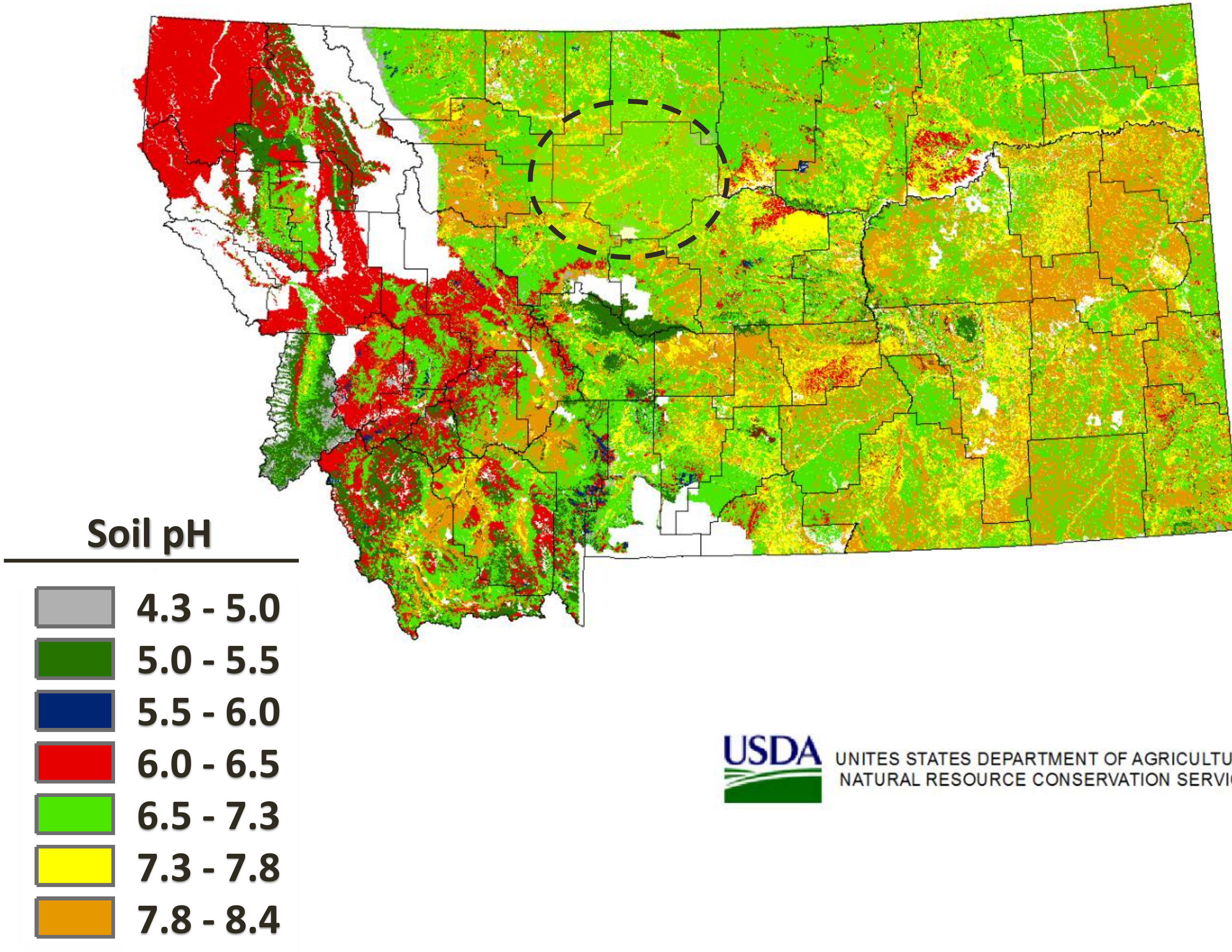
Understanding acidification and management of Montana soils

Clain Jones and Richard Engel
Dept of Land Resources and Environmental Sciences

Questions for you

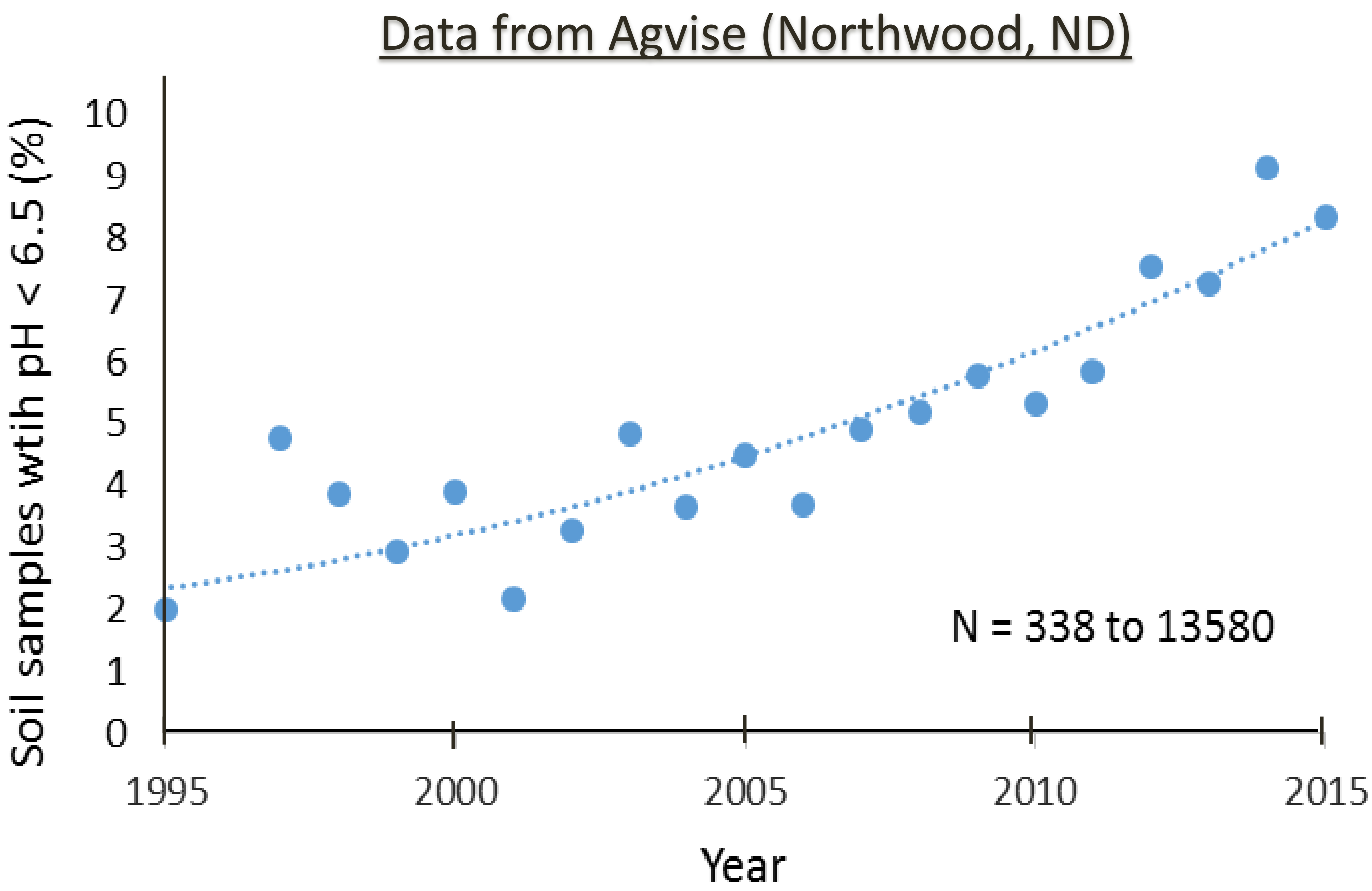
- How many of you have observed a downward trend in soil pH tests?
- How many think you have seen yield losses from acidic soils?
- How many of you have soil pH levels below 5.5?

