Soil Acidification in Montana - An Emerging Problem

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MFAC supported

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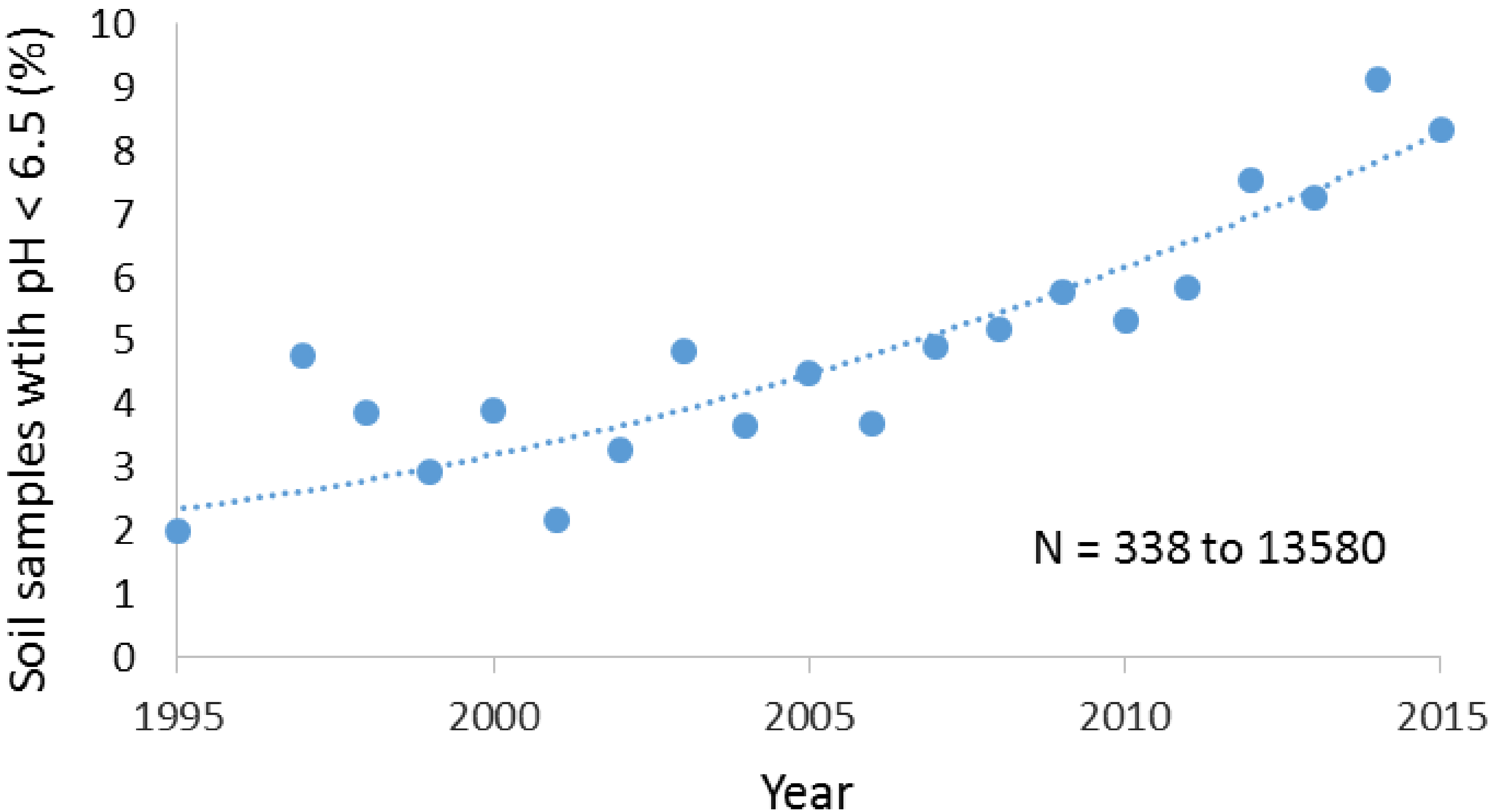
Acidic soil samples (pH<6.5) are increasing in MT



Unpub data AgVise

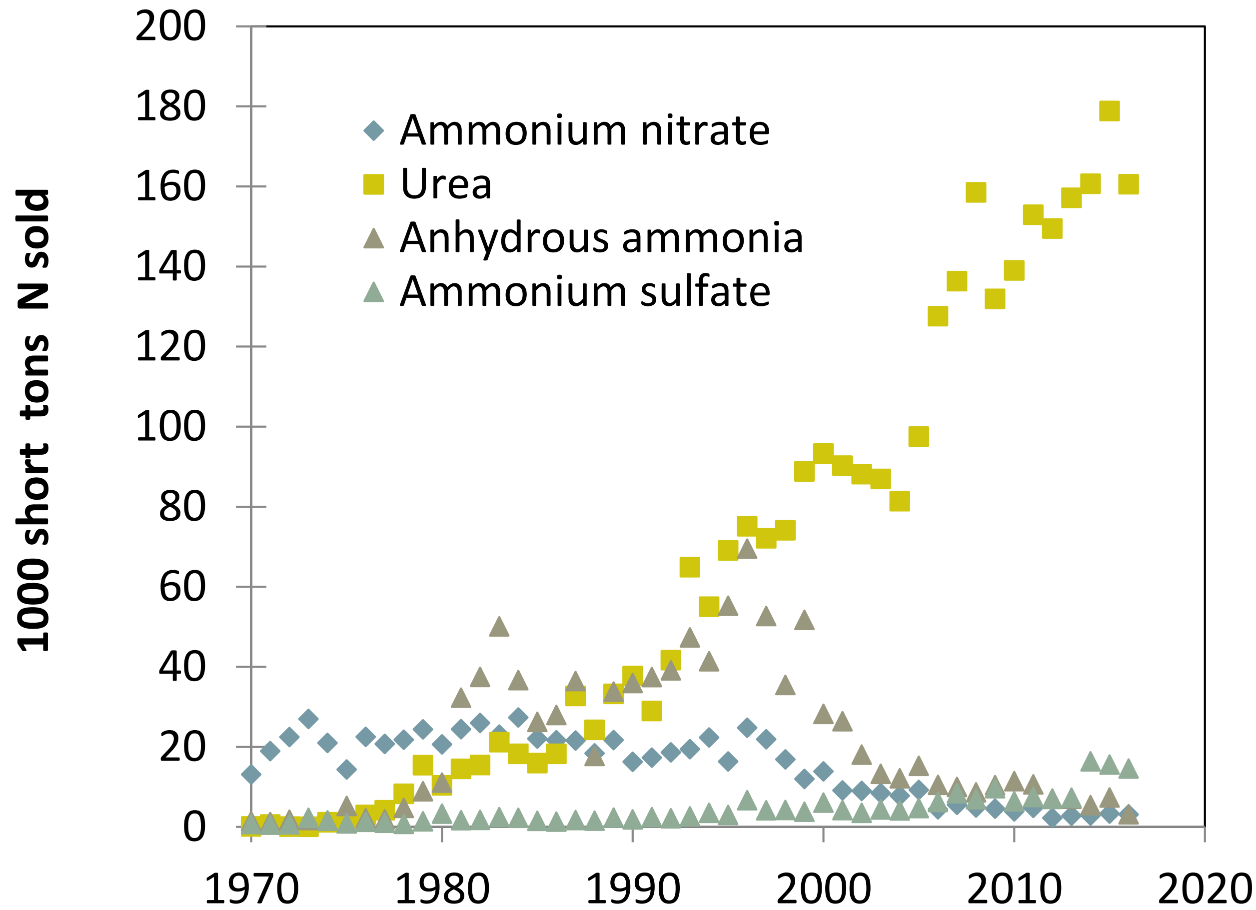
Objectives

- Discuss causes
- Illustrate consequences of acidic soils to crop production
- Soil acidity patterns in the field
- Present soil acidity management options – adaptation, prevention or remediation

