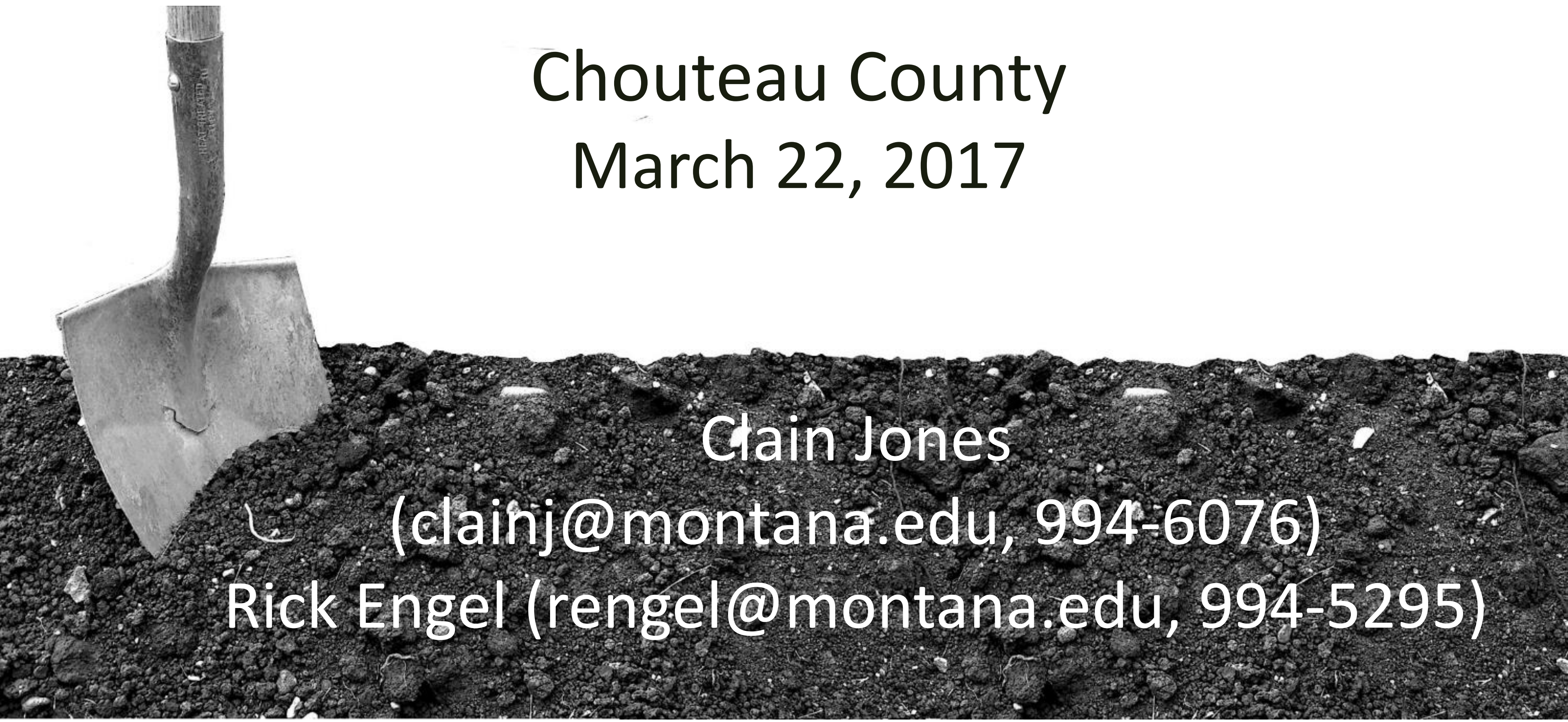
SOIL ACIDIFICATION: CAUSES, MANAGEMENT, AND RESEARCH

Chouteau County
March 22, 2017



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MONTANA STATE UNIVERSITY

Chouteau Co. CD, NRCS, and MSU Extension

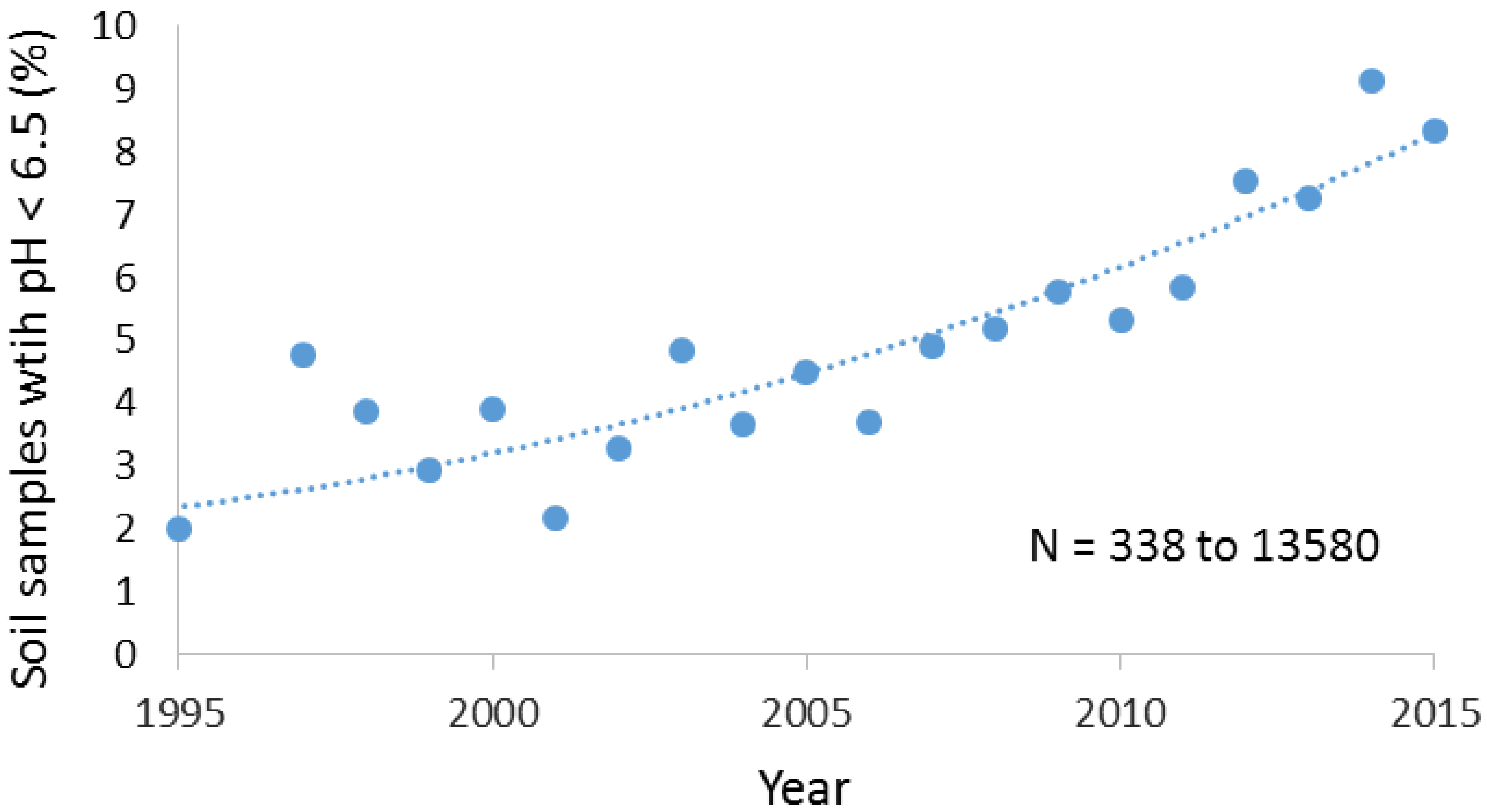
Questions for you

- How many think you have seen yield losses from acidic soils?
- How many of you have soil pH levels below 5.5?
- How many have observed decreasing pH levels on your soil test reports?

Clain's Objectives

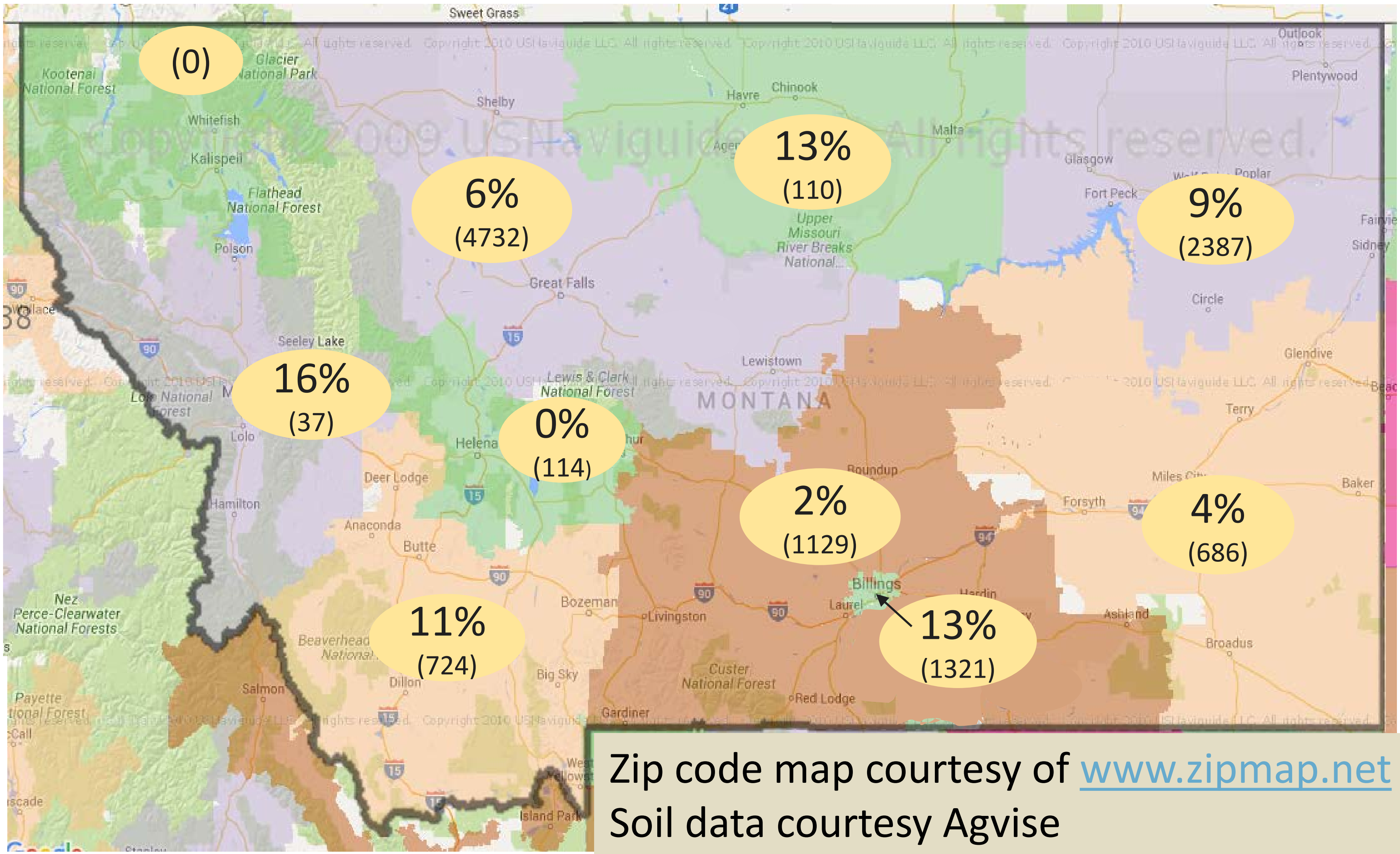
- Show how number of acidic soils have been increasing in Montana.
- Present natural and agronomic conditions that lead to acidic soils and some of the negative impacts
- Present management options to slow further acidification and increase productivity of acidic soil
  - Remediation: liming, tillage, others
  - Adaptation: crop species and variety selection
  - Prevention: crop harvest, nitrogen (N) fertilizer management

Acidic soil samples (pH<6.5) are increasing in MT



Unpub data Agvise

% of 2015 soil samples pH < 6.4 by zip code region (# samples)



Zip code map courtesy of www.zipmap.net
Soil data courtesy Agvise

Some may represent adviser’s business location rather than farm location

Natural reasons for low soil pH

- Soils with low buffering capacity (low soil organic matter, coarse texture), granitic > calcareous
- Historical forest vegetation > historical grassland, which developed greater buffering capacity