Soil pH – NRCS published info



USDA UNITES STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCE CONSERVATION SERVICE

Trends in Montana to lower pH

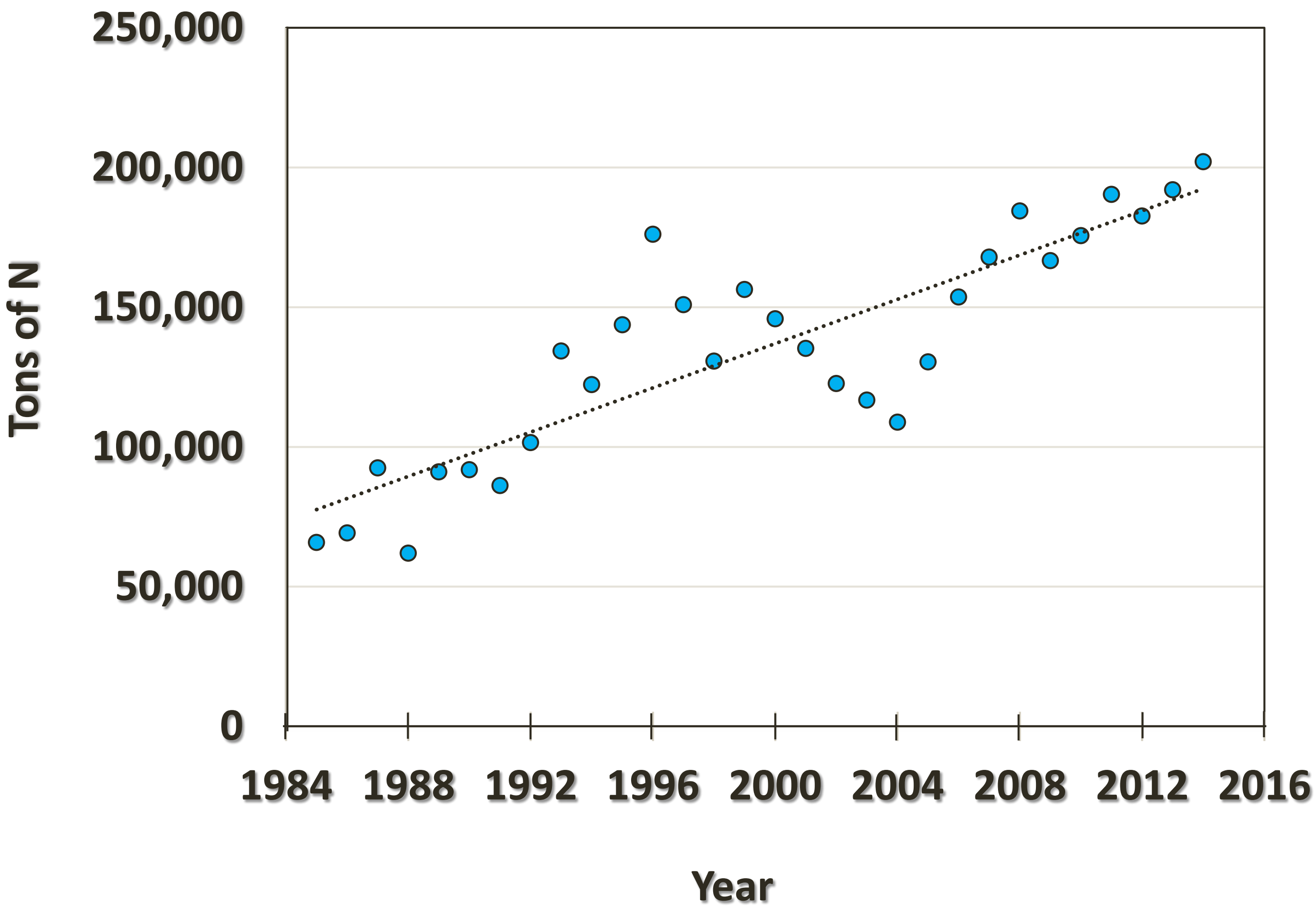


Soil acidification

- Natural processes – leaching of basic cations/salts, bicarbonates occurs over time which causes soils to acidify

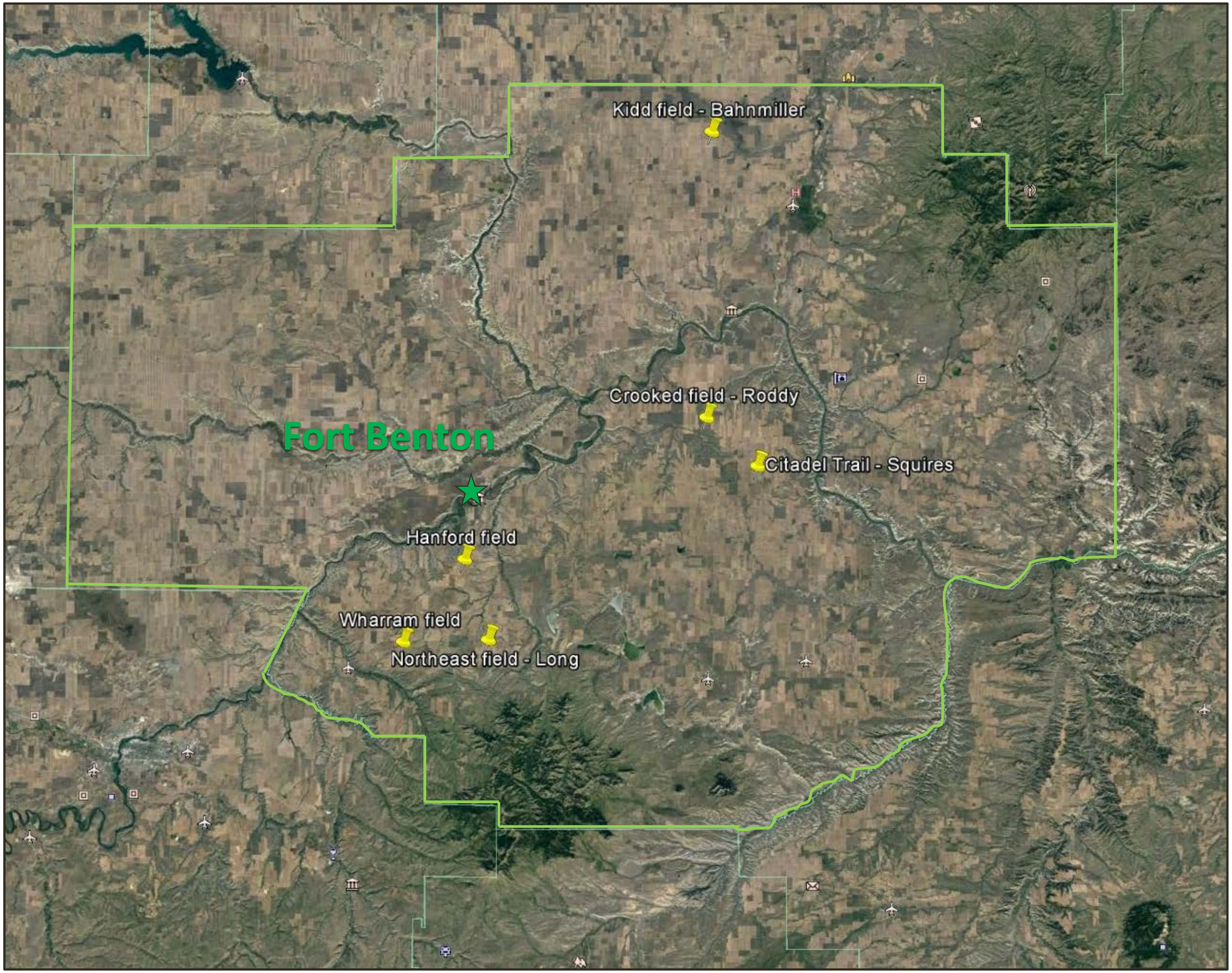
- Farming – has accelerated
  - no-till – absence of mixing can create pH stratification
  - summer-fallow can result in more leaching of basic cations/salts
  - residue removal - basic cations in the crop residue are removed from the soils
  - <u>fertilizer N – ammonium forms </u>***