Causes

- soil acidification can occur naturally as basic salts are leached from surface; carbonic acid in rainwater
  - slow process
- pH of cultivated soils < adjacent rangeland because of greater water transport through profile & also bases are removed by crops
- fertilizer N inputs

Montana Fertilizer N Consumption



- *consumption of fertilizer N is up 3x since 1985; 86% urea*

Fertilizer N reactions

- Urea hydrolysis (soil enzymes – urease)

$$CO(NH_2)_2 + H_2O + 2H+ \rightarrow 2NH_4^+ + CO_2$$

<u>1 N atom consumes 1 H^+</u>

- Nitrification (soil bacteria) - oxidation of ammonium to nitrate

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

<u>1 N atom produces $2H^+$</u>

Net effect urea addition → N atom produces 1 H^+

Fertilizer N reactions

- Urea hydrolysis (soil enzymes – urease)

$$CO(NH_2)_2 + H_2O + 2H^+ \rightarrow 2NH_4^+ + CO_2$$

<u>1 N atom consumes 1 H⁺</u>

- Nitrification (soil bacteria) - oxidation of ammonium to nitrate

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

1 N atom produces $2H^+$

What about other N fertilizers ? ammonium sulfate

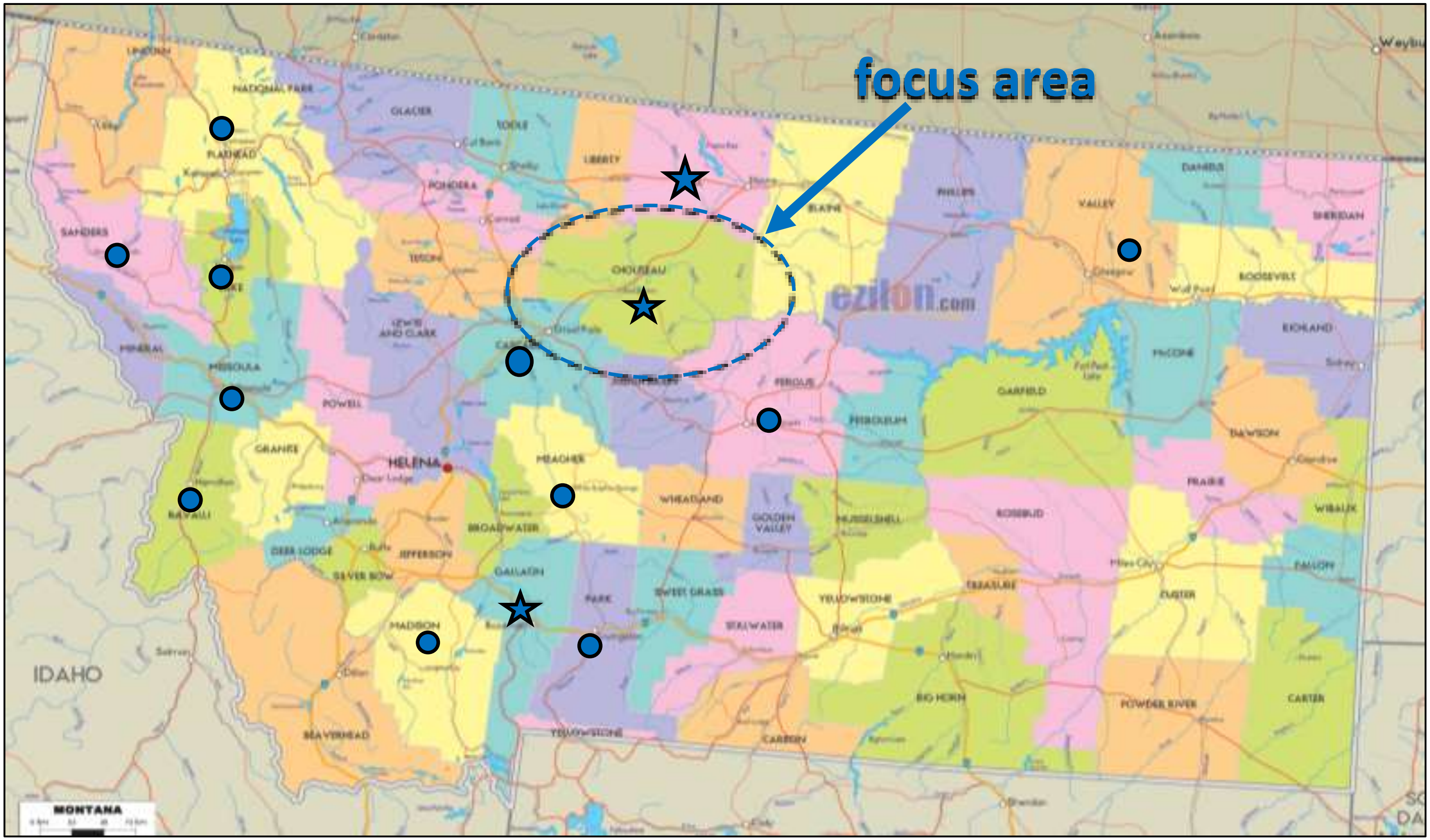
Fertilizers differ in potential to acidify soil

Most acidifying

- ammon. sulfate (21-0-0-24) = MAP (11-52-0) ≈ 2x urea
- DAP (18-46-0)
- urea (46-0-0)
- calcium ammonium nitrate (CAN; 27-0-0) ≈ 1/3 x urea
- sodium nitrate (16-0-0) - does not acidify