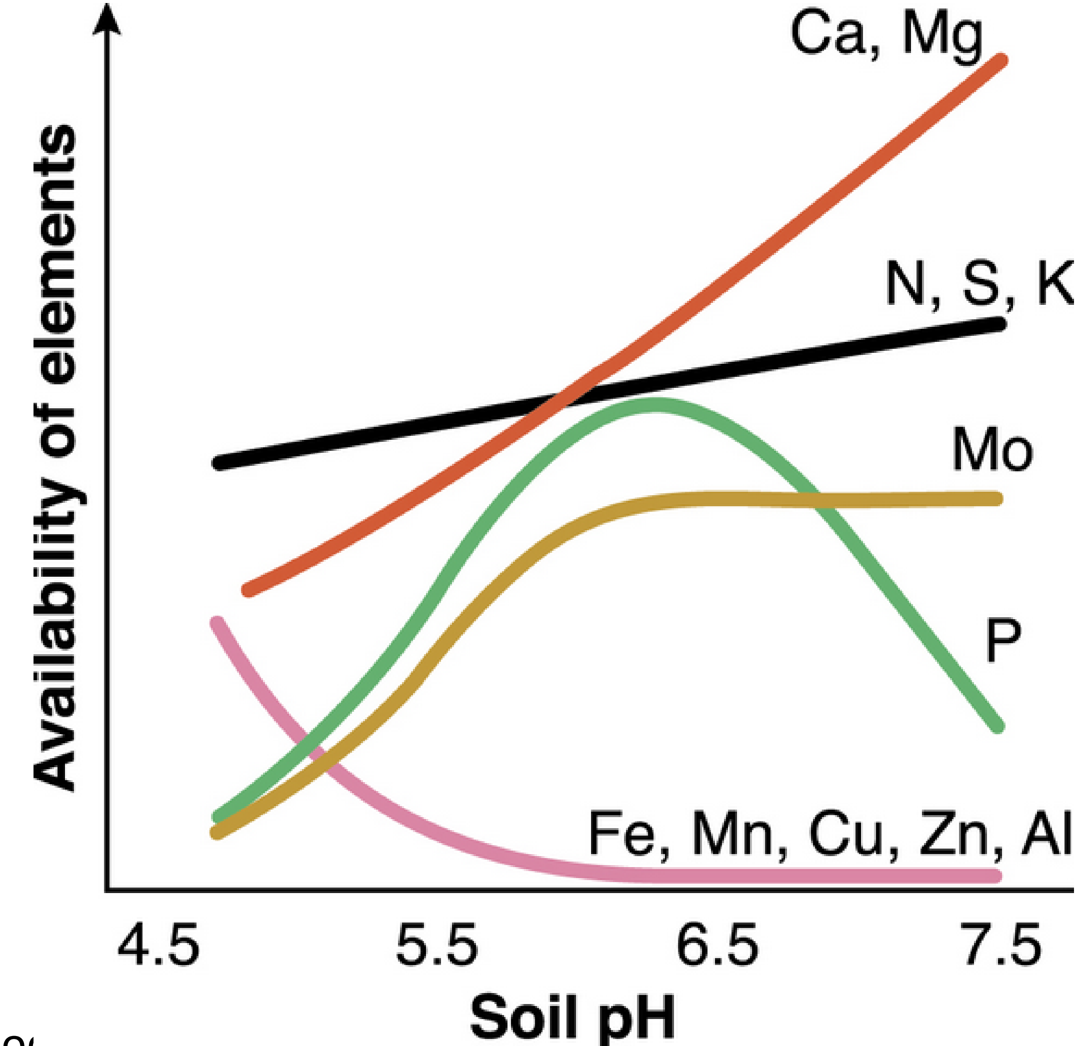
Agronomic reasons for low soil pH

- Ammonium-based N fertilizer above plant needs due to Nitrification: ammonium or urea fertilizer + air + $H_2O \rightarrow$ nitrate (NO_3^-) + acid (H^+)
- Leaching loss of nitrate prevents plants from buffering soil with basic anions (OH^- and HCO_3^-)
- Crop residue removal – removes Ca, Mg, K ('base' cations)
- No-till concentrates acidity where N fertilizer applied
- Legumes acidify their rooting zone through N-fixation. Perennial legumes (e.g., alfalfa) more so than annuals (e.g., pea).

Soil pH and nutrient availability

At low soil pH:

- Plants go hungry for some nutrients
- Nutrients can be lost to environment
- Al and Mn reach toxic levels



Gov. W. Australia, Dept. Ag. and Food

Acid soils have many additional negative impacts

- Herbicide persistence (Raeder et al., 2015)
- Damage to rhizobia (N-fixing by legumes)
- Increase in fungal diseases
- Toxic H^+ levels (Kidd and Proctor, 2001)

Images from Creative Commons

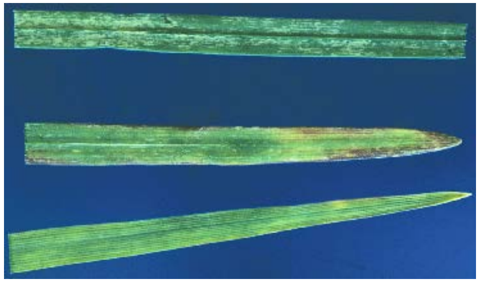


Image from CIMMYT, Int.

Questions?

Managing low pH

Remediate

- Use amendments
- Consider occasional tillage
- Plant deep rooted or perennial crops

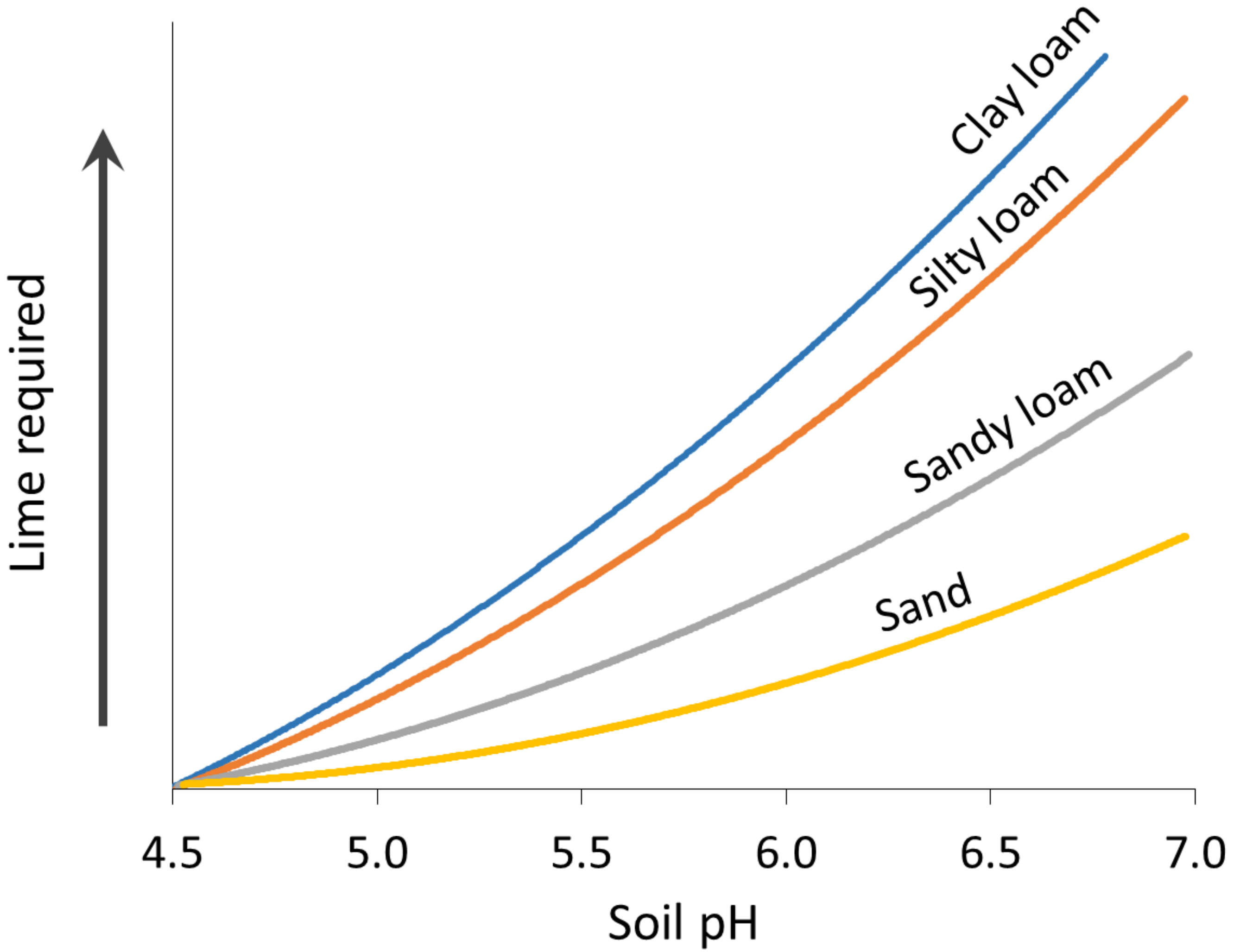
Adapt

- Plant Al-tolerant crops or varieties

Prevent

- Optimize N use efficiency – no left-over N
- Consider N sources
- Retain crop residue

Lime need to raise soil pH increases as soil texture becomes more fine



Havlin

Liming rate

- Know:
  - Calcium carbonate equivalent (CCE; how the source compares to pure $CaCO_3$)
  - Lime score (LS; adds factors for moisture and fineness to CCE)
  - Current soil pH and desired pH
    - > 5 to reduce Al toxicity
    - > 5.5 to have some buffer
    - > 6 to be good for 10+ years
  - Desired crop
- Rate: from soil test lab or calculate (WSU equation)

  Lime rate (ton/acre) = 1.86*(final desired pH – 4.6)

  Note: Rick will be developing a MT specific recommendation

Lime characteristics vary among sources

Material	CCE (%)	LS	Ca (%)
Common mined products			
Limestone ($CaCO_3$)	90-100	90-100	32-39
Dolomite ($CaCO_3$+$MgCO_3$)	95-110	95-110	18-23
Specialty oxides and hydroxides			
Hydrated lime ($Ca[OH]_2$)	120-135	120-135	54
Burnt lime or calcium oxide (CaO)	150-175	150-175	71
By-products			
Sugar beet lime	70-75	40-50	25

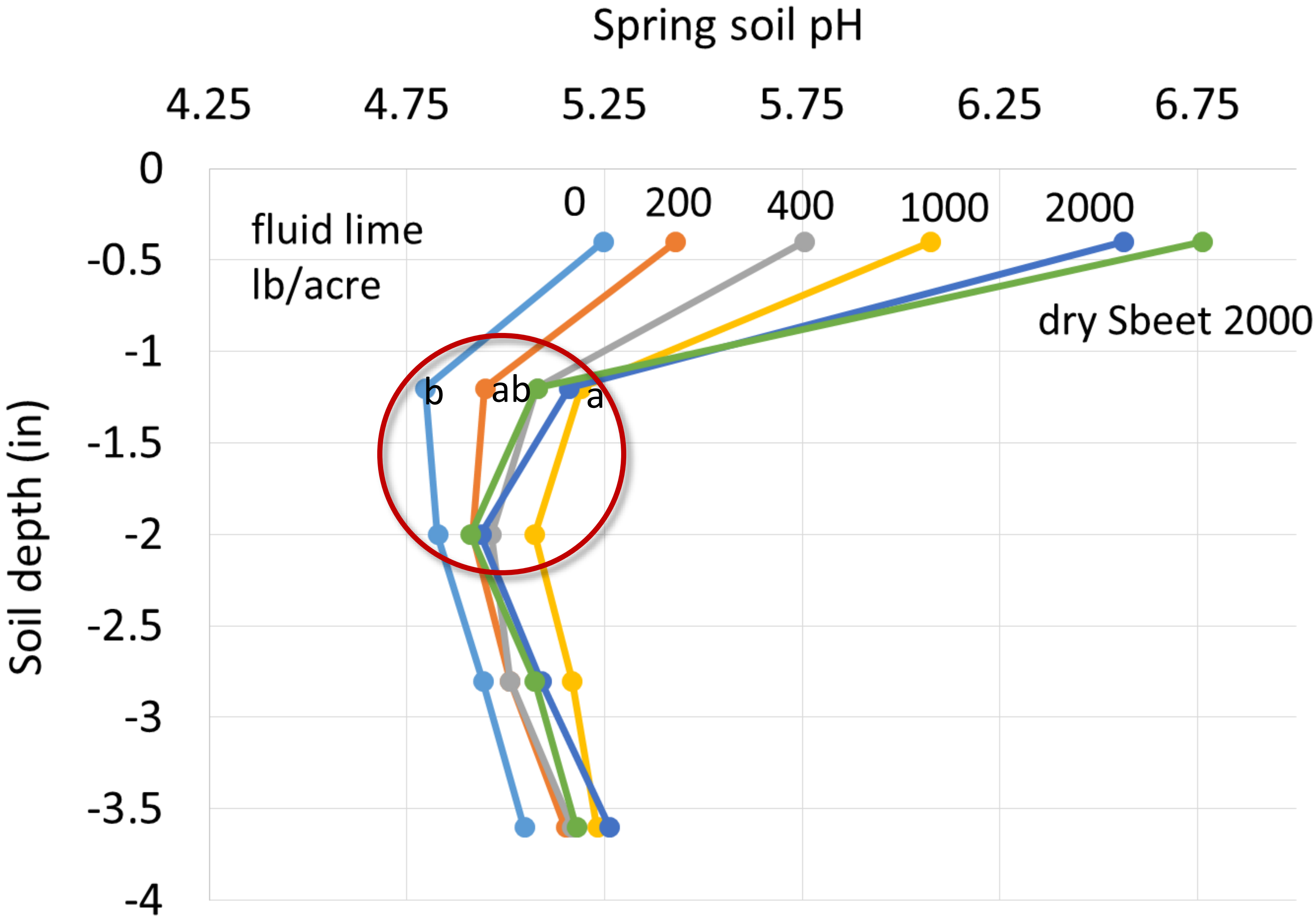
Source: Oregon State University; Dry weight basis

CCE calcium carbonate equivalent; LS lime score

Does liming work?