Montana N fertilizer consumption

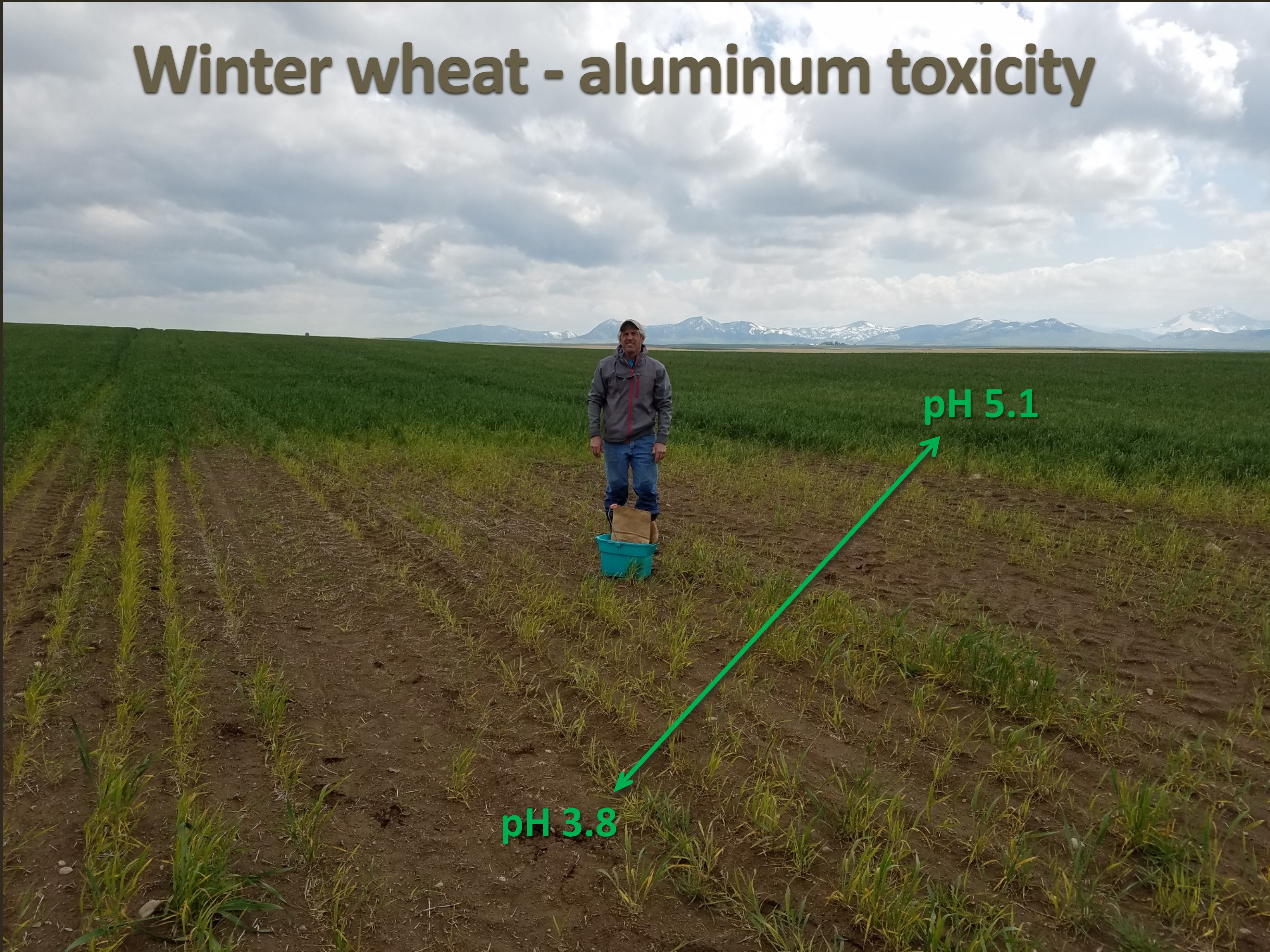


NH_4^+ (fertilizer) + 2 O_2 → nitrification (*soil bacteria*) → NO_3^- + H_2O + 2 H^+

Chouteau County field locations



Winter wheat - aluminum toxicity

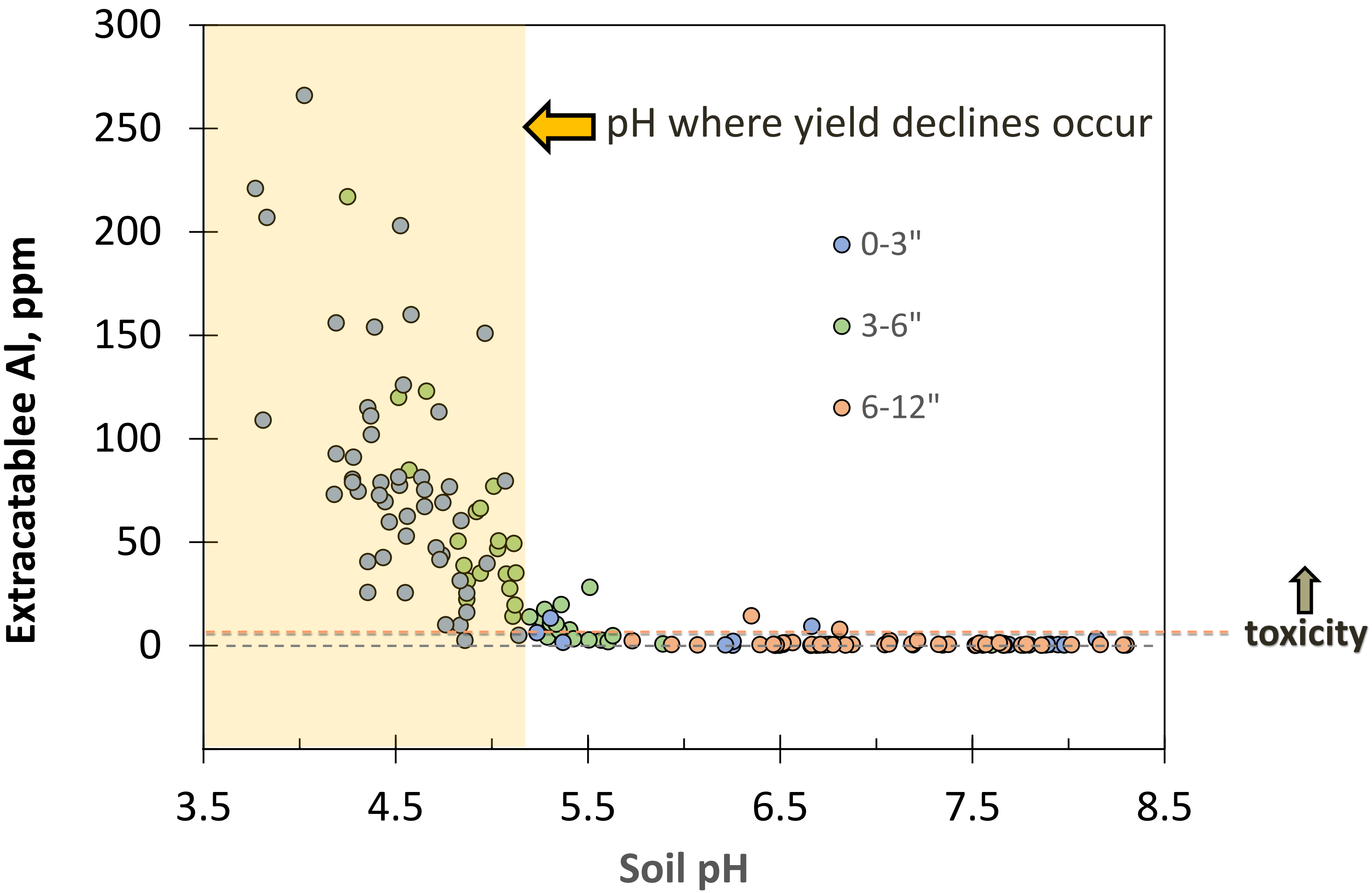



Durum wheat – aluminum toxicity

Plant Symptoms of Al toxicity

- Roots: witch's broom roots, thickened, twisted, club ends, stubby, no fine branching