Least acidifying

Counties with cultivated soils pH< 5.5



★ Sampled by MSU

● Reported by CCA or County Ext

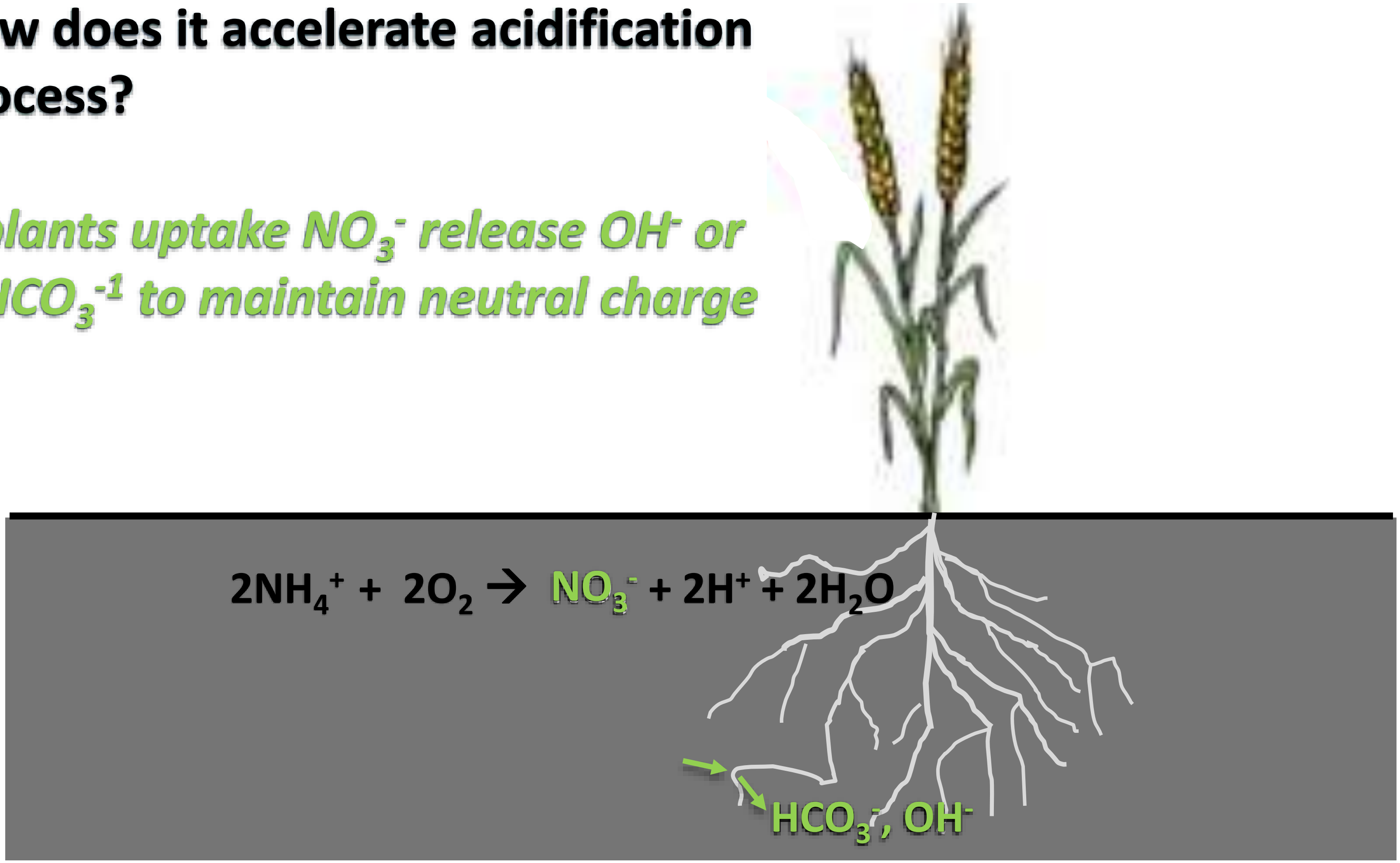
Why soil acidity problems are appearing in Chouteau Co. ? possible explanations

- saline seeps
- annual cropping to remediate – more fertilizer N inputs
- no-till – pH stratification
- annual precipitation in many areas (e.g. Highwood Bench) is somewhat greater than many other Montana dryland areas → promotes nitrate transport out of surface layers

Nitrate leaching

How does it accelerate acidification process?

- ***plants uptake NO_3^- release OH^- or HCO_3^{-1} to maintain neutral charge***



Legacy effects – Telstad loam – Big Sandy

Legacy effects of N fertilizer – e.g. Big Sandy

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

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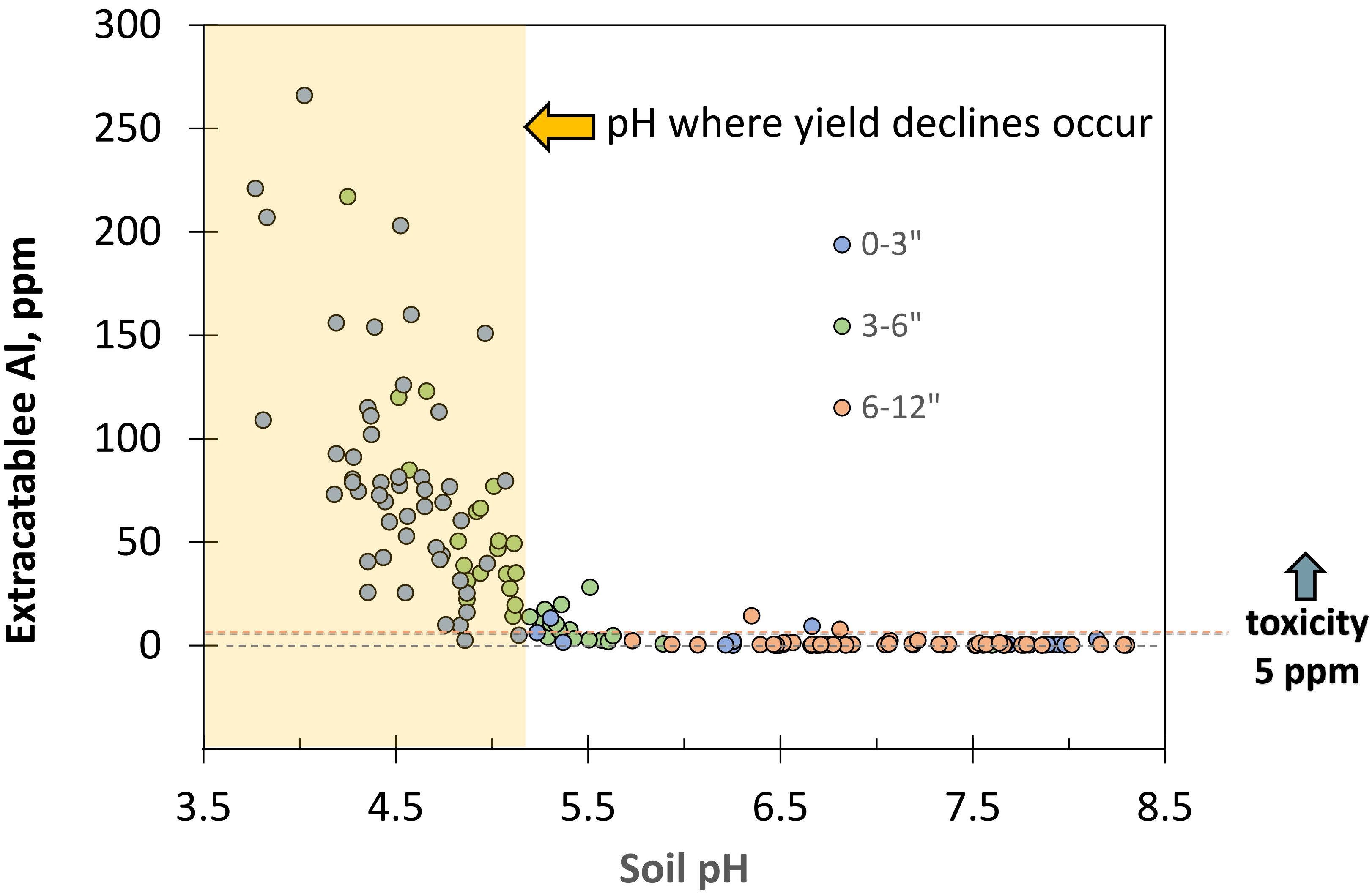
Aluminum toxicity in durum