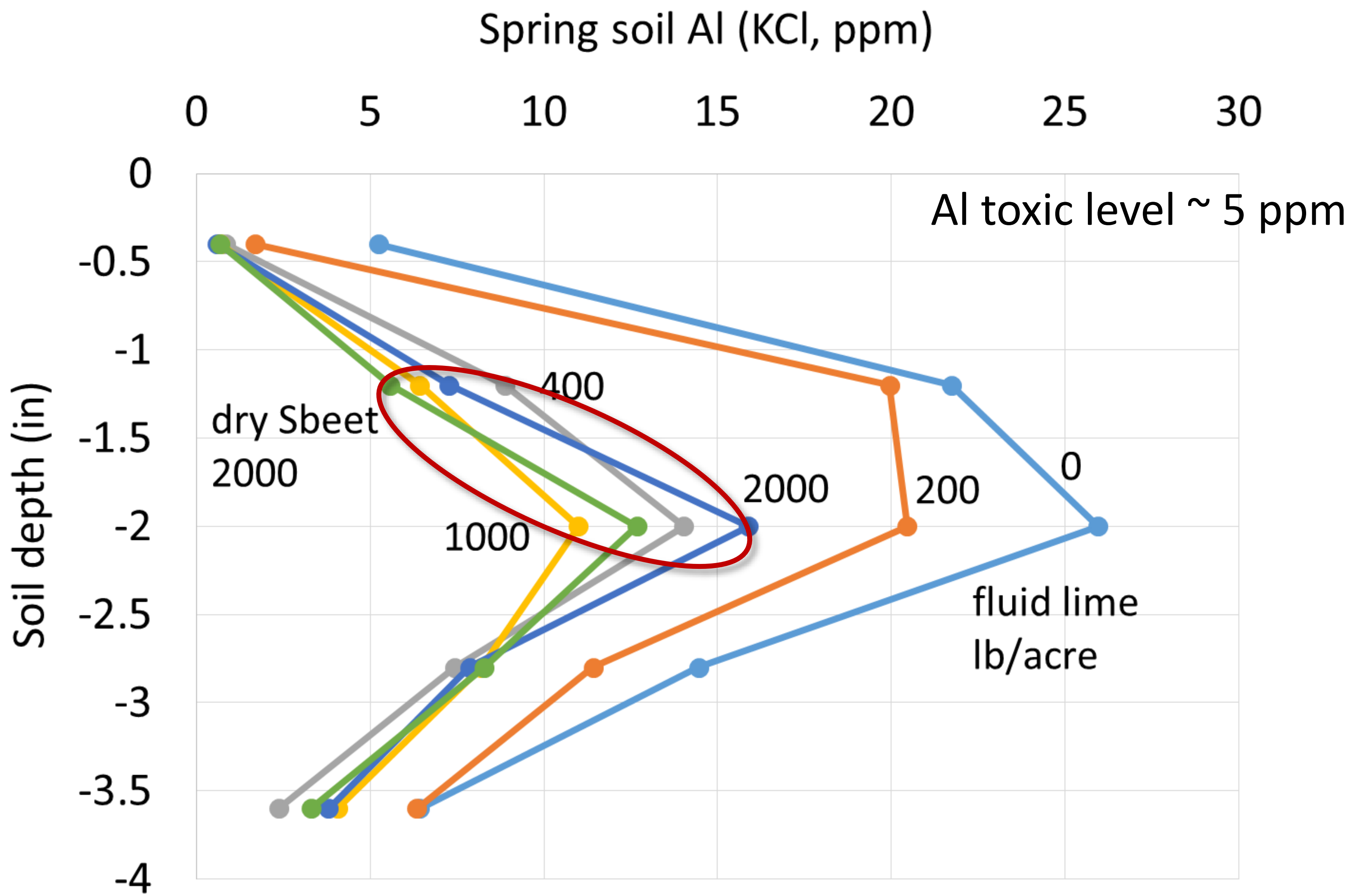
- Broadcast – 2-8 yrs. to reach 4" depth (Brown et al., 2008)
- Surface spray – 6 mo. to reach 2-3" depth (McFarland 2015)
- Incorporated – better but more $
- Seedplaced lime pellets – works in no-till, reduces Al toxicity in root zone with less lime/acre (Huggins et al., 2004)
- Inject fluid lime into seed zone – quick acting but more $
- Economics of variable rate unknown, but makes sense to only apply where needed

Only high rates of surface applied lime changed pH at seed depth within 6 months after application



McFarland 2015 (thesis defense, WSU)

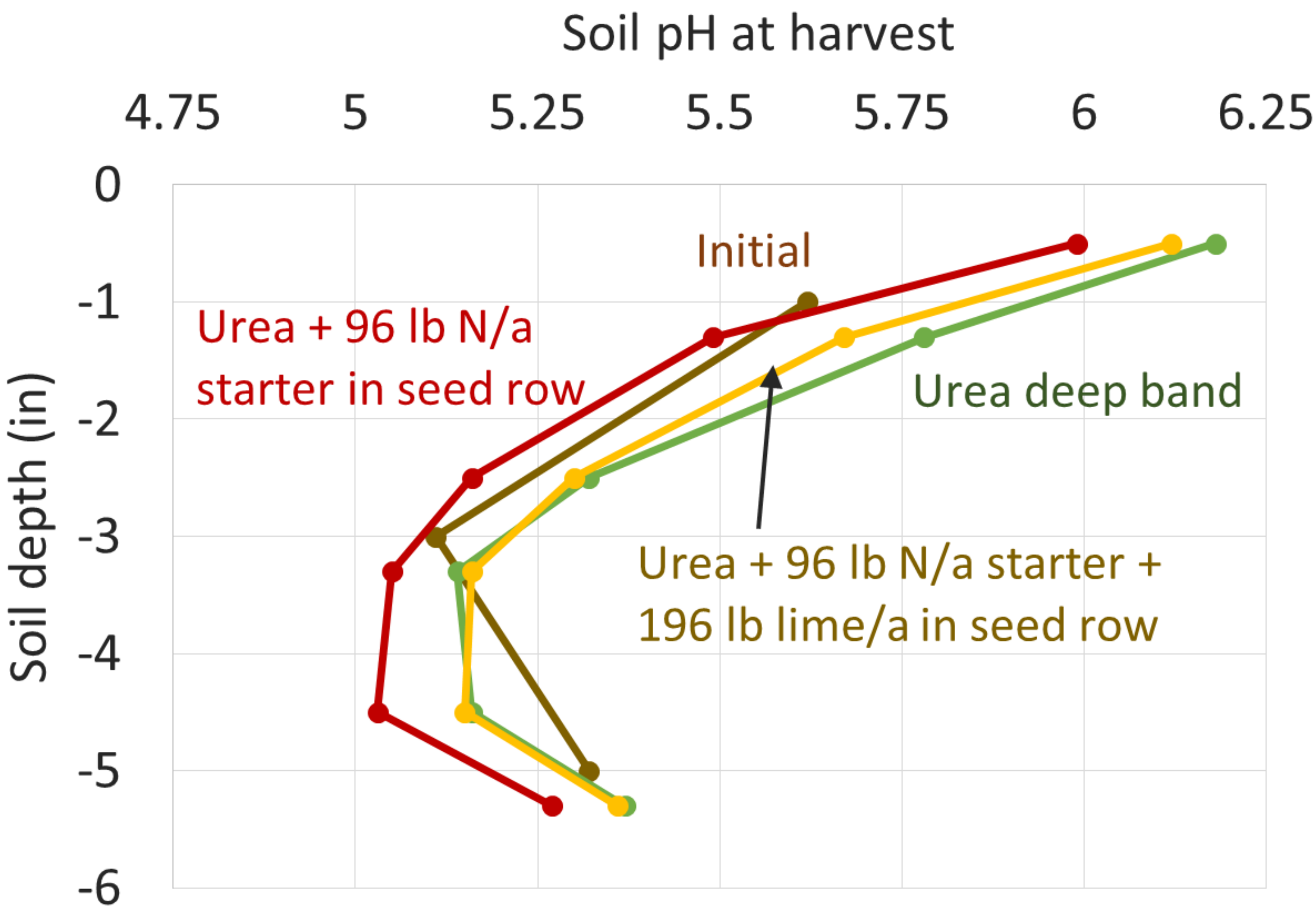
Surface applied lime did reduce Al concentration at seed depth within 6 months after application



McFarland et al., 2015

But did not increase yield??

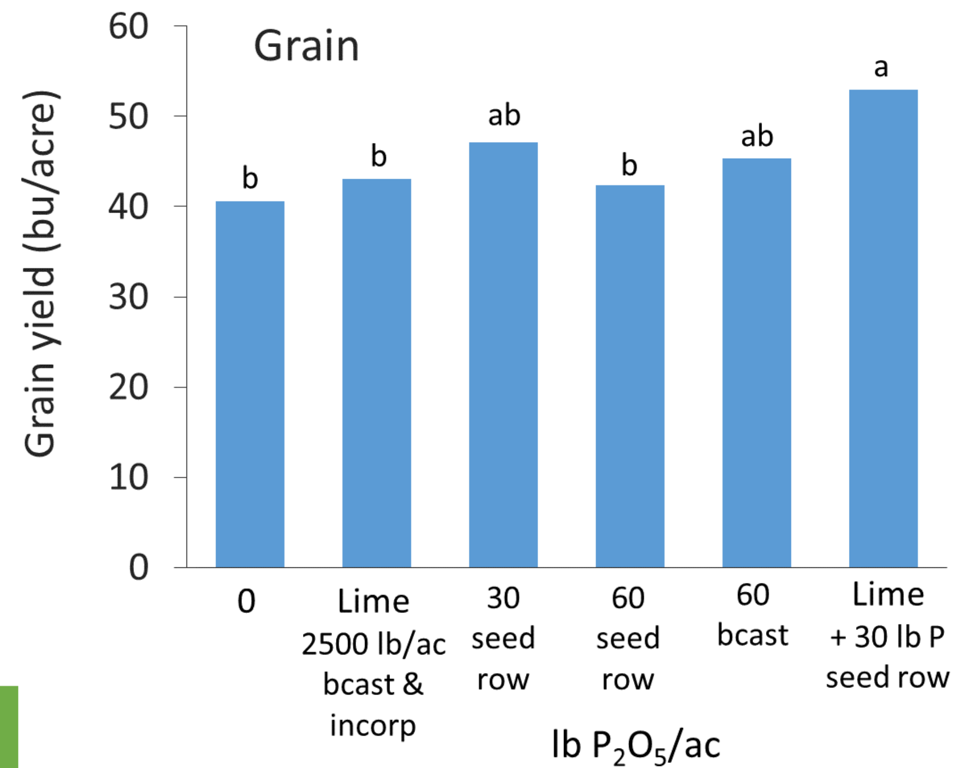
Seed placed lime reduces acidity caused by seed-placed fertilizer

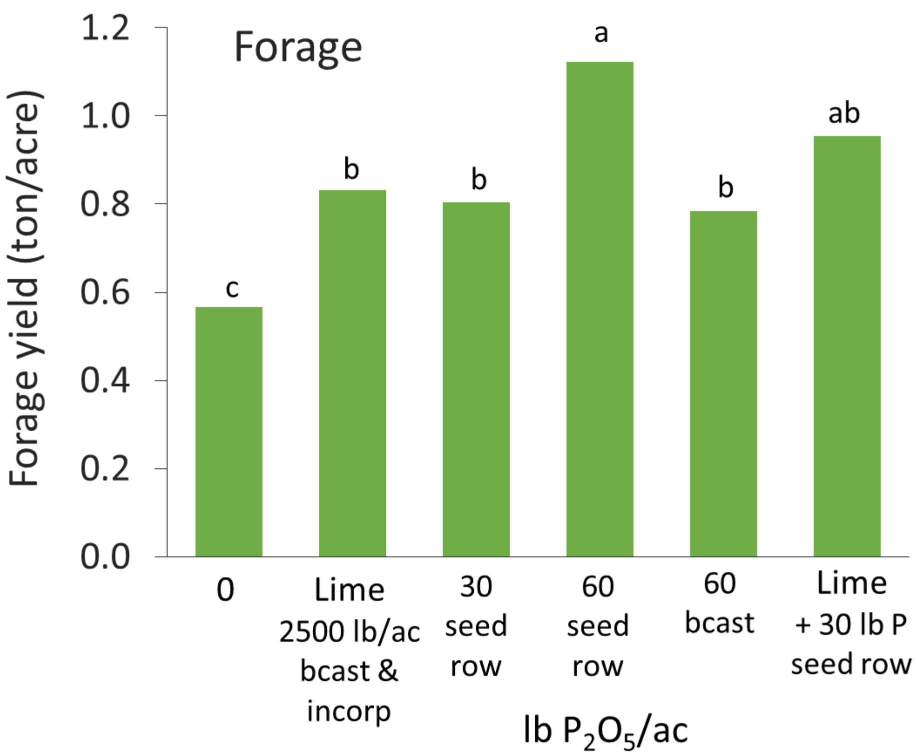


Huggins et al., 2004, Palouse Prairie, WA

Gypsum generally for sodic soils but with the seed helps reduce Al uptake

P fertilizer is quick acting 'band-aid' to increase yield even when P soil test is sufficient. Likely ties up some aluminum.





Initial pH = 4.6
High initial soil P level

Kaitibie et al., 2002, OK

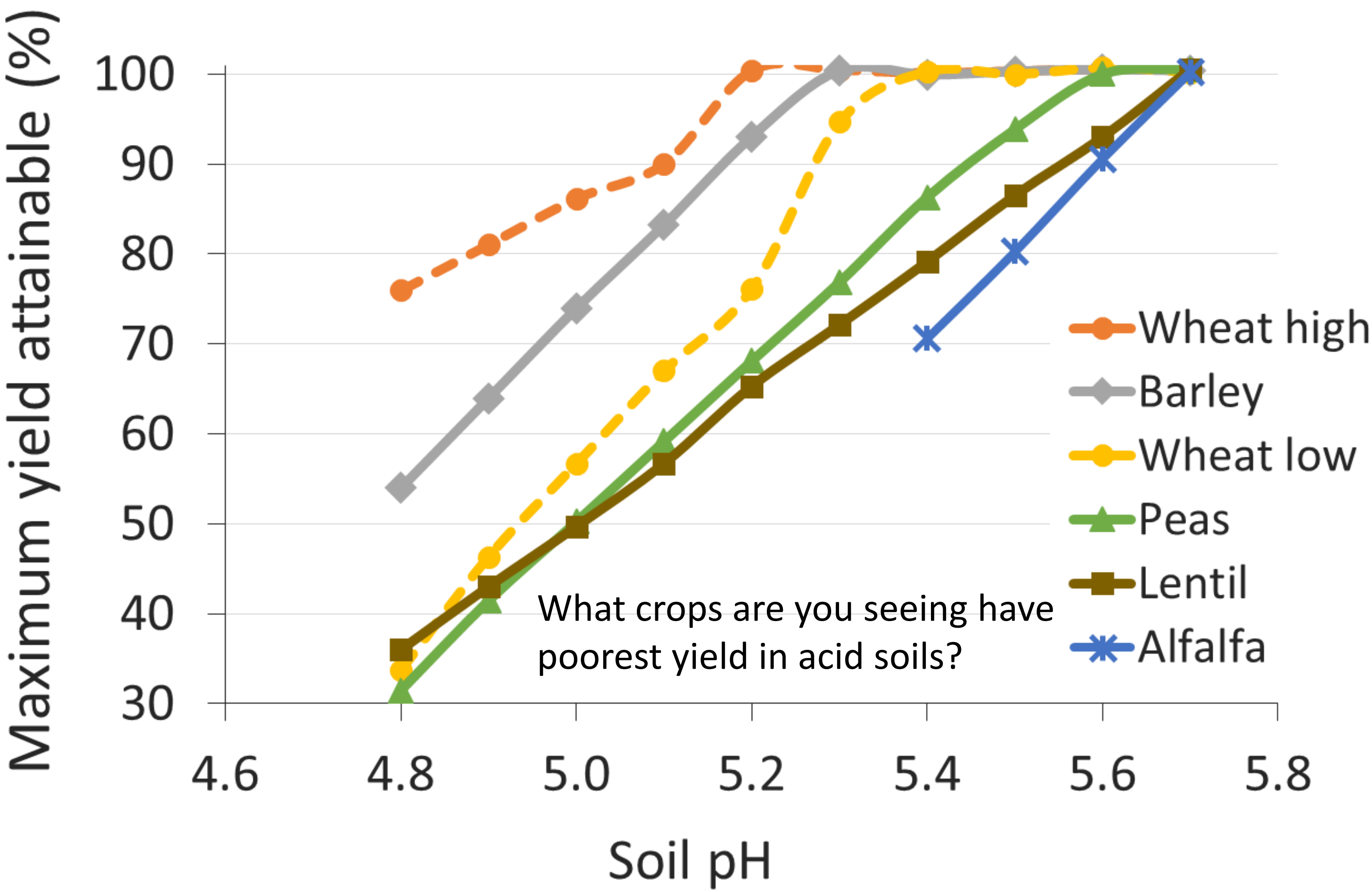
Additional remedial practices

- Inversion till to mix acid zone throughout plow layer – one time tillage doesn't negate long term benefits of no-till if done in dry summer (Norton et al., 2014, WY)
- Consider deep rooted perennial crops to bring base cations from sublayers to surface, and don't harvest. Though no research yet to back this up.
- Areas of field that aren't producing need some plants to prevent erosion.