Low pH increases Al to toxic levels

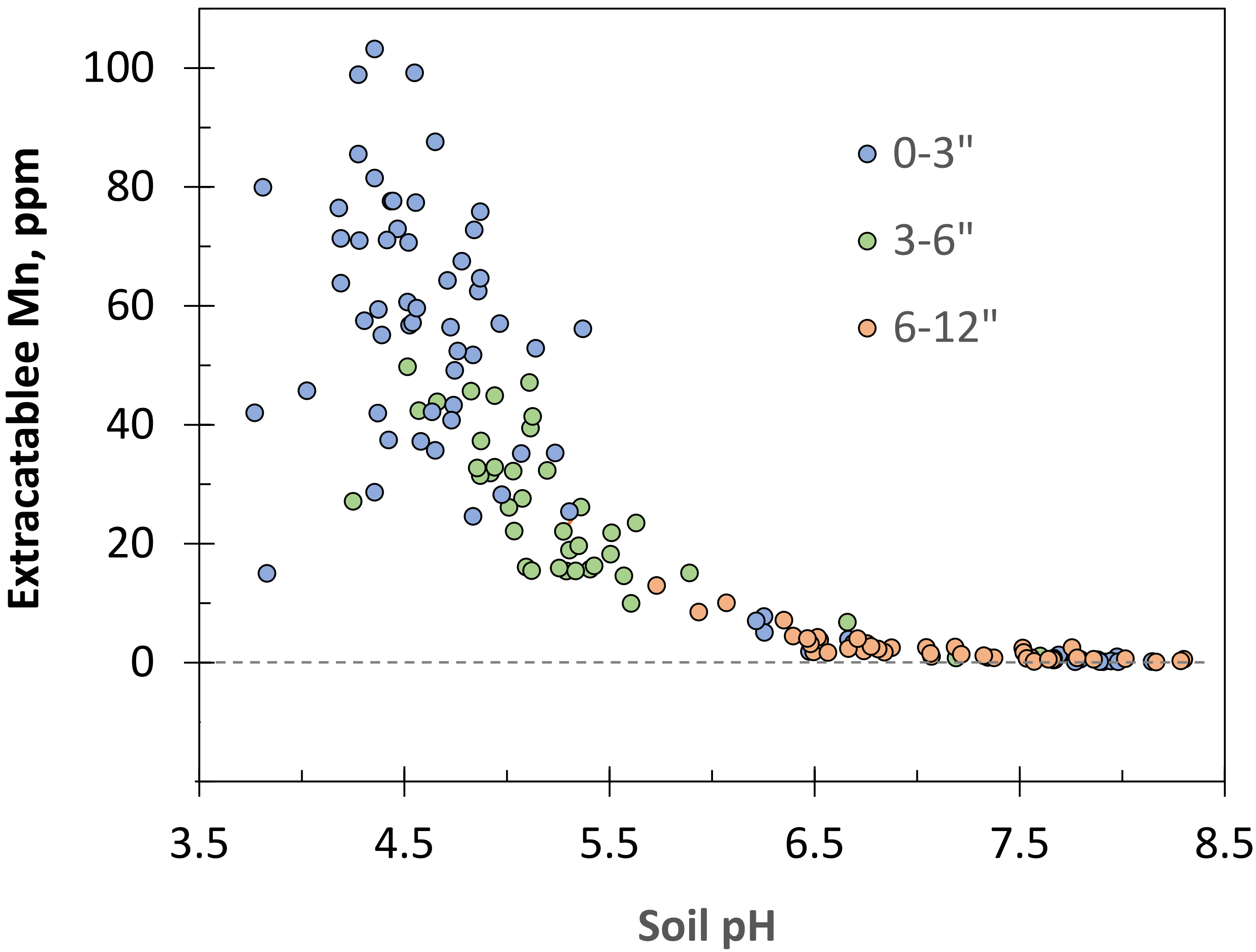


Engel unpub. data, 2016, 5 farms near Highwood, MT

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
- <u>solubility of aluminum </u>containing minerals increases as pH becomes more acidic ***

Soil pH also affects available Mn



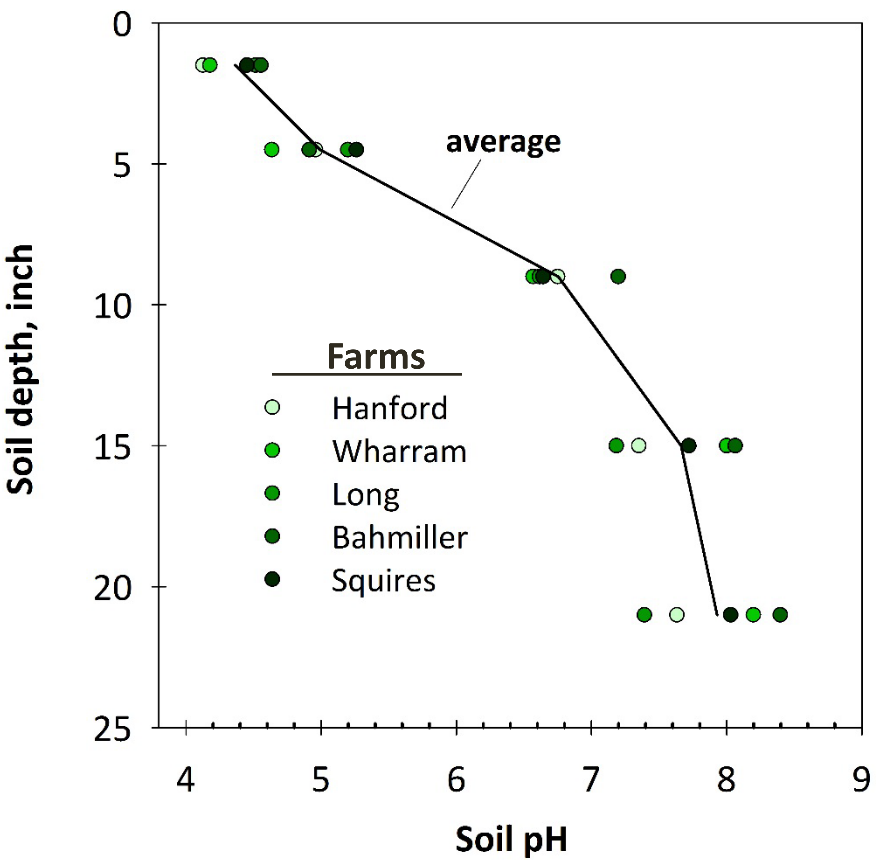
- ✓ Manganese toxicity has been associated with acidic soils - no evidence this has been a problem so far based on plant analysis

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



Summary

- 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).