Plant Symptoms of Al toxicity

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

Courtesy Shabeg Briar and Dave Wichman

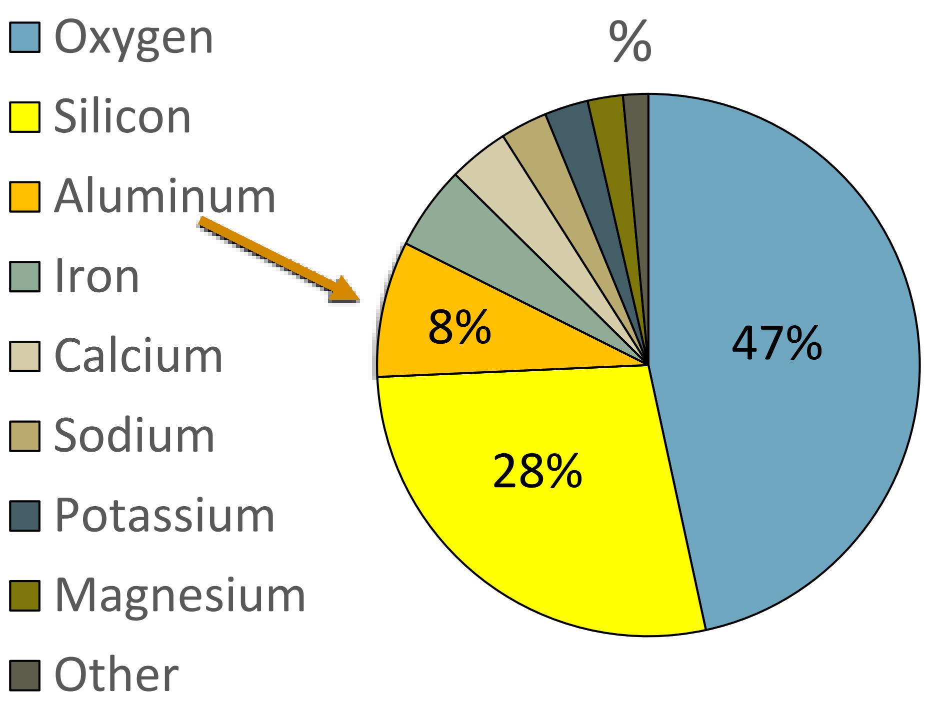
Low pH increases extractable soil Al to toxic levels



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

Where is the aluminum coming from?

Soil composition – 3rd most abundant element in earth crust



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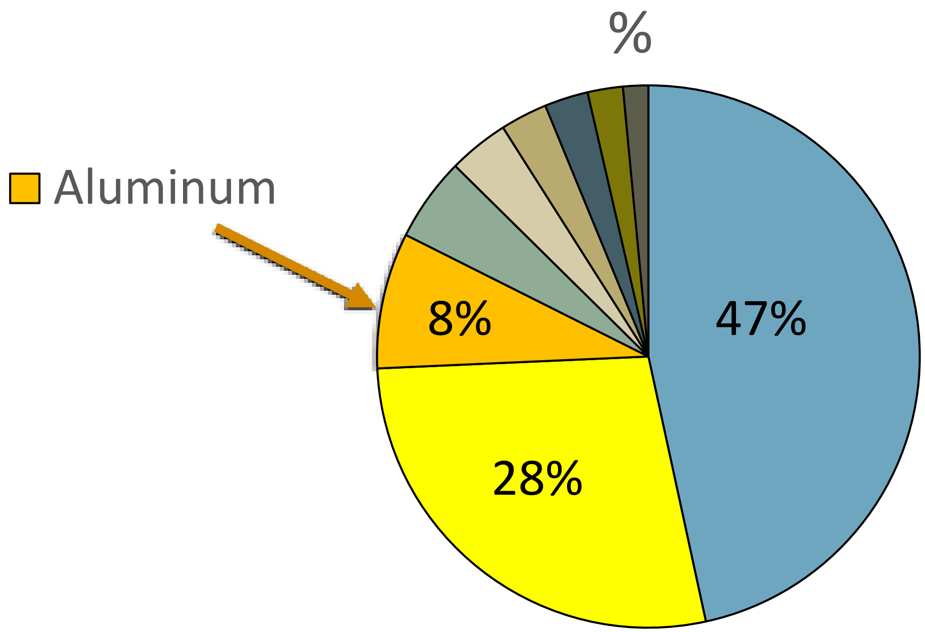


- clay minerals (Al-silicates layers)
- Al oxides and hydroxides
- solution = (0.5 ppm) x 0.25 water

Soil pH and Al toxicity – two issues

- solubility of Al increases as pH falls (more Al coming off minerals, and oxides and hydroxides)

- Al hydroxide ions in soil solution; Al ions can exist in soil solution as different charged ions Al^{+3}, $Al(OH)^{+2}$, $Al(OH)_2^{+1}$, $Al(OH)_3$,

most toxic ion and it is found in < abundance in acidic solutions

Acid soils - additional negative impacts

- Herbicide persistence (Raeder et al., 2015) – Metribuzin
- Damaging to rhizobia (N-fixing by legumes)
- Increase in fungal diseases
- Increase Mn to toxic levels

Images from Creative Commons

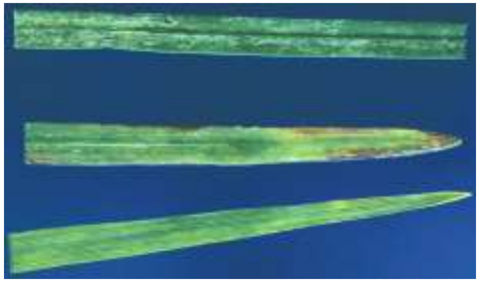
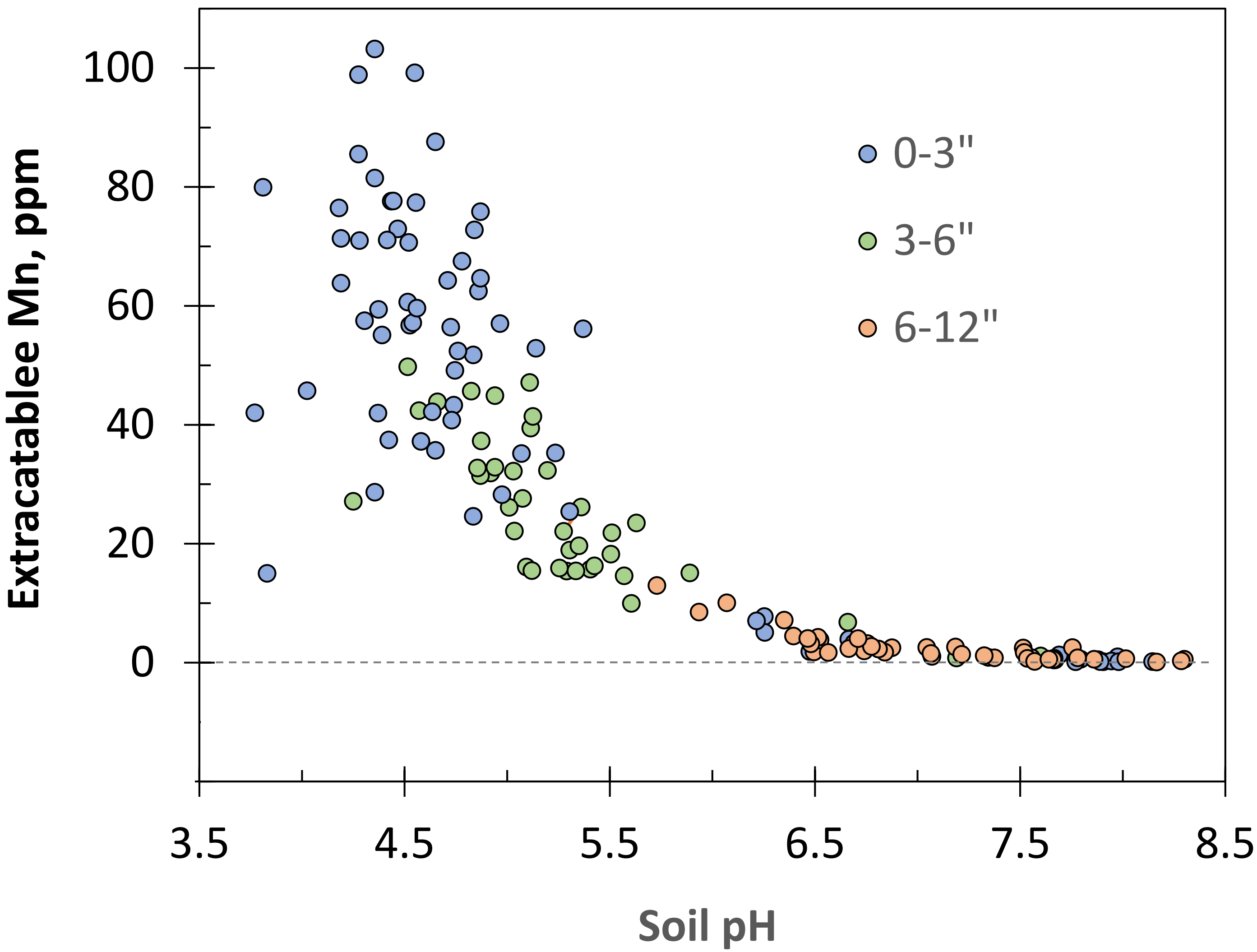