Would you consider these remedial practices?

- Liming?
- Occasional tillage or deep ripping (once in 5 to 10 years)?
- What other practices might you consider?

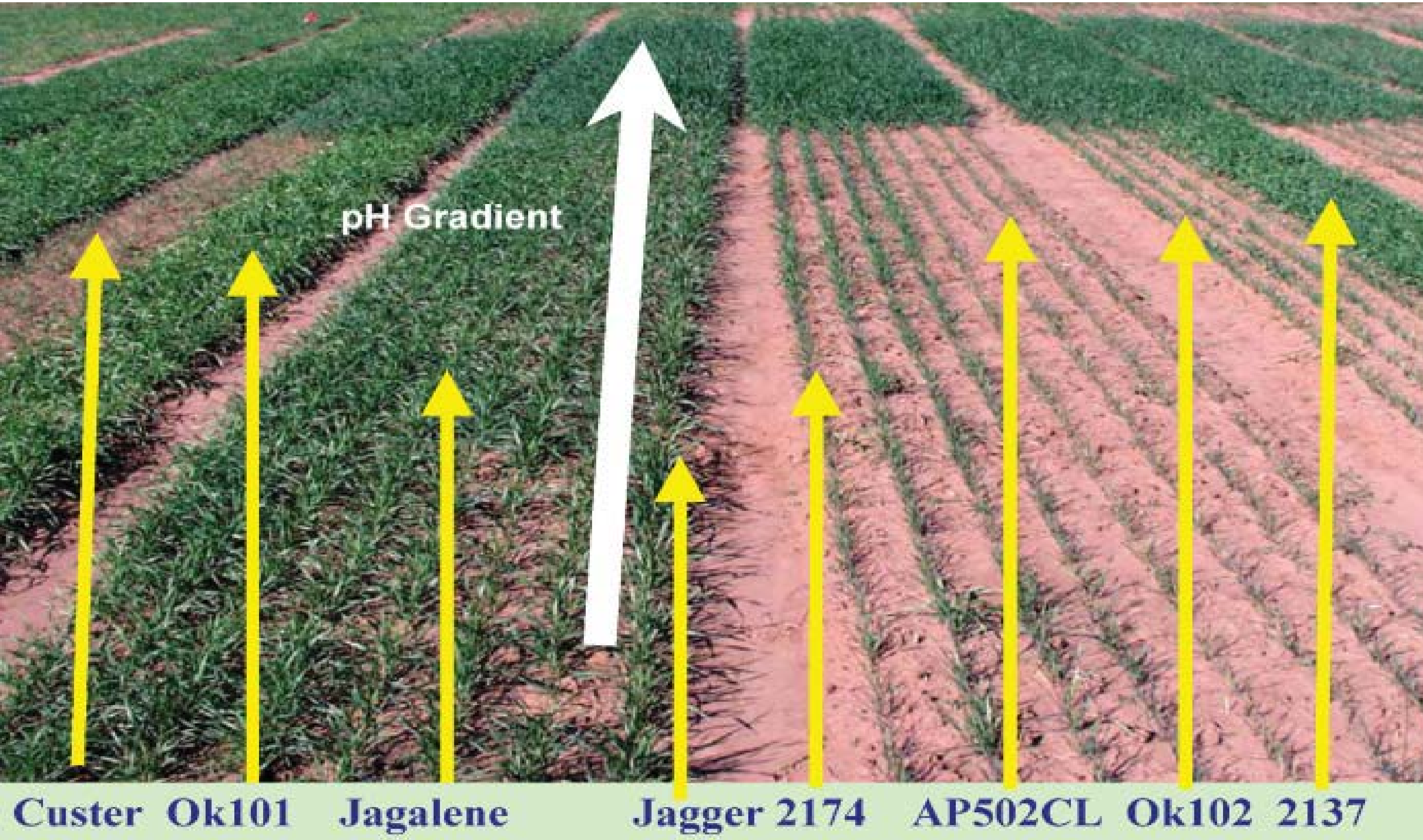
Adaptation: Crop species vary in tolerance to low soil pH legumes are least tolerant



McFarland et al., 2015

"Wheat high" are Al and acidity tolerant varieties

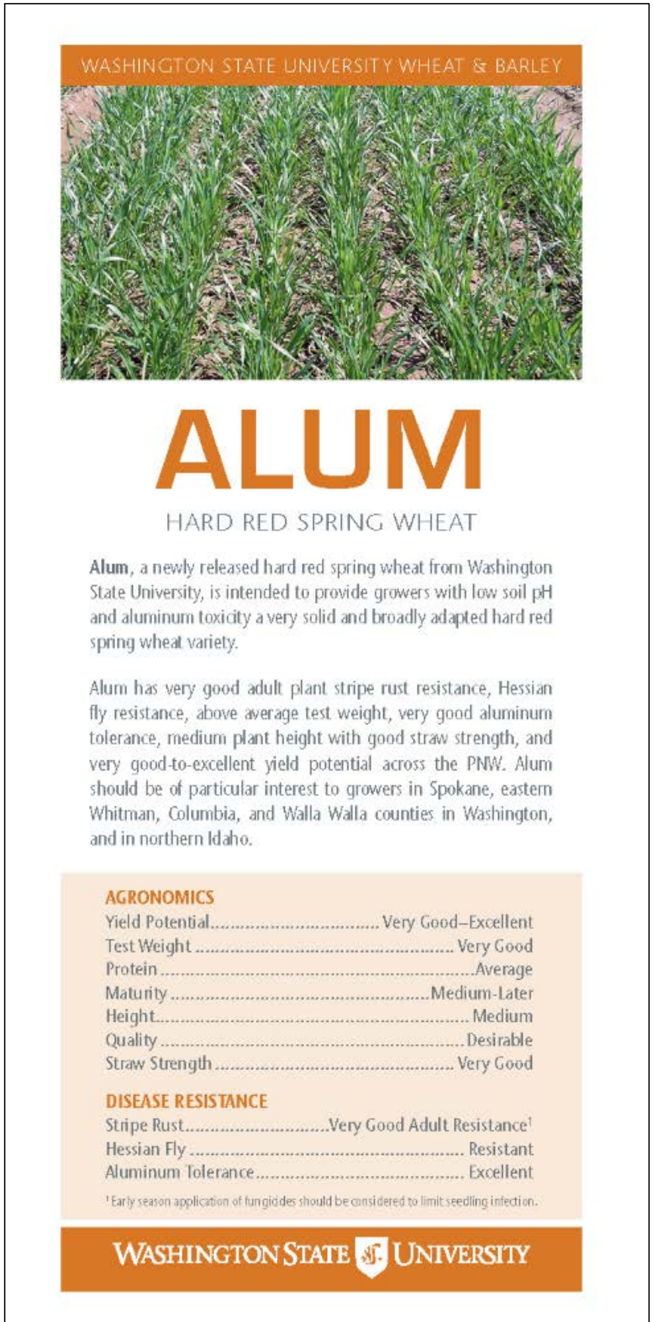
Wheat varieties have different tolerance to pH and Al



Custer	Ok101	Jagalene	Jagger	2174	AP502CL	Ok102	2137
6.6	5.5	6.0	5.8	5.9	6.2	6.4	5.3

Threshold pH

(Kariuki et al, 2007)



WASHINGTON STATE UNIVERSITY WHEAT & BARLEY

ALUM

HARD RED SPRING WHEAT

Alum, a newly released hard red spring wheat from Washington State University, is intended to provide growers with low soil pH and aluminum toxicity a very solid and broadly adapted hard red spring wheat variety.

Alum has very good adult plant stripe rust resistance, Hessian fly resistance, above average test weight, very good aluminum tolerance, medium plant height with good straw strength, and very good-to-excellent yield potential across the PNW. Alum should be of particular interest to growers in Spokane, eastern Whitman, Columbia, and Walla Walla counties in Washington, and in northern Idaho.

AGRONOMICS

Yield Potential	Very Good–Excellent
Test Weight	Very Good
Protein	Average
Maturity	Medium-Later
Height	Medium
Quality	Desirable
Straw Strength	Very Good

DISEASE RESISTANCE

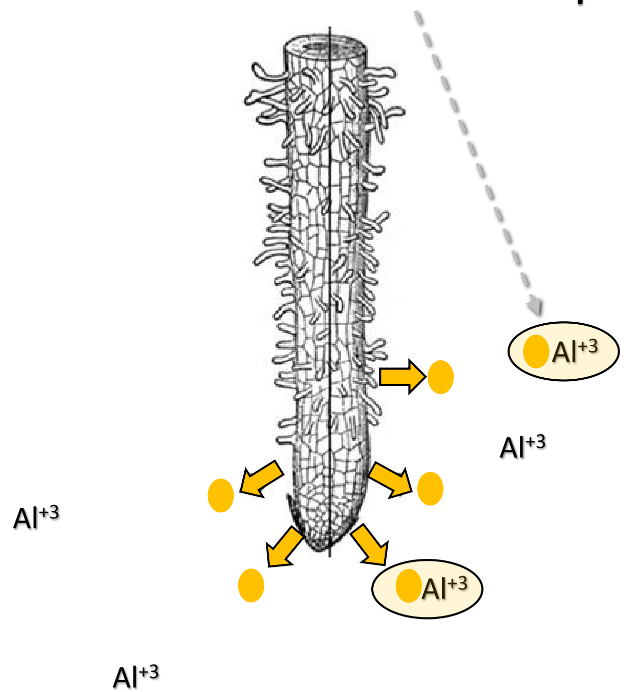
Stripe Rust	Very Good Adult Resistance[1]
Hessian Fly	Resistant
Aluminum Tolerance	Excellent

[1] Early season application of fungicides should be considered to limit seedling infection.

WASHINGTON STATE UNIVERSITY

Aluminum tolerance – single gene (Alt1)

Wheat cultivars with Alt1 release malate (organic acid) from root tips in response to high conc. of solution Al^{+3}; malate in turn chelates with Al^{+3} in the soil to form a non-toxic complex

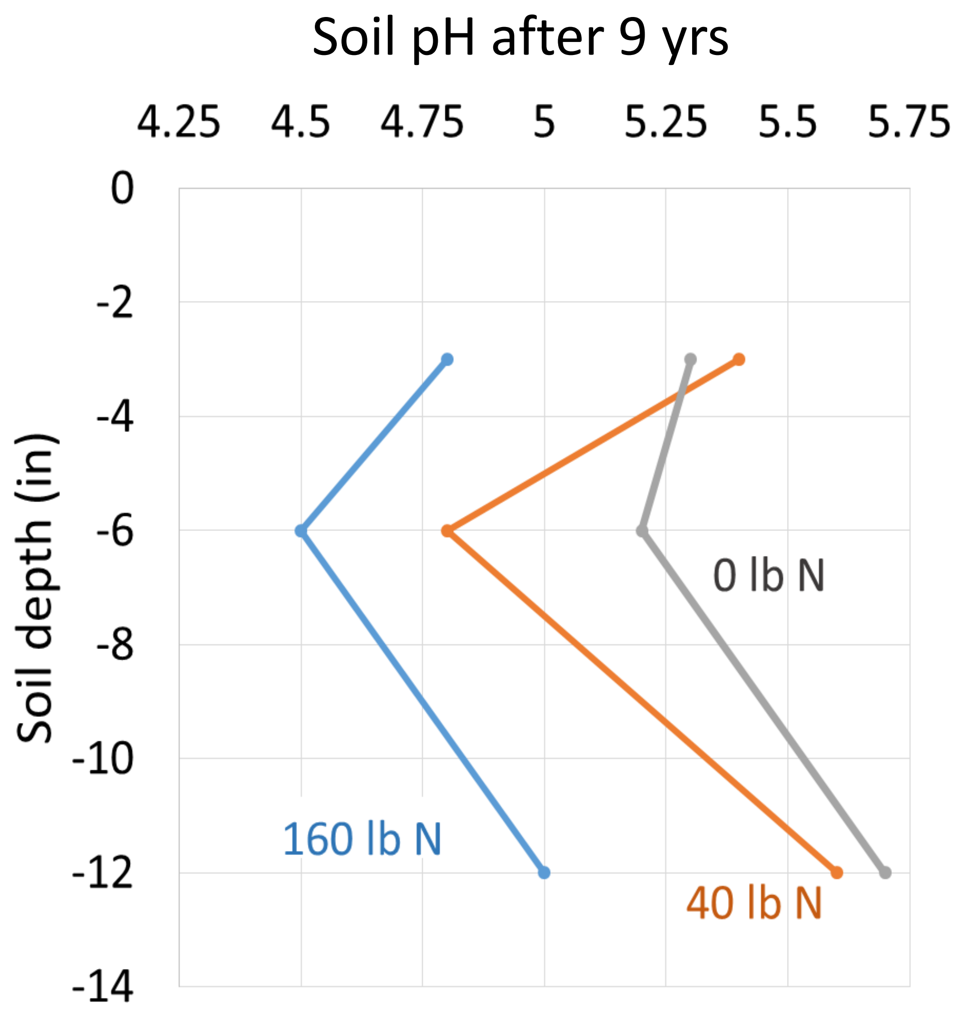


N fertilizer above crop requirements leads to soil acidification

Suggested rate = 40 lb N/acre

Urea injected at 6” depth annually

Especially consider under-applying N in the acidic areas given N has likely accumulated there due to low yields.