Managing low pH

Remediation	Adaptation	Prevention
• amendments • tillage • deep-rooted or perennial crops	• seed Al-tolerant varieties or crops	• optimize N use efficiency - no left-over N • N sources • crop residue

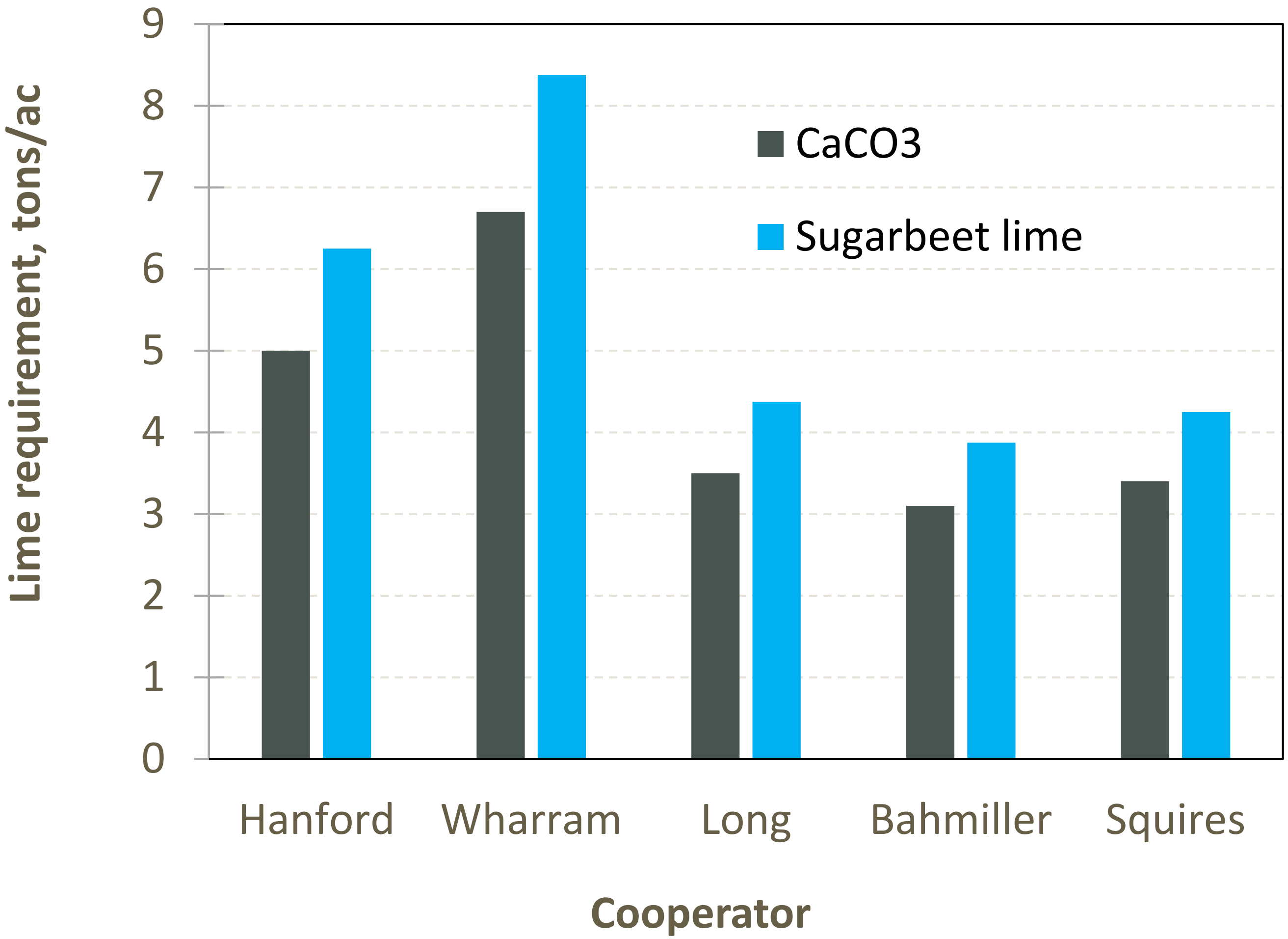
Remediation – sugar beet lime

- good – it doesn't cost anything

- bad – shipping costs (35 $ per 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 (Sikora method) field sites with soil pH < 5

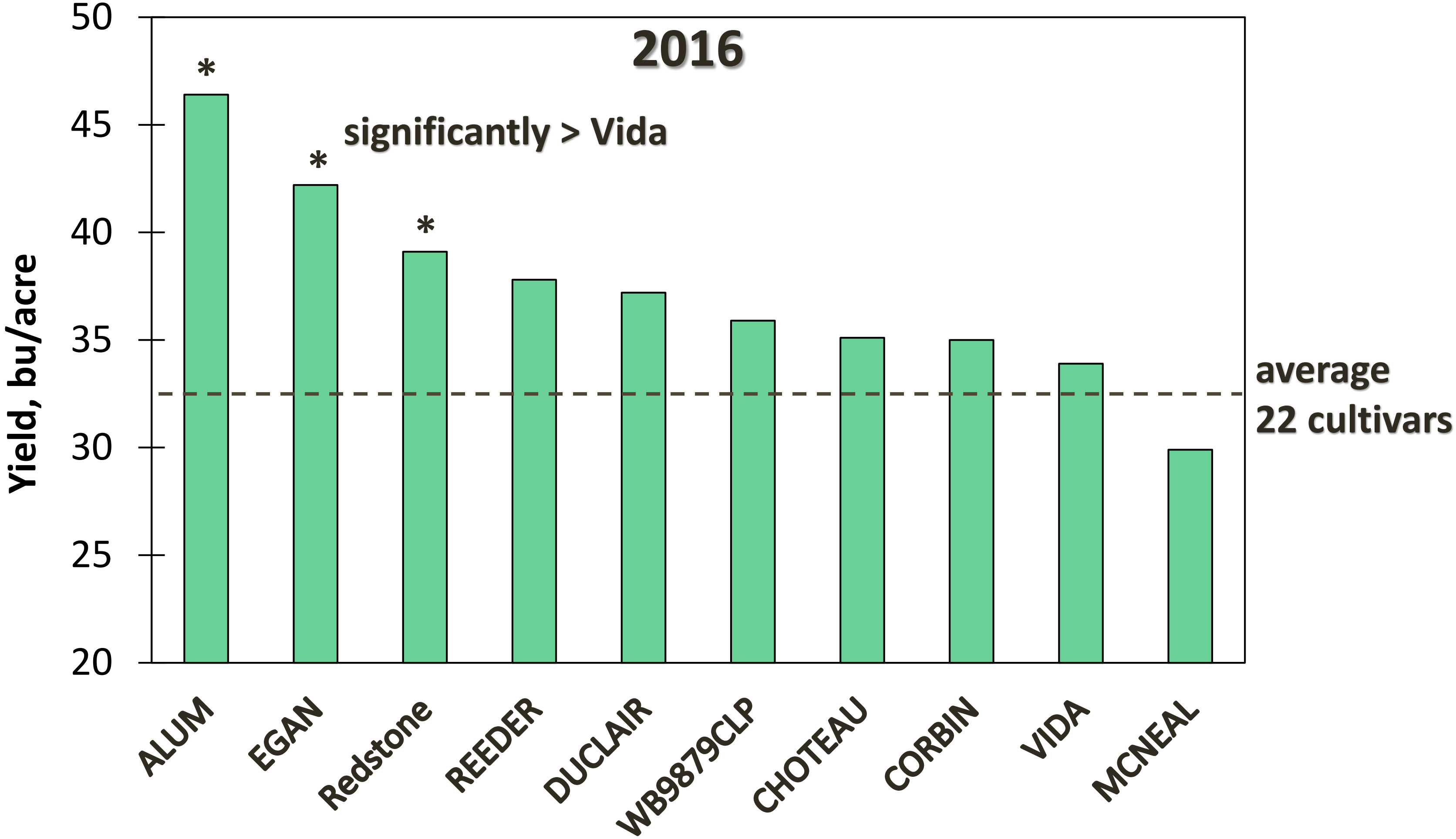


- ✓ lime requirements based on target pH 6.0;
- ✓ pH 5.5 target would require ↓ lime

Remediation – deep ripping

not sure this will work ?