Image from CIMMYT, Int.

Soil pH also affects extractable Mn



✓ **Manganese toxicity has been associated with acidic soils - pH < 5.8 threshold – do we have a problem?**

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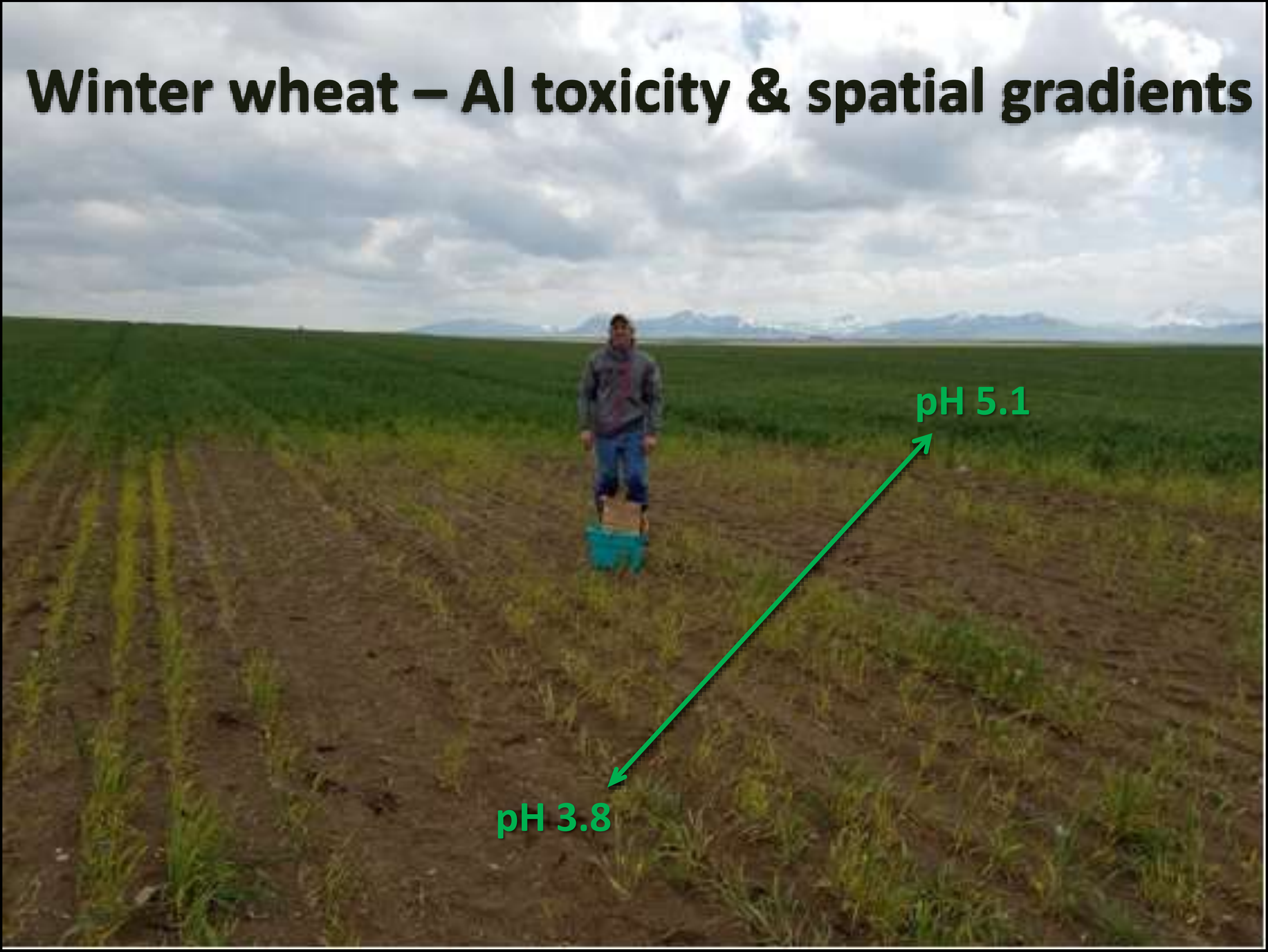
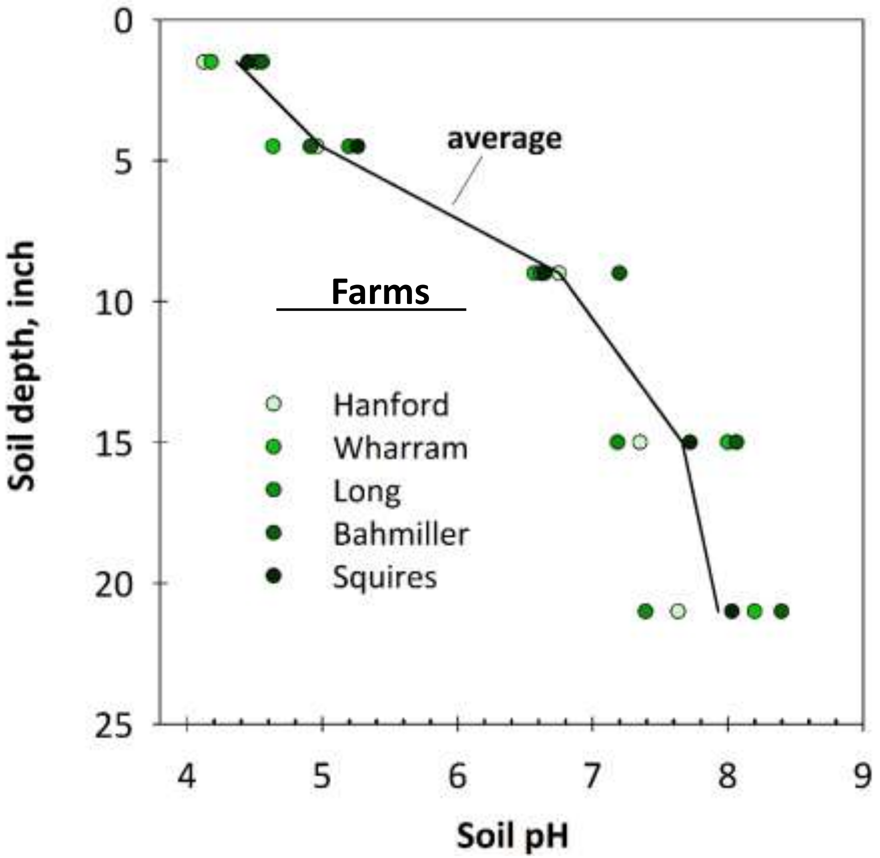
Dryland fields can exhibit large spatial gradients in pH
e.g. north Geraldine

Winter wheat – Al toxicity & spatial gradients



Soil pH stratification in Montana



Summary

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

  1. N applied near surface & no-till
  2. subsoils have a lot of natural lime (Ca, Mg, Na carbonates).

Questions for you

- Observed stand issues in low lying areas?
- Soil pH levels < 5.0 or 5.5?
- How many of you are aware of pH stratification ?

