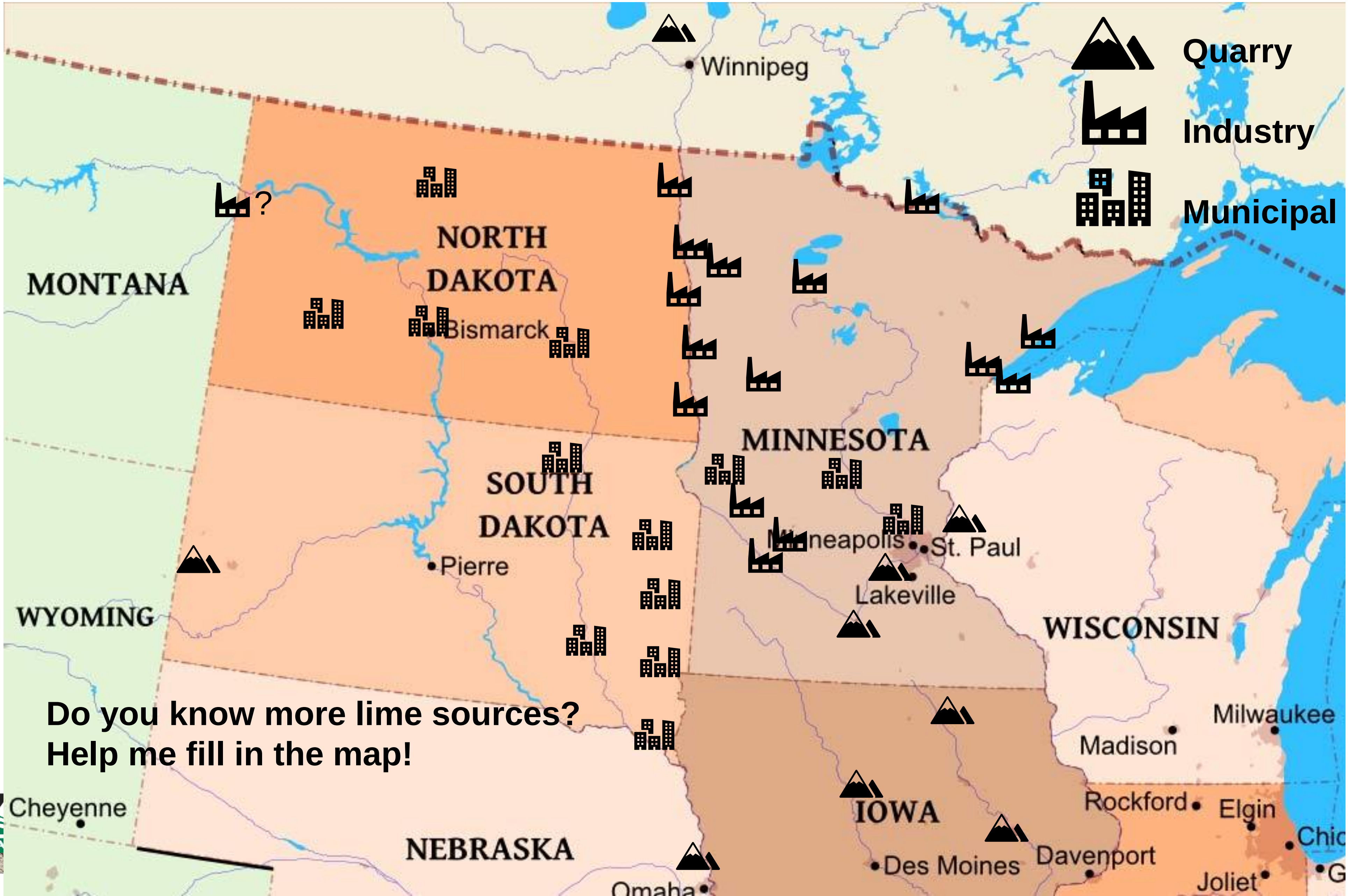
Soil and Disease Relationships

- Diseases suppressed by optimal fertilizer
- Chloride
  - Common root rot, leaf rust, and take-all in small grains, spot blotch in barley
- Copper
  - Take-all and ergot
- Boron
  - Ergot
- There isn't a magical mix of fertilizer that will fix all your problems, you need to know where you are through soil sampling to know if something is needed
- **Important to remember that diseases can be complex and impacted by a wide range of factors, host, pathogen, and environment all play a part**

Environment

- We aren’t applying these products in a vacuum
- There will be interactions with moisture levels (or lack of), temperature, soil type, equipment, management decisions, etc.
- Each field is different, and each year in that field is different
- Learn what works best for you by setting up strip trials in your own fields (always have an untreated check)

Lime sources across the northern Great Plains



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