Bouman et al., 1995, SK.

Steps to minimize and prevent soil acidification due to fertilizer N

Increase efficiency of N use
Base nitrogen rate on spring soil test and realistic yield potential
Split nitrogen applications
Reduce nitrate loss
Use slow-release nitrogen sources
Use nitrogen sources with nitrification inhibitors
Plant deep rooted crops to ‘catch’ deep nitrate
Consider non-ammonium based nitrogen sources
Legume rotations
Calcium ammonium nitrate (27-0-0)

Fertilizers differ in potential to acidify the soil

Ammonium sulfate (21-0-0-24) = MAP (11-52-0)	≈ 3 x acid as urea
> urea (46-0-0)	≈ 3 x acid as CAN
> calcium ammonium nitrate (CAN; 27-0-0)	Little acidification

Summary

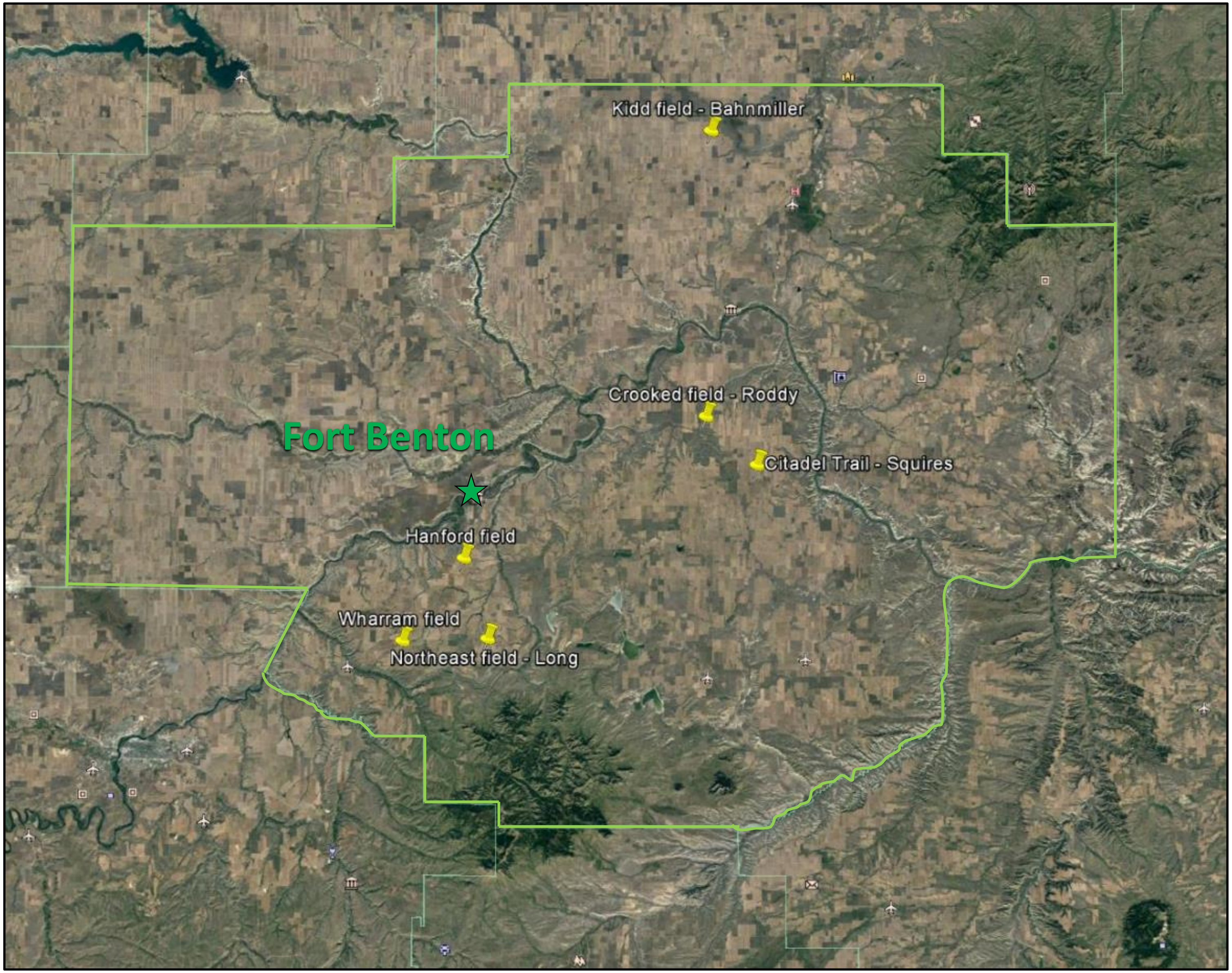
- Cropland soils are becoming more acidic, at least on Highwood Bench and other places in Choteau County, in part due to N fertilization
- This reduces yields for several reasons
- Sound N fertilizer and residue management can slow down or prevent soil acidification
- Crop and variety selection can help adapt to acid soils
- Liming or perhaps deep ripping can reverse acidification

Questions?

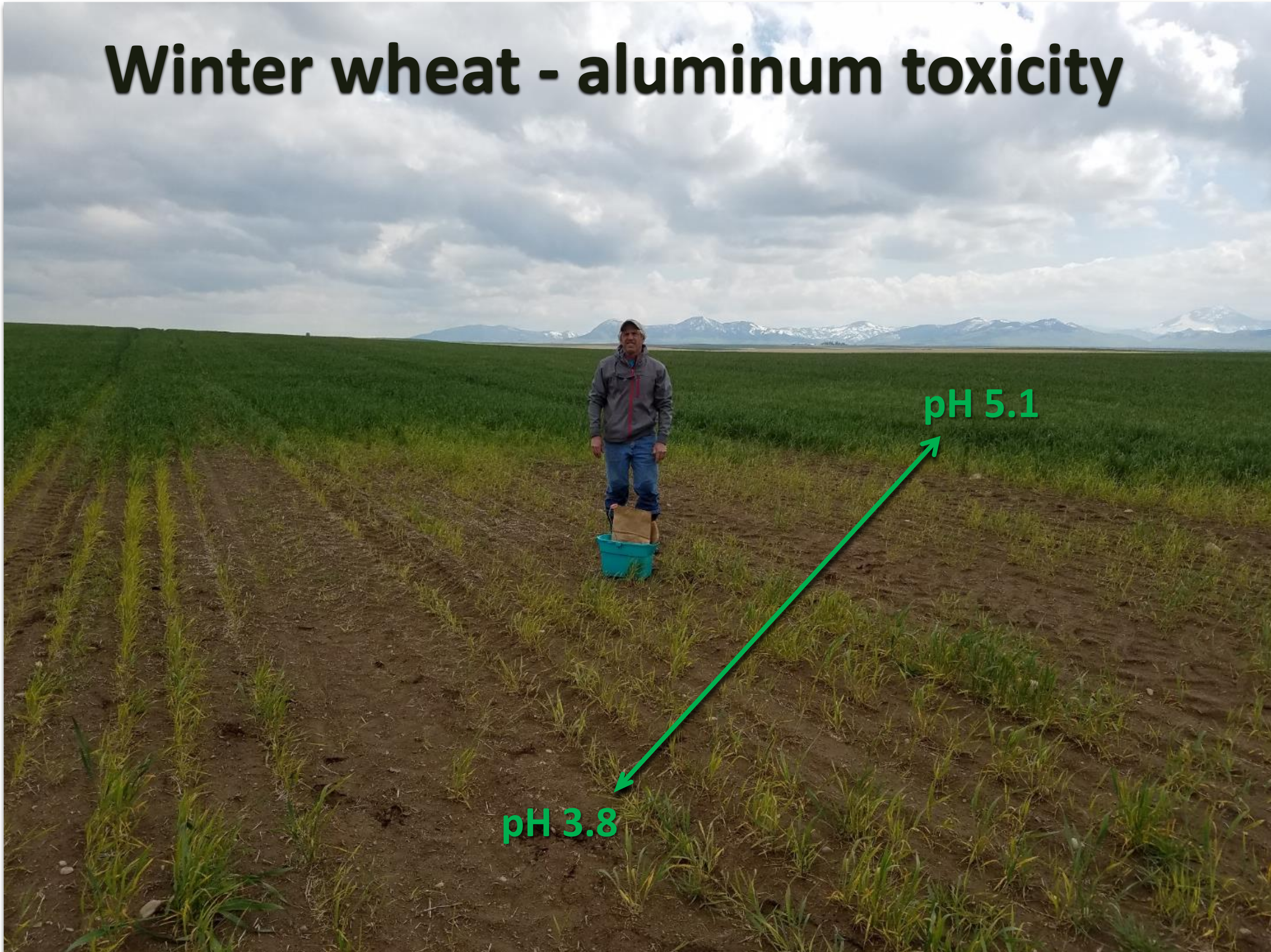
Rick’s Tasks

- Aluminum toxicity symptoms
- Review – research results from this past season
- Research plans for 2017 - 2019
  - USDA-Western SARE
  - Montana Fertilizer Check-off

Chouteau County field locations



Winter wheat - aluminum toxicity

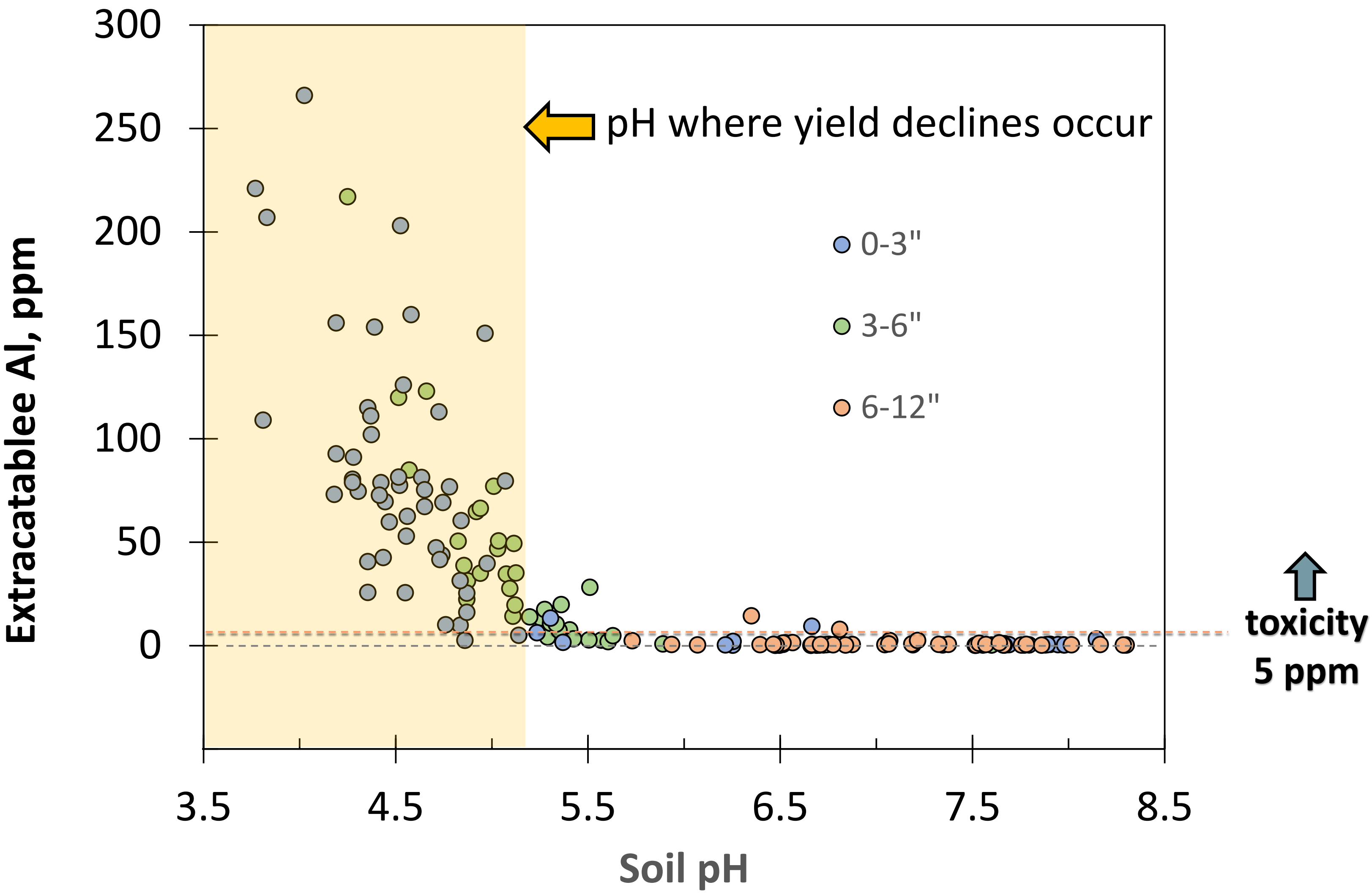


Durum wheat – aluminum toxicity

Plant Symptoms of Al toxicity

- Roots: witch's broom roots, thickened, twisted, club ends, stubby, no fine branching
- Tops – stunted growth, yellowing or purple upper leaves