Soil sampling approaches

- Compare between ‘good’ and ‘bad’ areas – use color kits to select ‘bad’ soils to send to lab
- Avoid compositing from different slope positions
  - mixing a soil sample pH 8 + soil sample pH 4 → ?
- Sample top foot of soil, divide into 0-3, 3-6, 6-9 and 9-12” increments

Soil Al analysis by soil testing labs

- KCl, NH_4Cl or $CaCl_2$ extraction protocols
- 2-5 ppm (mg Al/kg) toxic to some crop species; > 5 ppm toxic to most.
- Highwood Bench where pH close to 4.5: Al = 20 to 169 ppm (Wichman, unpub data)
- % saturation of Al, 10-30% of CEC = plant toxic (McFarland et al, 2015; Kariuki et al, 2007)

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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

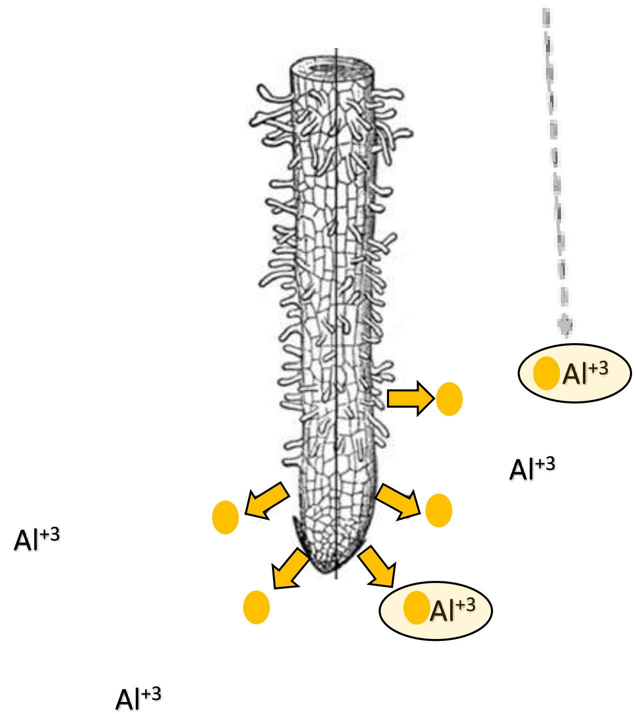
[1] Early season application of fungicides should be considered to limit seedling infection.

WASHINGTON STATE UNIVERSITY

Cultivar selection

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



Montana breeding program

- field trials & screening on the Highwood Bench (in coop. with CARC) and Palouse of eastern Washington
- marker for Alt1 gene

Wheat varieties with have higher acid tolerance (Bruckner & Talbert personnel comm)

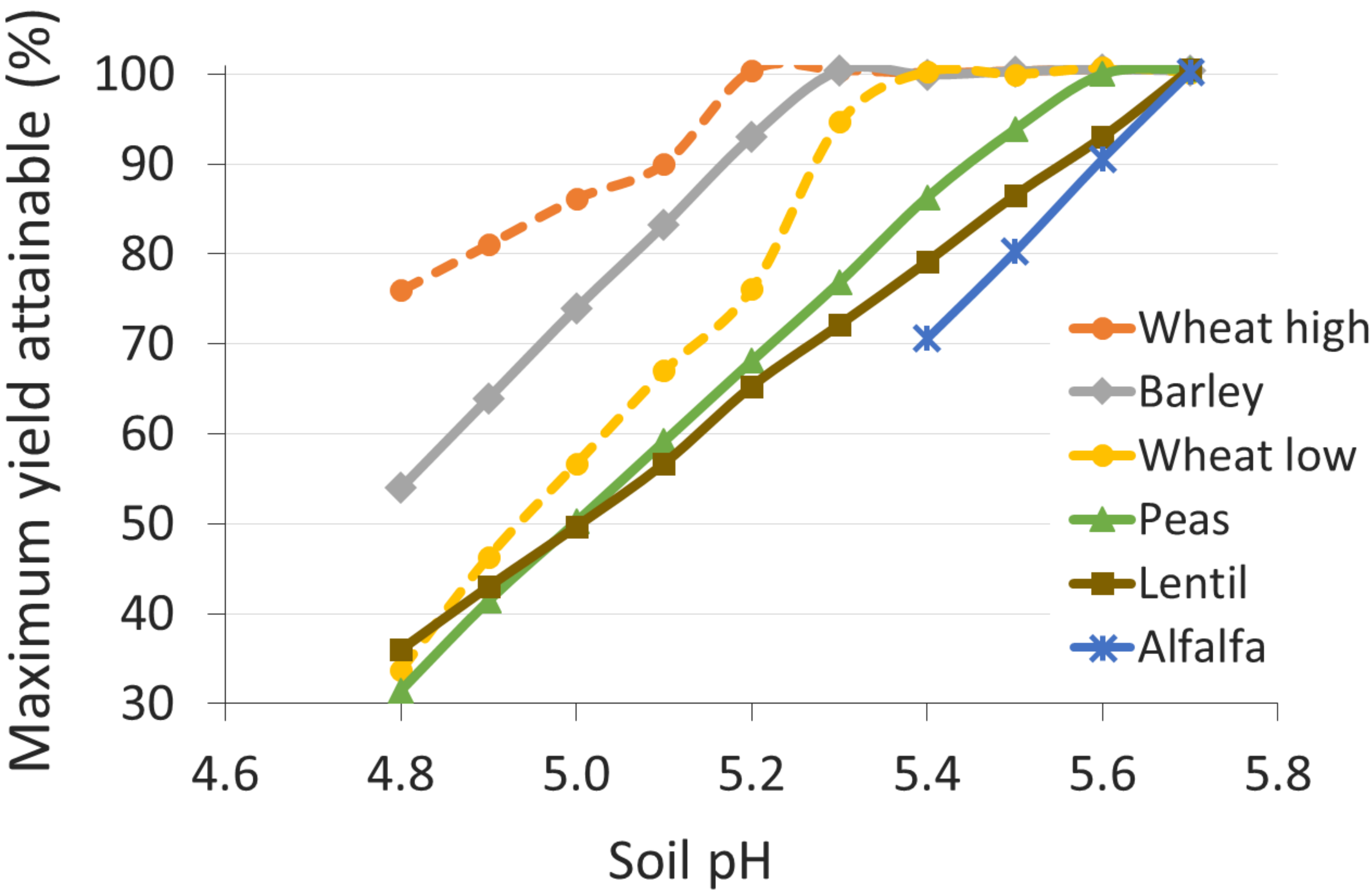
Winter wheat

- Judee based on variety screening in Oklahoma
- Warhorse and Bearpaw have gene for Al tolerance

Spring wheat (50% cultivars with Alt1 gene)