Adaptation -spring wheat cultivars – Highwood Bench (soil pH 4.7)



Courtesy Briar, Wichman, and Talbert

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

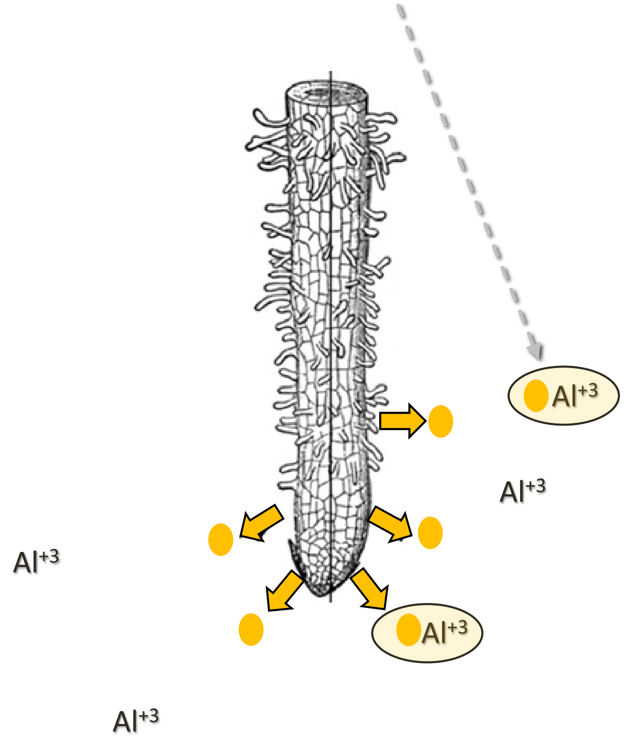
Stripe Rust	Very Good Adult Resistance[1]
Hessian Fly	Resistant
Aluminum Tolerance	Excellent

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

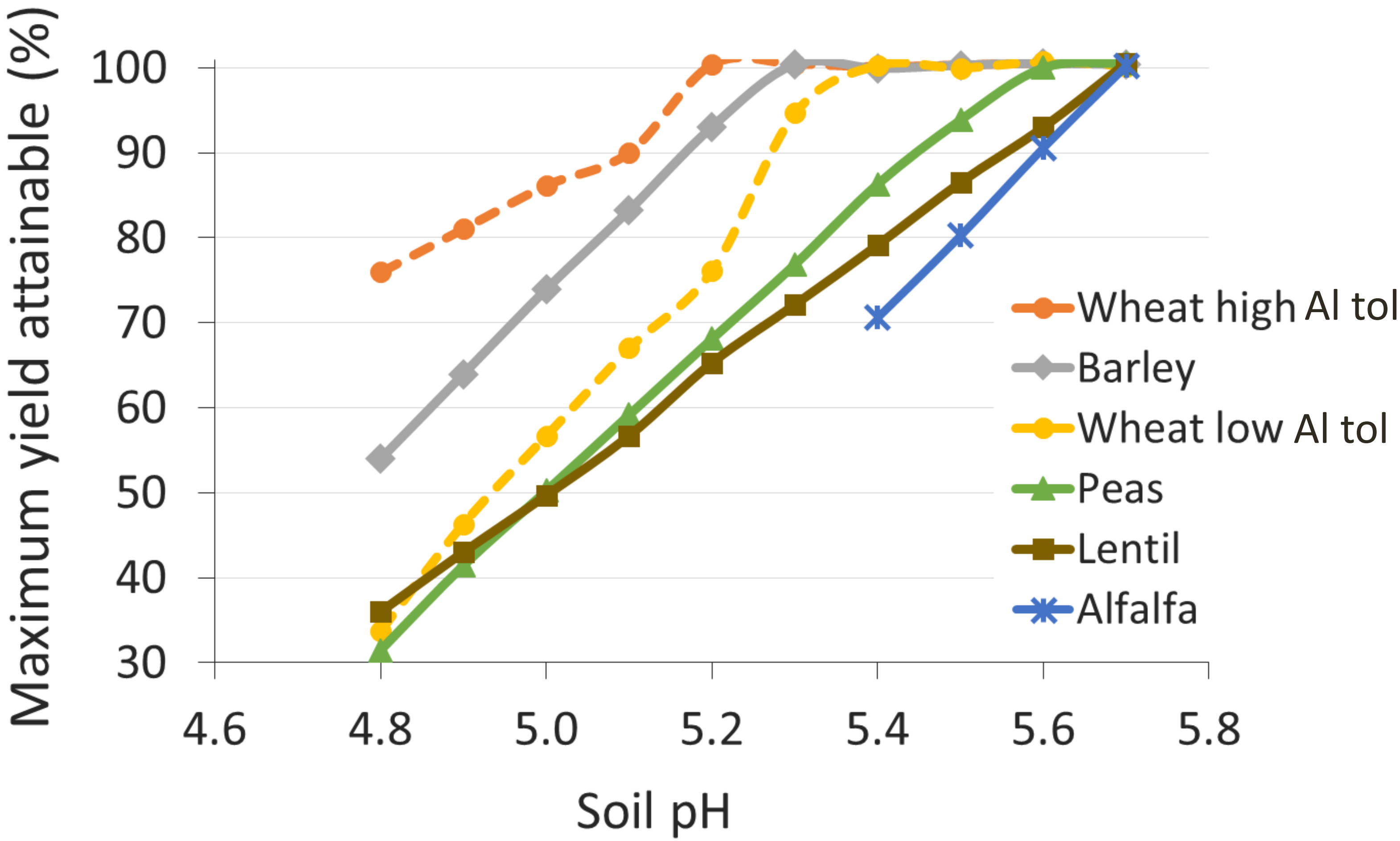
WASHINGTON STATE UNIVERSITY

Aluminum tolerance – single locus (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