Low pH increases soil Al to toxic levels

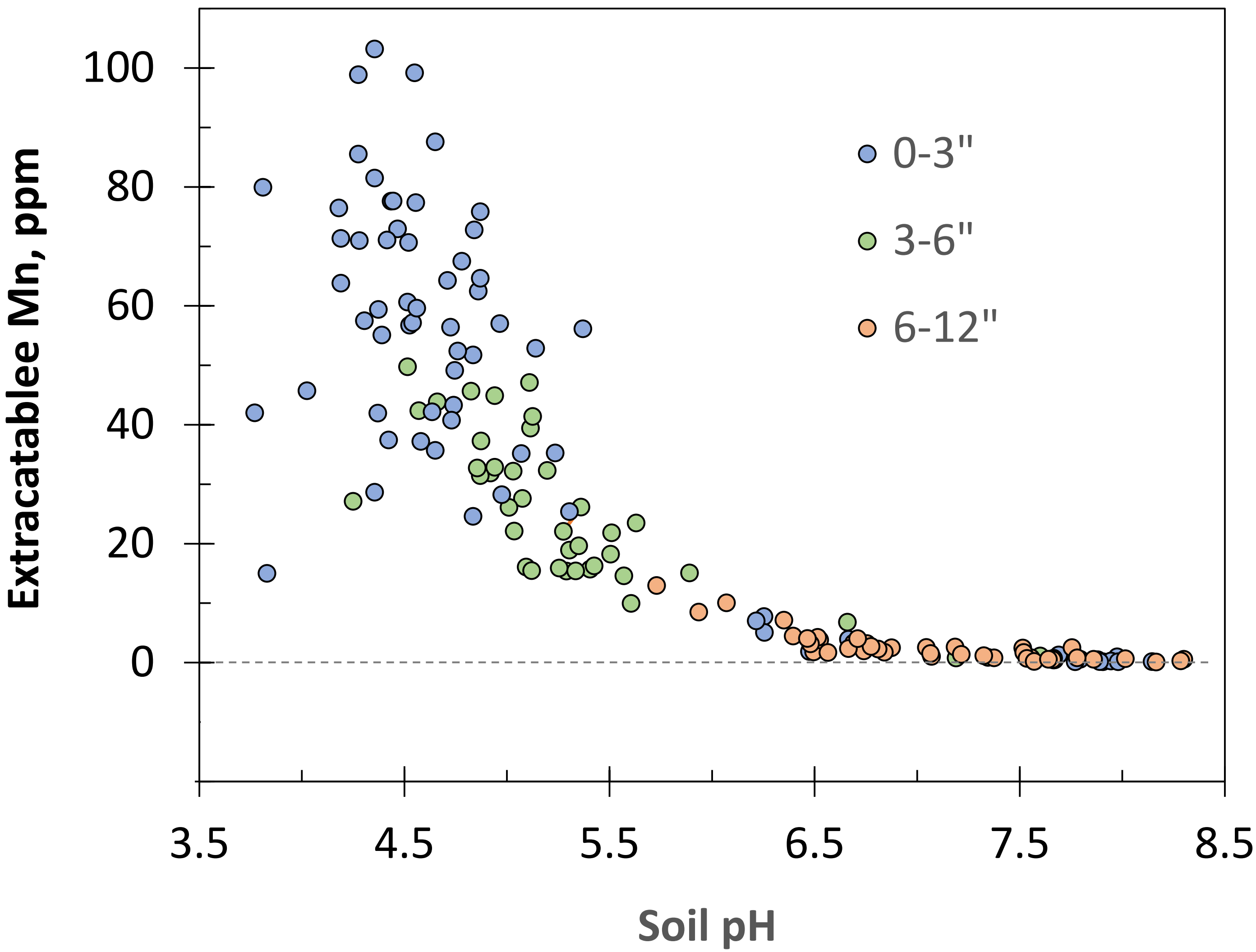


Engel unpub. data, 2016, 5 farms near Highwood, MT

Why does soil pH affect aluminum?

- aluminum toxicity is most important growth-limiting factor in acidic soils
- all Montana soils contain considerable aluminum; very abundant element in the soil; 6-7% of total soil dry mass
- solubility of aluminum containing minerals increases as pH becomes more acidic ***

Soil pH also affects extractable Mn



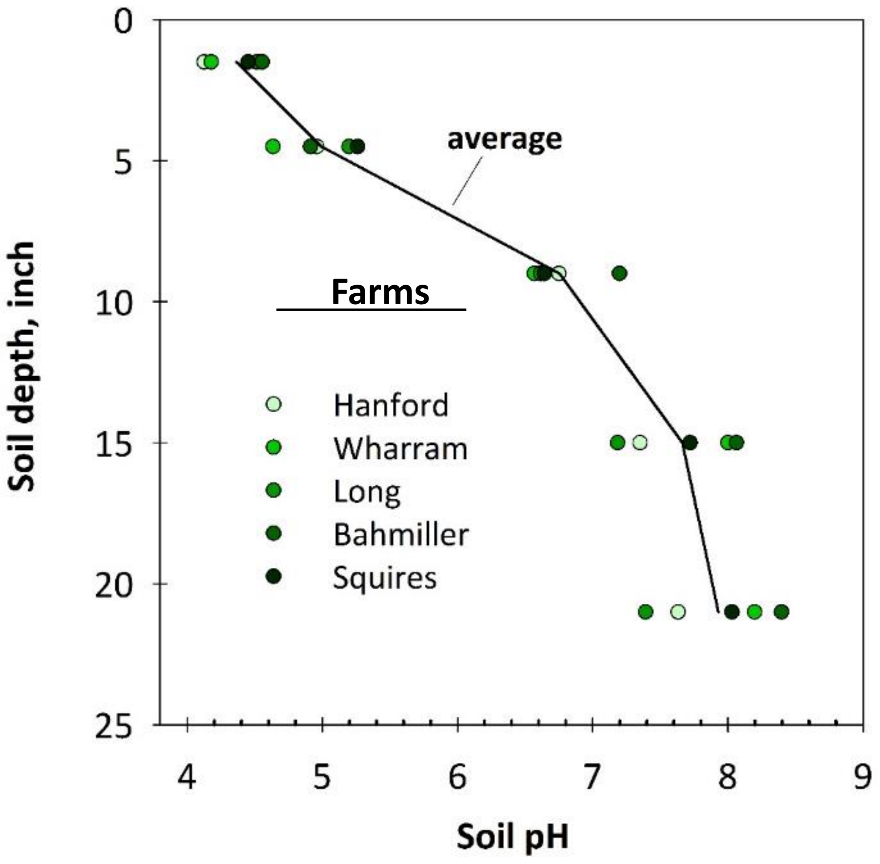
- ✓ **Manganese toxicity has been associated with acidic soils - pH < 5.8 threshold – however no evidence this past season that we have a problem**

Manganese tissue conc (normal vs. poor growth areas)

Cooperator	Tissue	Normal	Poor
		------------- ppm	---------------
Bahnmiller	shoot	135	257
Squires	shoot	47	182
Wharram	shoot	57	207
Hanford	shoot	57	127

Conclusion: normal vs. poor growth areas differed in Mn but below expected toxicity range >400-500 ppm

Soil pH stratification in Montana



<u>Summary</u>

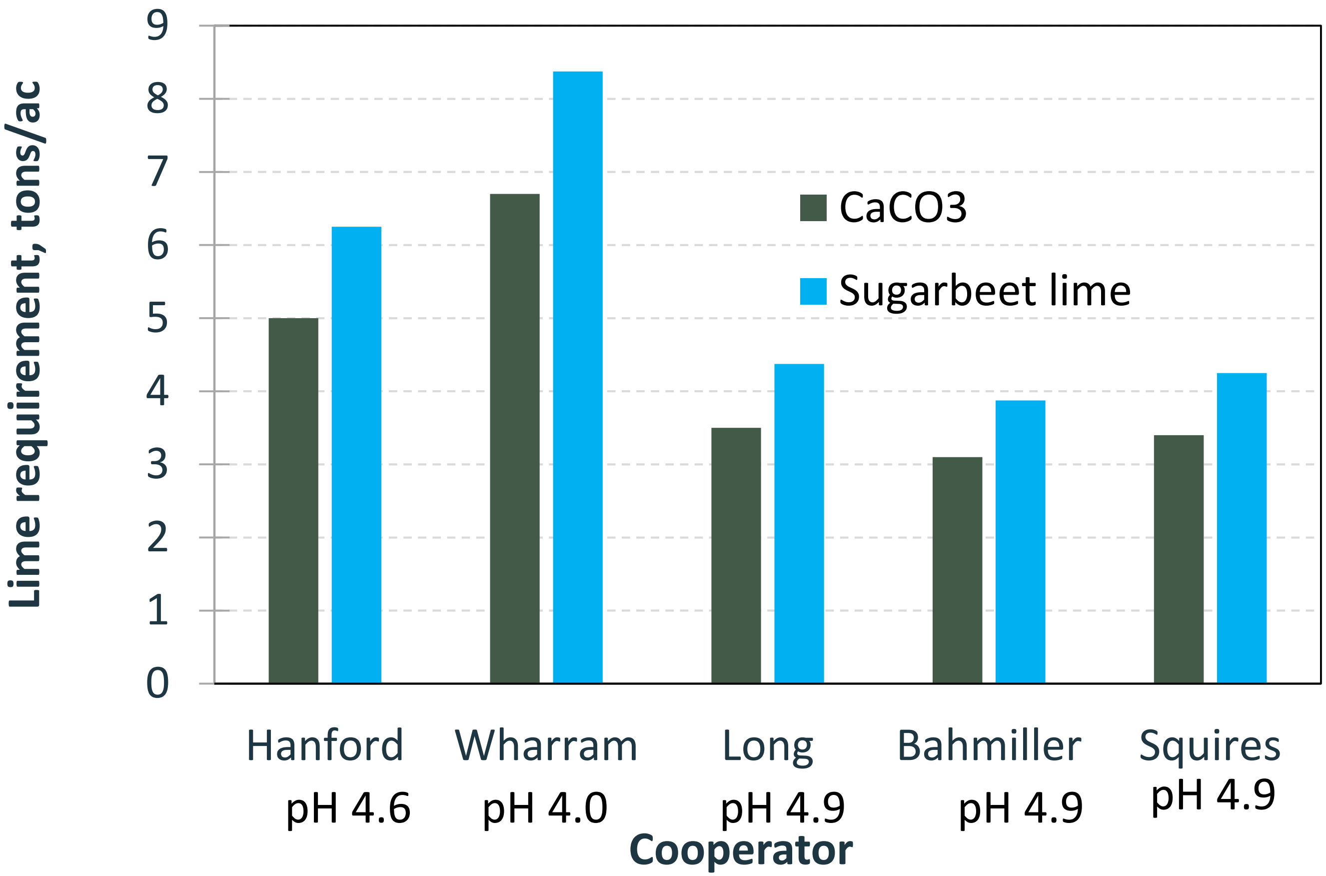
- lowest pH likely to be found in shallowest depth because…

  1. N applied near surface
  2. subsoils have a lot of natural lime (Ca, Mg, Na carbonates).

Remediation – sugar beet lime

- good – it doesn't cost anything
- bad – shipping costs ($35/ton); challenging material to work with (moisture and clumping) and incorporation is needed for best results
- rates of 3-6 tons/acre may be necessary to bring pH to acceptable level (pH 6); presently we do not have a lime recommendation test for Montana nor do we have experimental trials to evaluate its efficacy

Lime requirement soil tests 0-6”



Sikora buffer test run by Agvise

- ✓ **lime requirements based on target pH 6.0; a pH 5.5 target would require ↓ lime;**

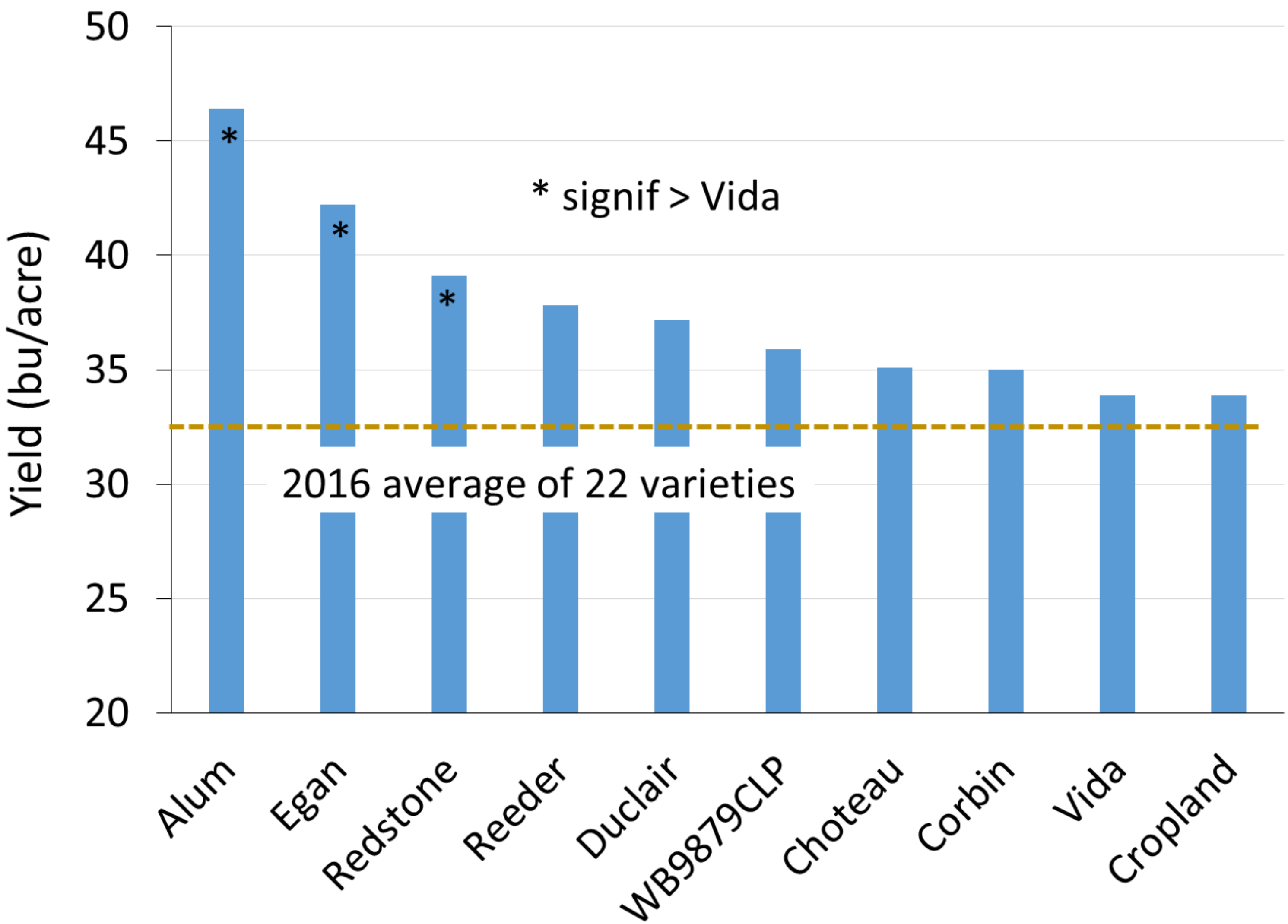
Adaptation – Variety selection

- 2016 trials at Long farm – courtesy Briar, Wichman, Sherman, Elmore and Miller – CARC