- Egan, Alum, Egan, McNeal, Duclair, Reeder

Crop species vary in tolerance to low soil pH



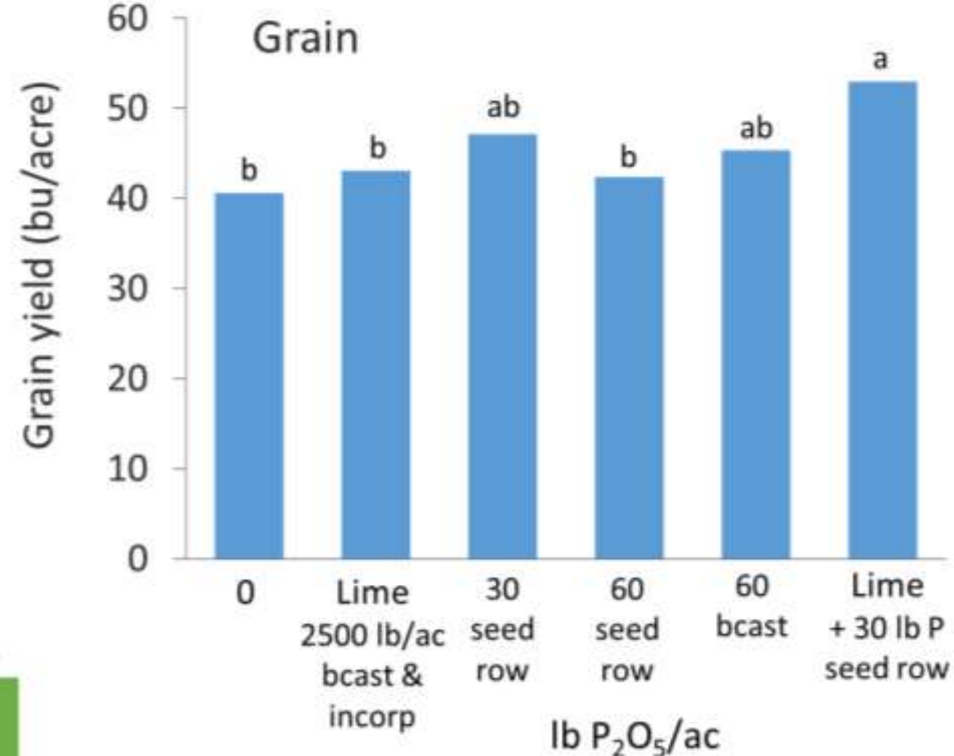
McFarland et al., 2015

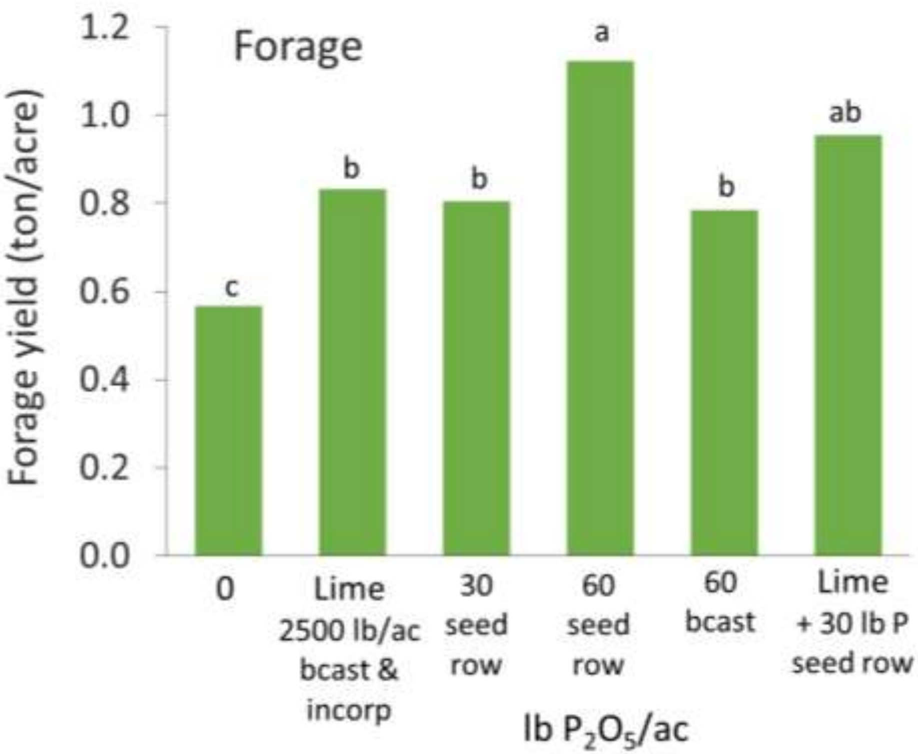
Wheat high and low are Al tolerant varieties

Management strategies - prevention

- leave crop residue in field – retains base cations and SOM buffers pH changes and Al toxicity
- minimize N inputs - legumes in rotation – they don't need N fertilizer
- inversion till to mix acid zone throughout plow layer – one-time summer tillage doesn't negate long term benefits of no-till (Norton et al., 2014)
- band P with seed (binds some Al)

P fertilizer is quick acting 'band-aid' to increase wheat yield even when P soil test is sufficient