Adaptation - crop species & tolerance to low soil pH



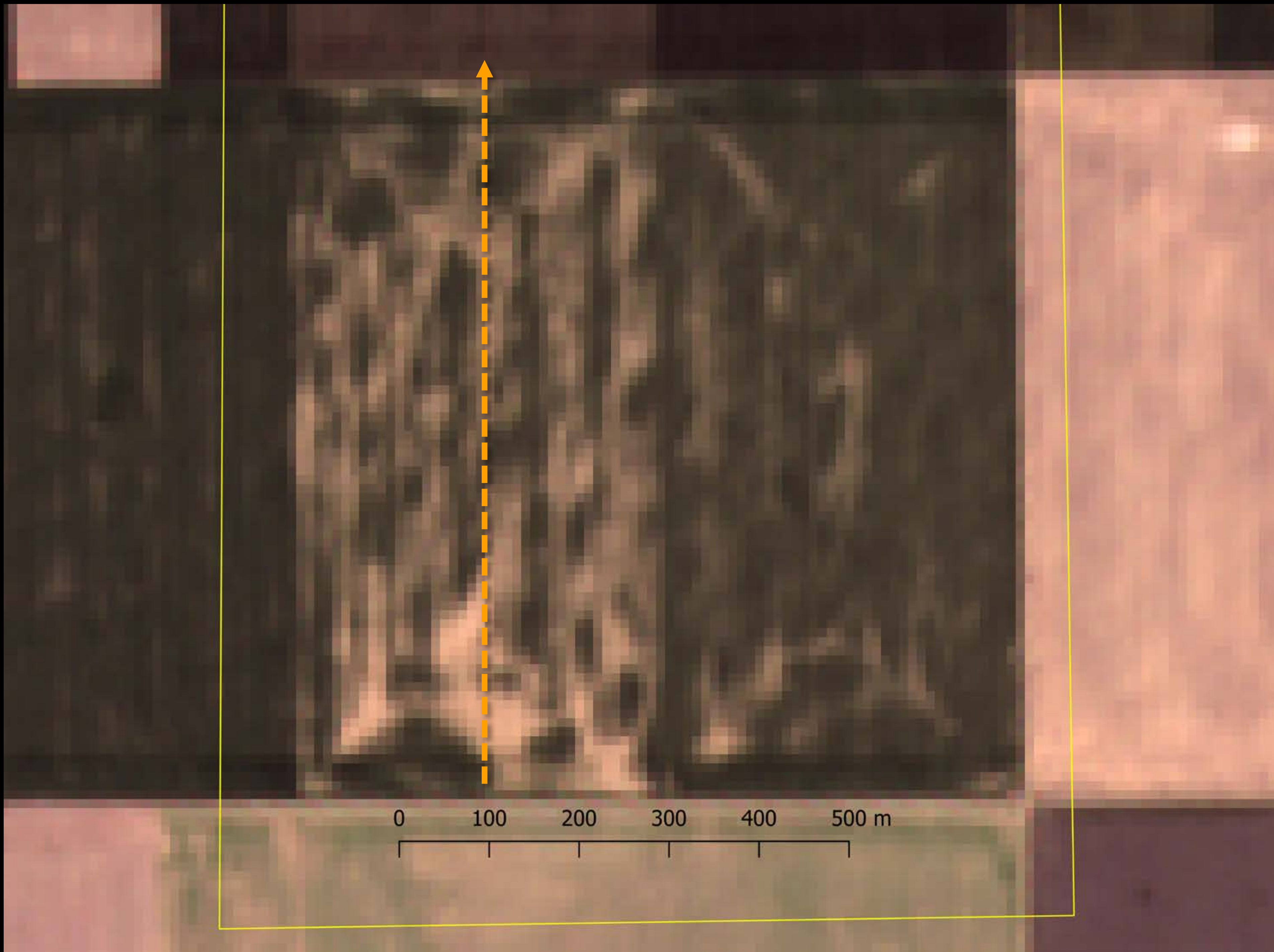
✓ peas and lentils are more susceptible than cereal grains

McFarland et al., 2015

My Research - activities for 2017

- Sugar beet lime applications with tillage
- Lime requirement soil tests
- Legacy effects
- Soil pH mapping - gradients in the field are very large, acidity problem is not ubiquitous across the field landscape. Initial surveys suggest problem maybe confined to lower slope positions (relevant to $ of liming)

Legacy effects – an example from field

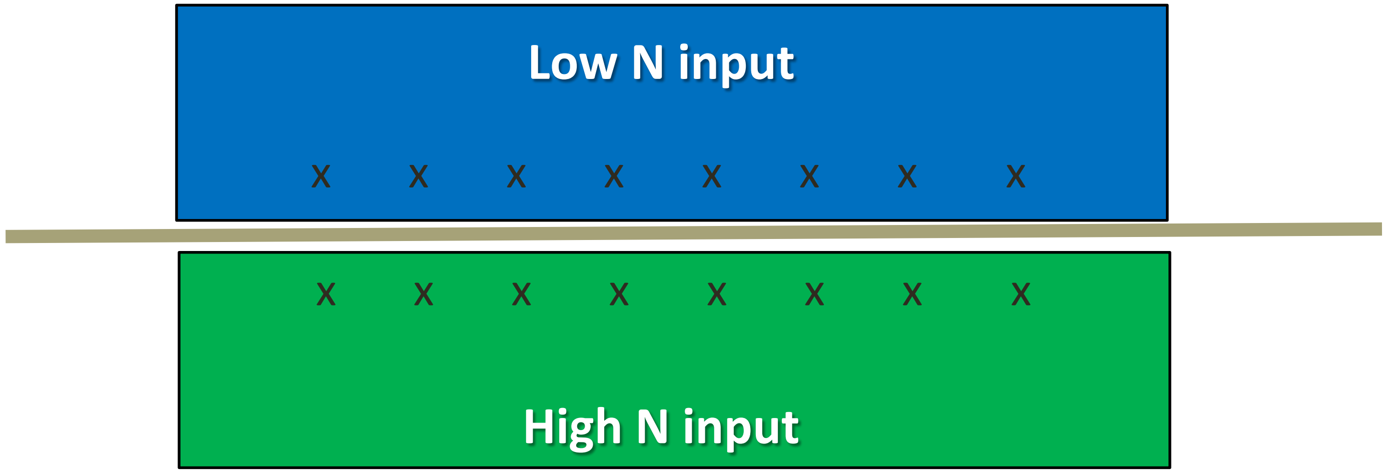

0
100
200
300
400
500 m

Legacy effects – durum & w. wheat field

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

Cross-the-road (Big Sandy)

Paired comparisons – high and low N input farms (legacy effects of N fertilizer)



Protocol

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

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 County – growers have observed problems, Highwood – higher precipitation area

- 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

Soil Scoops

THE SOIL SCOOP

December 2016

Soil Acidification: Problems, Causes, & Testing

MONTANA STATE UNIVERSITY EXTENSION

cycling organic matter placement rate residue timing

by Clain Jones, Montana State University Extension Soil Fertility Specialist, and Kathrin Olson-Rutz, Research Associate

Most agricultural soils in Montana have near-neutral to basic conditions with surface soil pH 6.5 to 8. However, some areas of Montana have acidic soils, especially in the seeding zone. The decrease of soil pH in the seeding zone can be relatively rapid. Idaho agricultural soils went from neutral pH to pH less than 6 in about 25 years. The Soil Scoop *Soil Acidification: Management* presents management options. More details on soil pH and references are available in *Soil pH and Soil Organic Matter*.

SOIL pH

Soil pH is a measure of the soil solution's acidity on a scale from 0 to 14. By definition, pH = -log[H$^+$], where [H$^+$] is the hydrogen ion concentration. The negative sign means as pH goes up, acidity (and H$^+$ concentration) goes down. Acidic soils have low pH values (<7), basic soils have high pH levels (>7), and pH 7 is neutral. Each pH unit change represents a 10-fold change in acidity. For example, a soil with pH = 6 is 10 times more acidic than a soil with pH = 7.

AGRONOMIC CONCERNS OF LOW SOIL pH

- Aluminum (Al), H$^+$, and manganese (Mn) toxicity lead to yellow foliage and poor growth. Aluminum toxicity creates plants with club or broom shaped roots (Figure 1).

FIGURE 1. Club roots of wheat from Al toxicity.

- Plants are hungry due to low soil nutrient levels (Figure 2). Phosphorus (P) is tightly bound to clay or iron particles, while nitrogen (N), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg) are easily leached and lost from the soil.

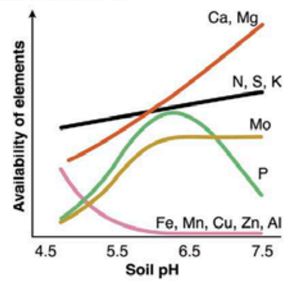


FIGURE 2. Nutrient availability as soil pH changes. Source: Government of Western Australia, Department of Agriculture and Food

- Reduced rhizobial growth; legume (e.g., pea, alfalfa) nodulation/N fixation is severely limited at pH < 6
- Increased fungal diseases (e.g., *Rhizoctonia*)
- Changes in herbicide/pesticide effectiveness and residual (e.g., Group 2, B herbicides)

CONDITIONS CONTRIBUTING TO LOW SOIL pH

- Ammonium-based N fertilizer above plant needs (Figure 3)
- No-till (concentrates acidity in 3-5" rooting zone), although even with 9" moldboard plowing N fertilizer above plant needs caused soil acidification in the 0 to 9" soil layer (Rasmussen et al., 1989).
- Soils with high sand content and/or low levels of soil organic matter (SOM)

For more soil fertility informaton and resources see http://landresources.montana.edu/soilfertility/

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Most agricultural soils in Montana have near-neutral to basic conditions with surface soil pH 6.5 to 8. However, some areas of Montana have acidic soils, especially in the seeding zone. The Soil Scoop *Soil Acidification: Problems, Causes & Soil Testing* introduces soil pH, why it is a concern, agronomic practices that contribute to soil acidification, and soil testing for pH.