- soil pH 4.5 ± 0.2

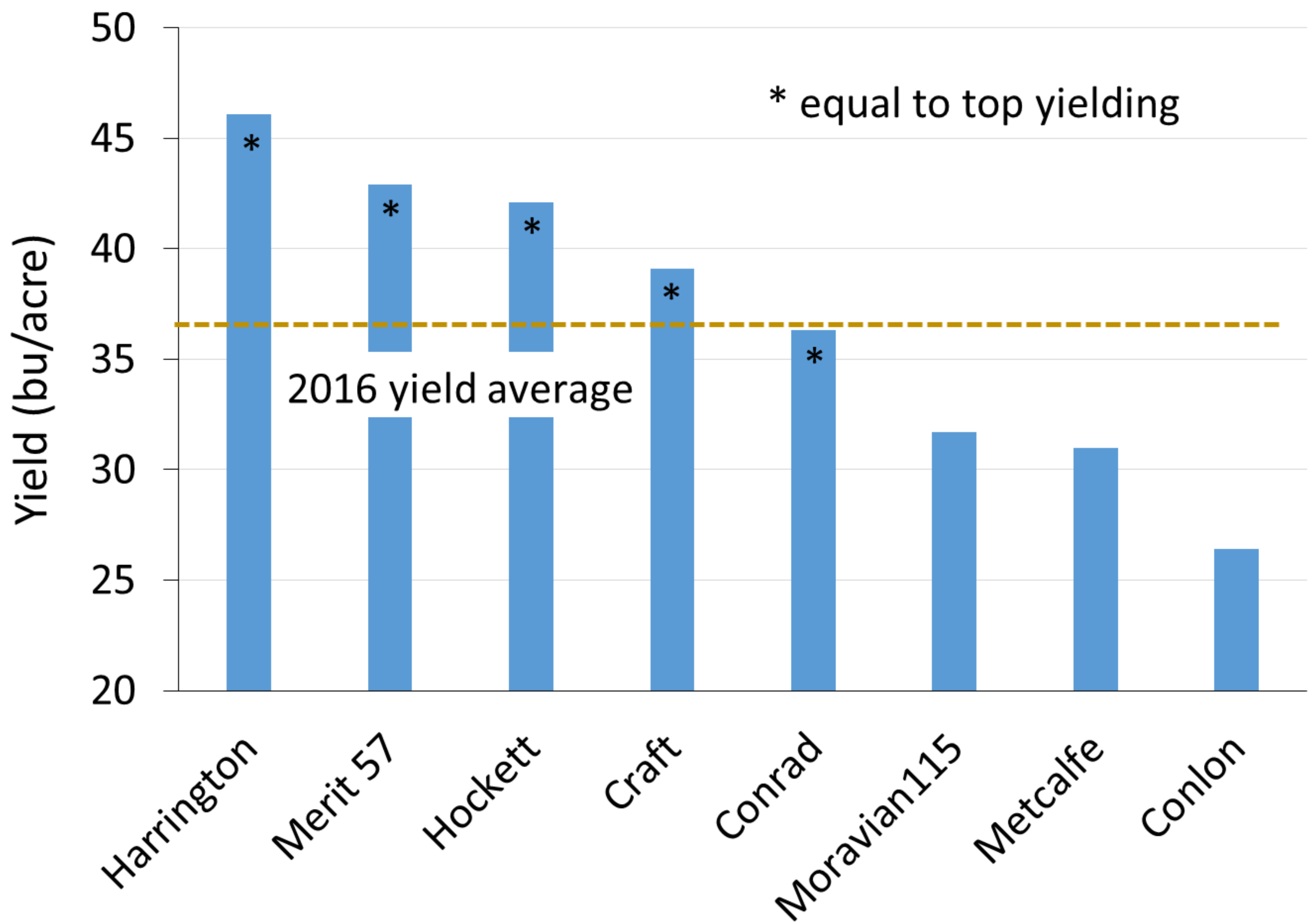
http://agresearch.montana.edu/carc/2016varietytrialresults/Spring%20Wheat%20Highwoods.pdf

Spring wheat yield at Highwood - soil pH 4.5



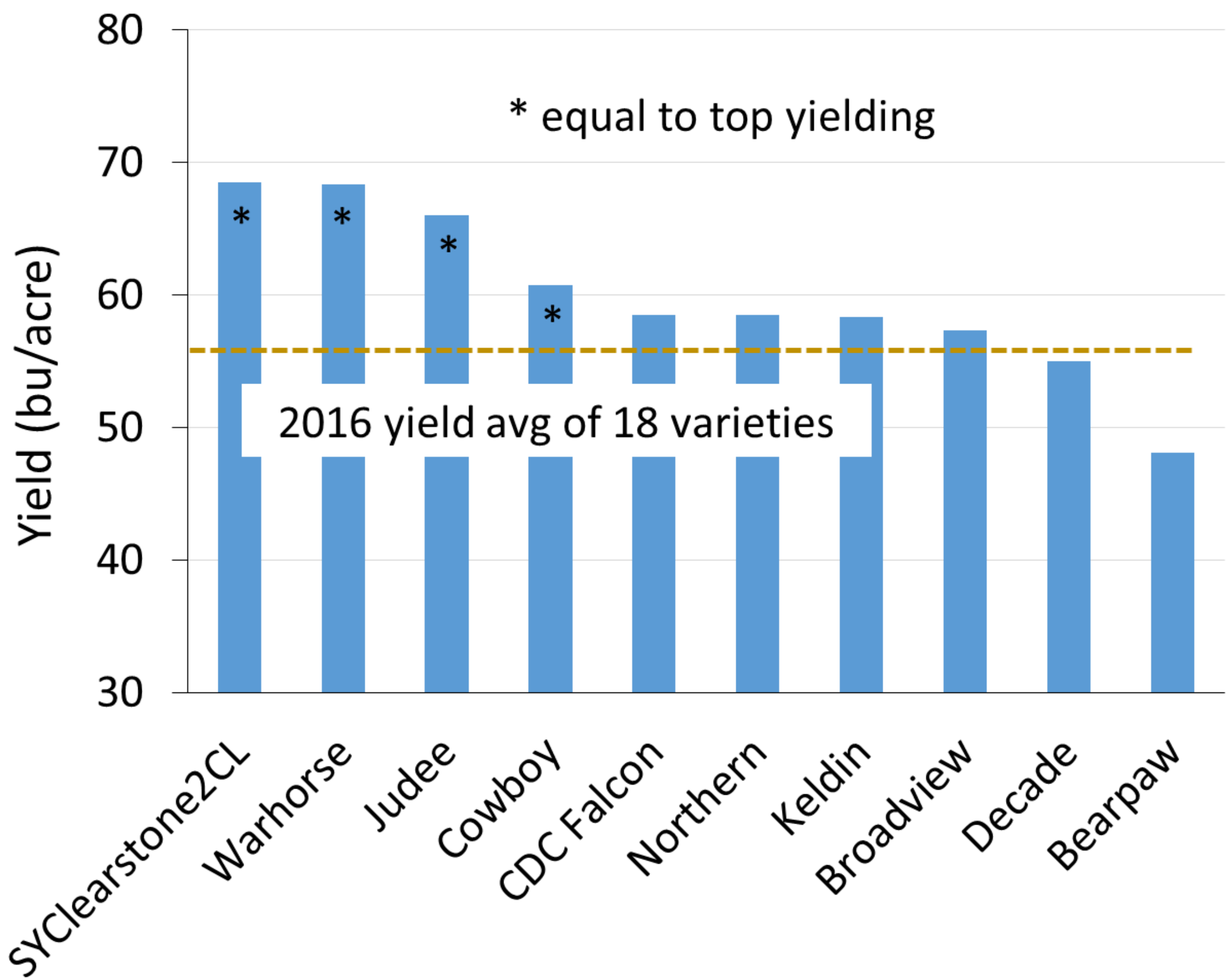
Courtesy: CARC

Barley yield at Highwood - soil pH 4.5



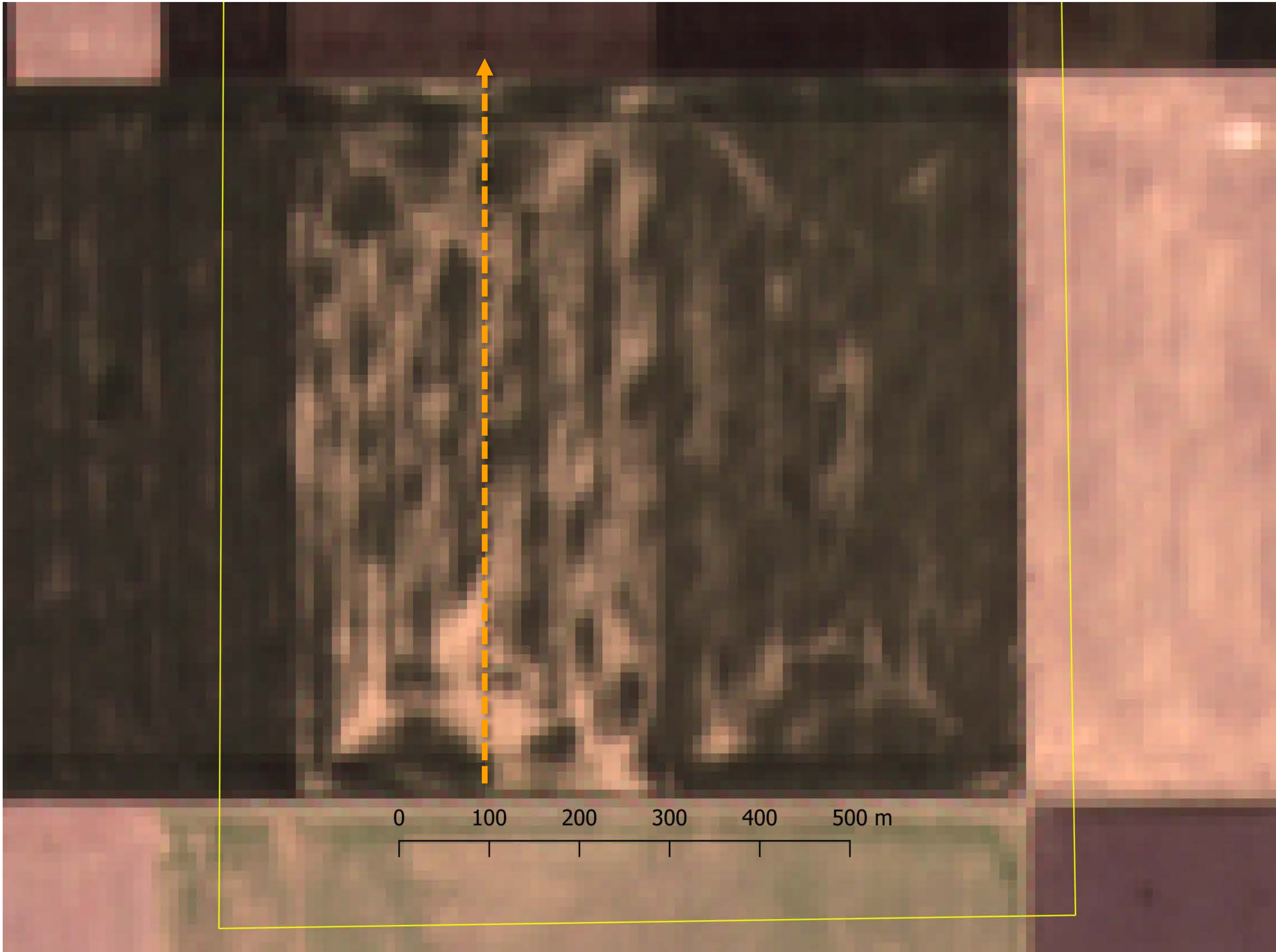
Courtesy CARC

Winter wheat yield at Highwood – soil pH 4.5



Courtesy CARC


Legacy effects of fertilizer N –
an example from field ?

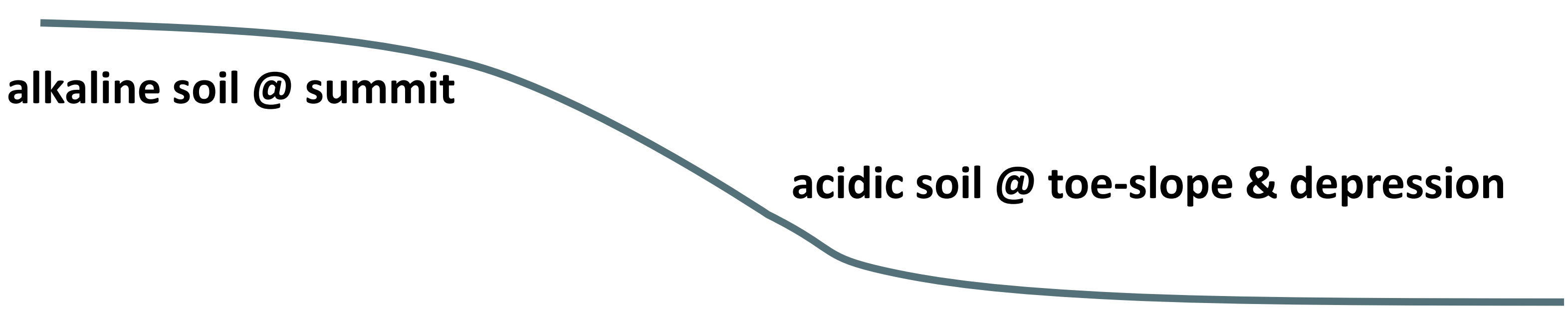

0
100
200
300
400
500 m

Legacy effects of fertilizer N

pH_{91}	7.77
pH_{90}	8.15
pH_{89}	7.89
pH_{88}	7.98
pH_{87}	7.67
pH_{86}	6.52
pH_{85}	7.95
pH_{84}	7.80
pH_{83}	6.22
pH_{82}	4.36
pH_{81}	4.42
pH_{80}	4.28
pH_{79}	4.19
pH_{78}	4.76
pH_{77}	4.28
pH_{76}	4.45
pH_{75}	4.18
pH_{74}	4.87

Research 2017 and
USDA-WSARE and MT Fertilizer Check-off

1. Sugar beet lime applications with incorporation
2. Lime requirement soil tests (<u>lab incubation study</u>) – 10 fields/soils with pH < 5.1
3. Cultivar selection trials for tolerance
4. Legacy effects of fertilizer N - pair field comparisons
5. Soil pH/Al toxicity mapping - gradients in the field are <u>very large</u>, acidity problem is not ubiquitous across the field landscape. Initial surveys suggest problem maybe confined to lower slope positions (relevant to $ of liming)



Objective 1 - on-farm soil acidity remediation and prevention program

- on-farm strip trials with sugar beet lime - 4 rates
- 3 fields with very acidic areas (pH < 5)

0 lb/ac

2000 lb/ac

4000 lb/ac

6000 lb/ac

60-100’

≤ 2600’

~ 4-6 acres per strip

WSARE grant will cover transport cost of lime to participating/cooperating farms

Objective 1 - on-farm soil acidity remediation and prevention program

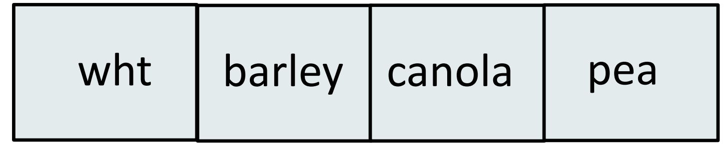
- on-farm strip trials with sugar beet lime - 4 rates
- 3 fields with very acidic areas (pH < 5)

- Soil sampling at GPS referenced points
- Time – 0, 6, 12, and 18 months
- Record pH, extractable Al levels

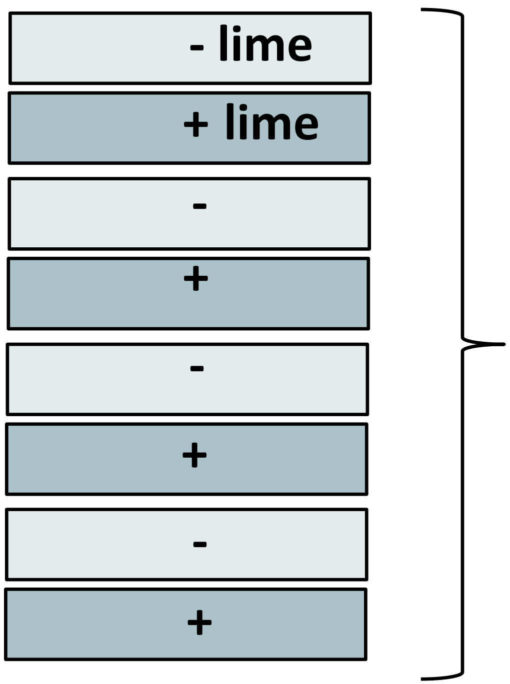
Objective 2 – lab incubation study

Objective 3 – wheat, barley, canola, and pea cultivar tolerance trials

- 10 selections per crop species



- 2 lime treatments (-lime, +lime) – probably fine mesh limestone
- two growing seasons (2018 and 2019) but with lime app in 2017

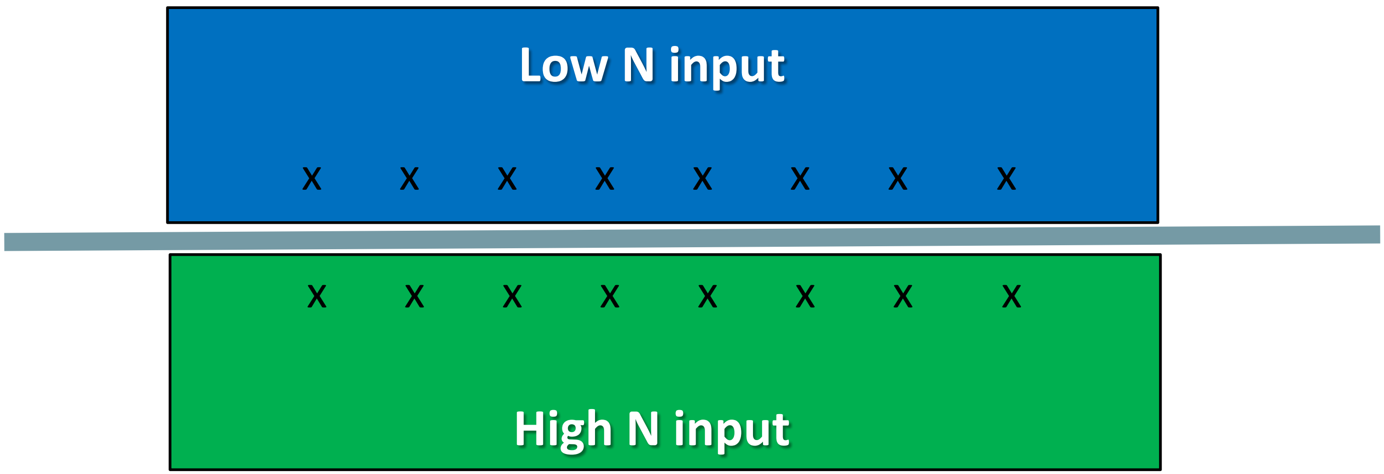


Our needs for this study

- 1.5 ac area per season
- uniform very acidic, pH <5
- farmer-cooperation

4. Legacy effects of fertilizer N

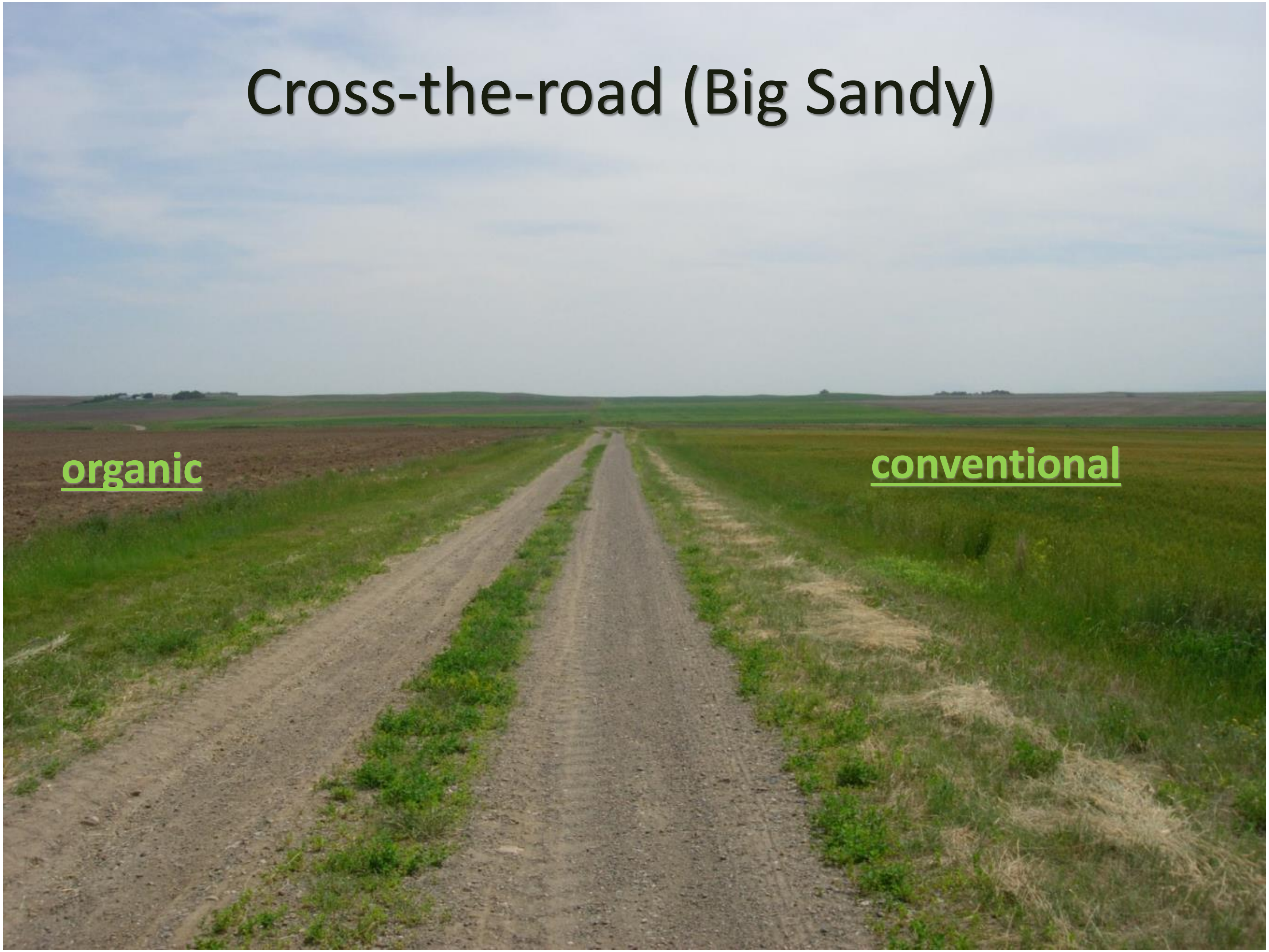
conduct paired comparisons between high and low N input farms



Protocol

- ✓ soil cores (0-3, 3-6, and 6-12”)
- ✓ compare pH
- ✓ extractable aluminum, exchangeable bases

Cross-the-road (Big Sandy)

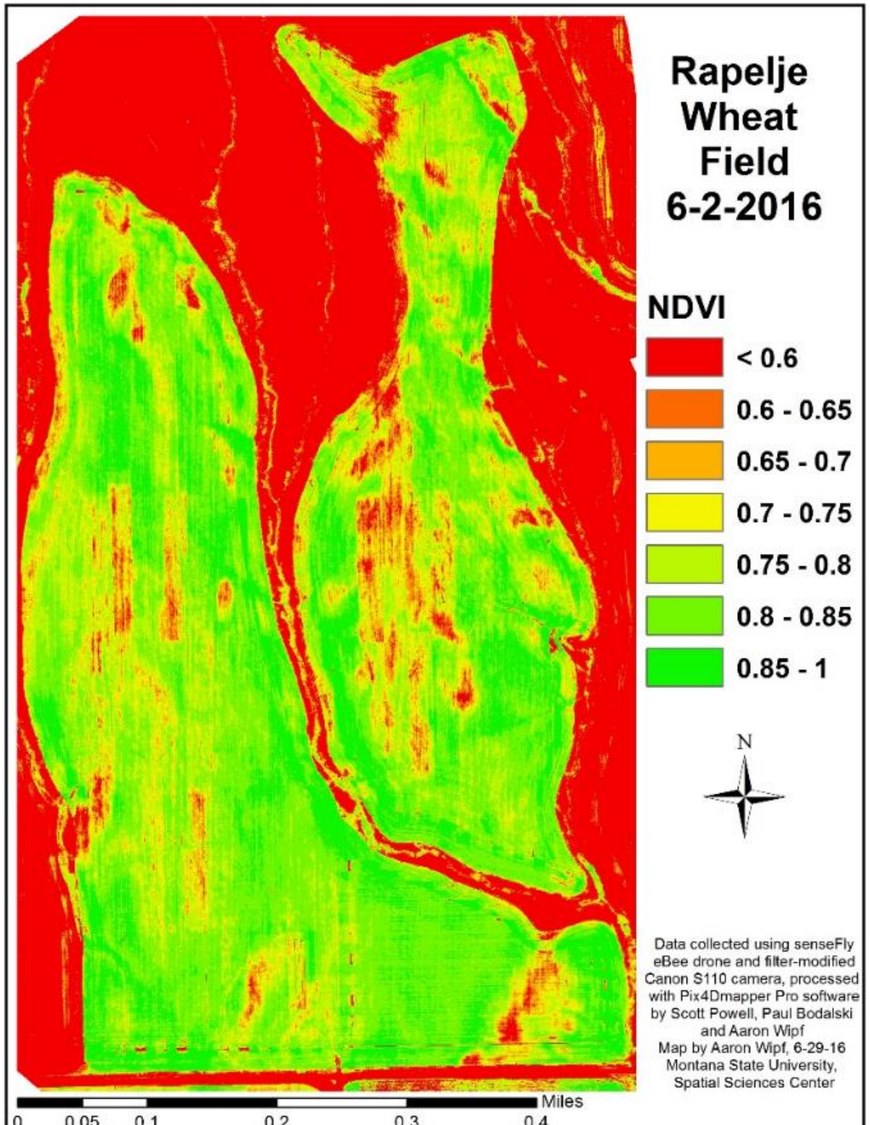


Objective 5. Soil pH/aluminum toxicity mapping

- Symptoms are not uniform across field landscapes
- Mapping symptoms may be a way to reduce lime remediation costs.
- How to map efficiently?

Unmanned aerial vehicles (UAV)
= drone flights by Dr. Scott Powell

NDVI imagery with UAV



- Up to 45 minutes flight time
- Up to 400 acre flight coverage
- Less than 1 inch/pixel ground sampling distance
- 1-3 inch horizontal/vertical accuracy

Final comments

- Soil acidity is likely to increase in the coming years and decades in Montana as similar phenomena has occurred in other semiarid regions – Palouse, Great Plains.
  - **How many acres will be affected and how soon??**
  - **Chouteau Co. – Highwood – higher precipitation area than much of Triangle**
- Likely will be more interest in aluminum tolerant cultivars of cereal grains
- Crop intensification & diversification - pulse acreage/production is rising; peas and lentils are very susceptible to low pH so may affect viability of some cropping systems
- Findings from our research study should help producers make informed decisions, but success of project will depend in part on your ideas and on-farm collaboration – <u>obtaining funding has been a challenge</u>

Questions?

Increase in alfalfa yield with lime application, Lane County, OR, 1926.
Image from Oregon State University

For more information on soil fertility see MSU Extension's:
http://landresources.montana.edu/soilfertility

For more information on acidic soils in PNW see WSU's site:
http://smallgrains.wsu.edu/soil-and-water-resources/soil-acidification-in-the-inland-northwest/