MANAGEMENT: PREVENTION & MITIGATION

- Use practices and rates to optimize nitrogen (N) use efficiency – no left-over N. Base N rate on spring soil tests and realistic yield potential, split N applications (and don't apply 2nd time in dry springs), and place N in the root zone.
- Reduce nitrate (NO_3^-) loss. Use slow-release N sources or N sources with nitrification inhibitors, and plant deep rooted crops to 'catch' deep nitrate. Deep rooted crops can also pull base-forming cations (Ca^{2+}, K^+, Mg^{2+}) from the subsurface to the surface.
- Use calcium ammonium nitrate (27-0-0) which has less acidifying potential than urea (46-0-0).
- Use pulse crops in rotation – they don't need N fertilizer
- Plant aluminum (Al)- or low-pH tolerant crops (Figure 1) or varieties such as Judee, Wesley, Overland, or AAC Gateway (from 1 Oklahoma study)

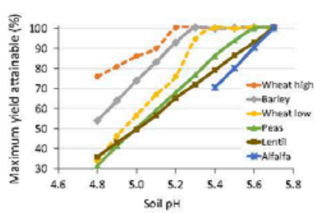

FIGURE 1. Crop species vary in tolerance to low pH, or high aluminum levels (McFarland et al., 2015).

- Inversion till to mix acid zone throughout plow layer and bring up calcium carbonate ($CaCO_3$) from deeper layers. A soil with 5% $CaCO_3$, typical in Montana, contains 100 tons of $CaCO_3$ in the top foot. One-time summer tillage doesn't negate long term benefits of no-till (Norton et al., 2014).
- Increase soil organic matter (SOM) to buffer pH changes and reduce Al, manganese (Mn) and H$^+$ toxicity. Leave crop residue in field to retain base cations or apply manure. Replace fallow with crops or cover crops.
- Seed-place lime to compensate for annual N application or amend whole field with several years' of potential lime need. Broadcast conventional ag-lime needs to be tilled to affect the seeding zone. Other options are presented below.
- Band P with seed (binds some Al).

LIMING

Liming material reacts with carbon dioxide and water in the soil to yield bicarbonate (HCO_3^-), which takes H$^+$ and Al^{3+} (acid-forming cations) out of solution, raising soil pH. The benefits are varied and depend on the soil pH level reached (Table 1).

Source Different materials have different 'potency' to raise soil pH. Calcium carbonate equivalent (CCE) compares a liming material to pure $CaCO_3$. Lime Score (LS; Table 2), also called effective neutralizing value (ENV), combines CCE with factors for moisture and fineness to calculate

Table 1. The benefits of increasing pH of acidic soils[a].

Soil pH	Effect
6.1 - 6.5	Improve soil structure; reduce crusting reduce power need for tillage
5.6 - 6.0	Increase soil microbial activity; increase rhizobia health for nitrogen-fixation and other mycorrhizal assisted crops (legumes and barley); increase plant nutrient availability
5.1 - 5.5	Reduce Al, H$^+$, and Mn toxicity; increase availability of P and other nutrients
< 5.1	Few crops can produce if not limed

[a] Alberta Agriculture & Forestry

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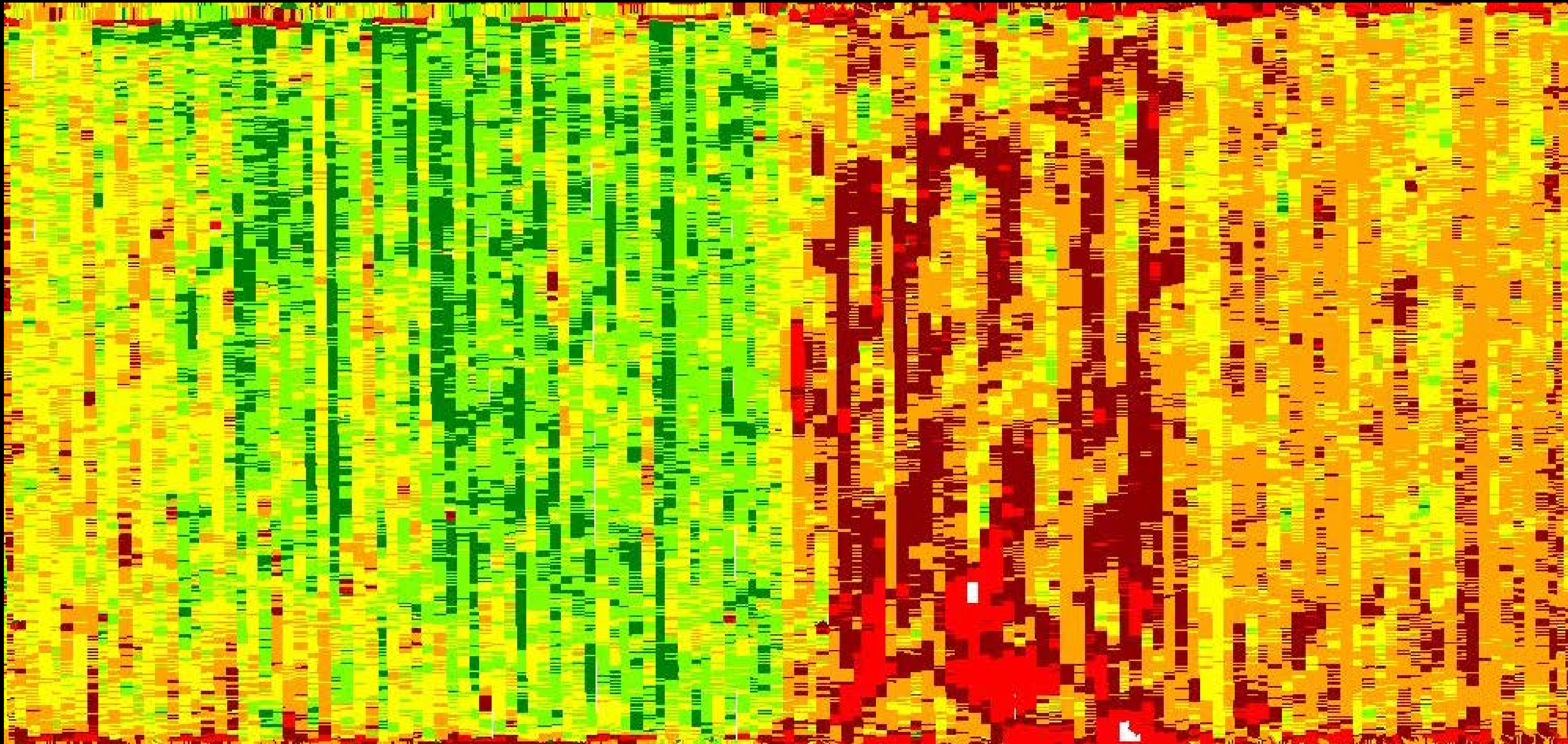
Thank you



Legend - Map data contains points with no GPS information.

Color	Minimum	Maximum
	46.70	or Greater
	37.69	46.70
	30.50	37.69
	23.57	30.50
	12.76	23.57
	Less than	12.76

Aluminum toxicity and P

double seeded durum and P