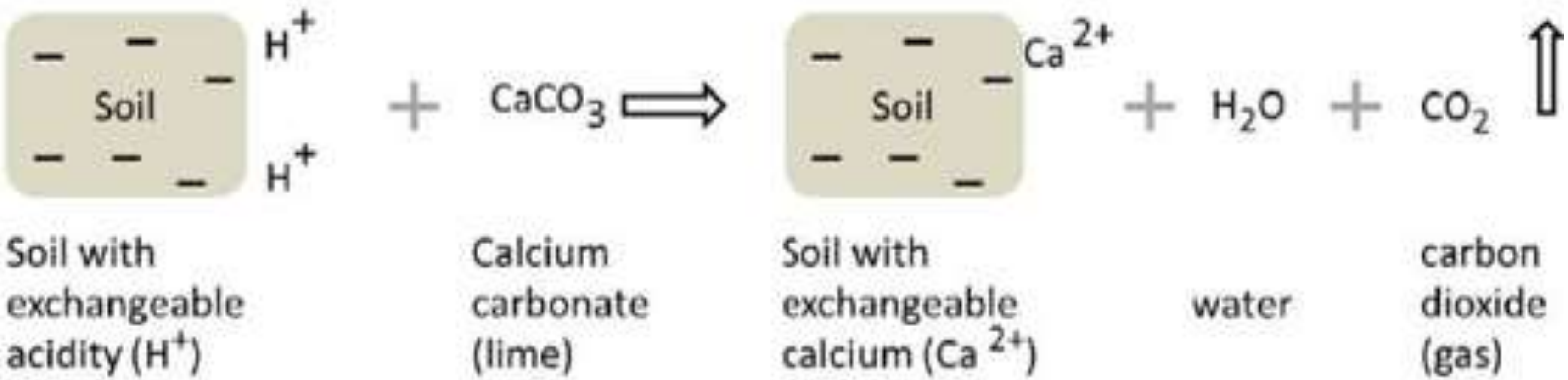


Kaitibie et al., 2002, OK


double-seed row +
double seed-placed P

Remediation – lime applications

- Lime or limestone products – neutralize the soil acidity



lime effectiveness will be defined by particle size also composition of product

Lime characteristics vary among sources

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

Source: Oregon State University

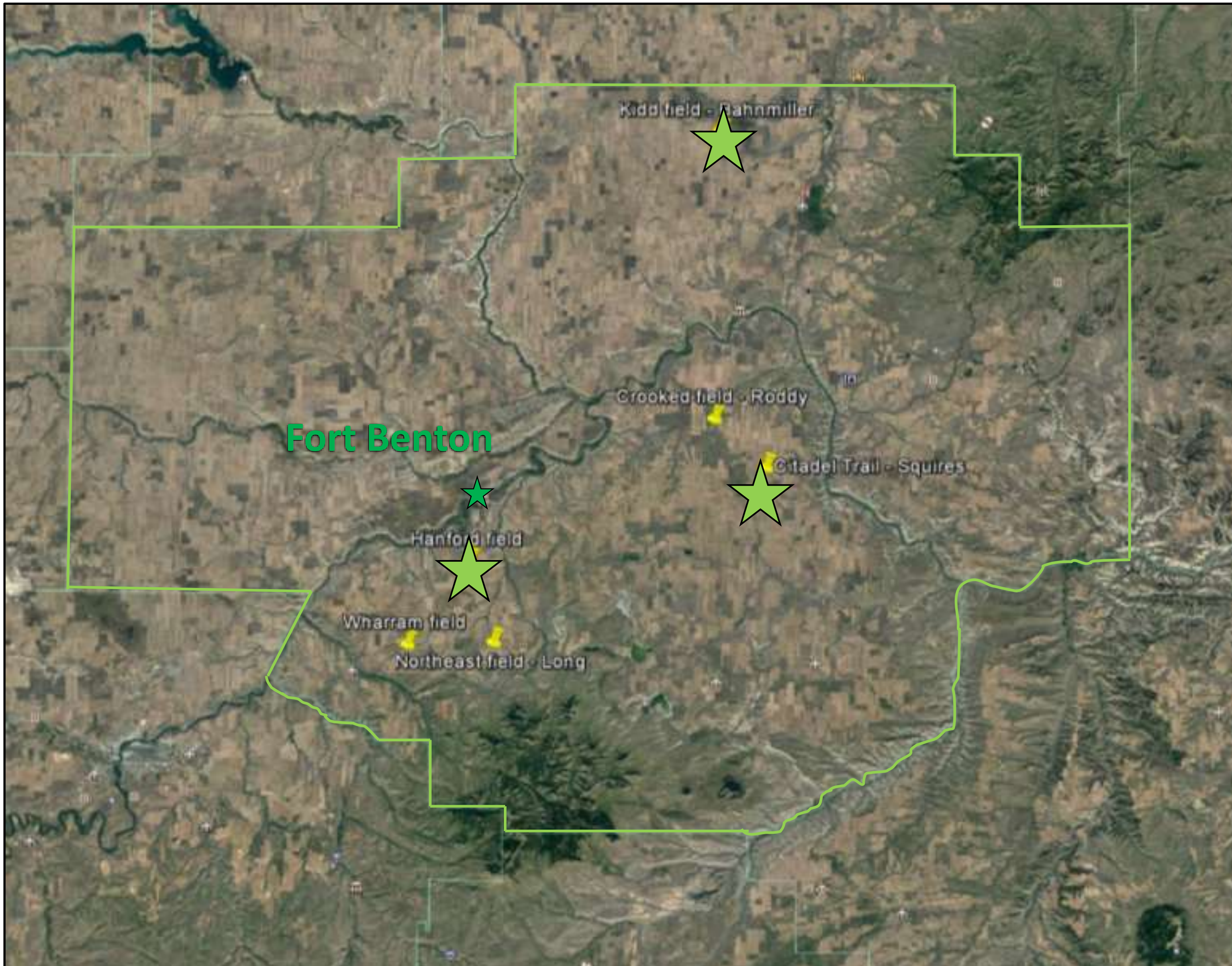
CCE = calcium carbonate equivalent, LS = lime score

Sugar beet lime – Western Sugar Co.

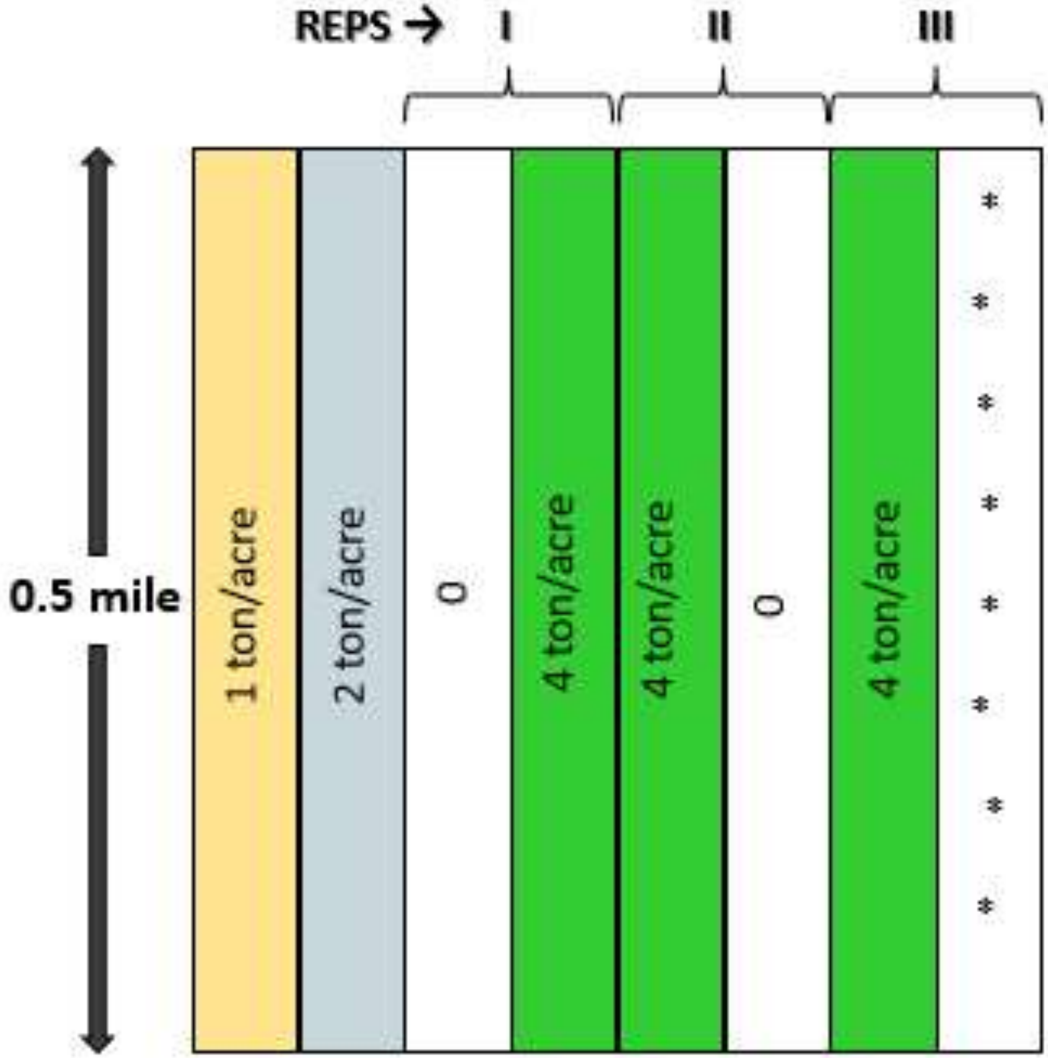
35$/ton to ship to Chouteau County

Stoltzfus wet-lime applicator

Sugar beet lime strip trials – Chouteau Co



Sugar beet lime strip trials (example)



Lime app rates (each strip is 60' wide)

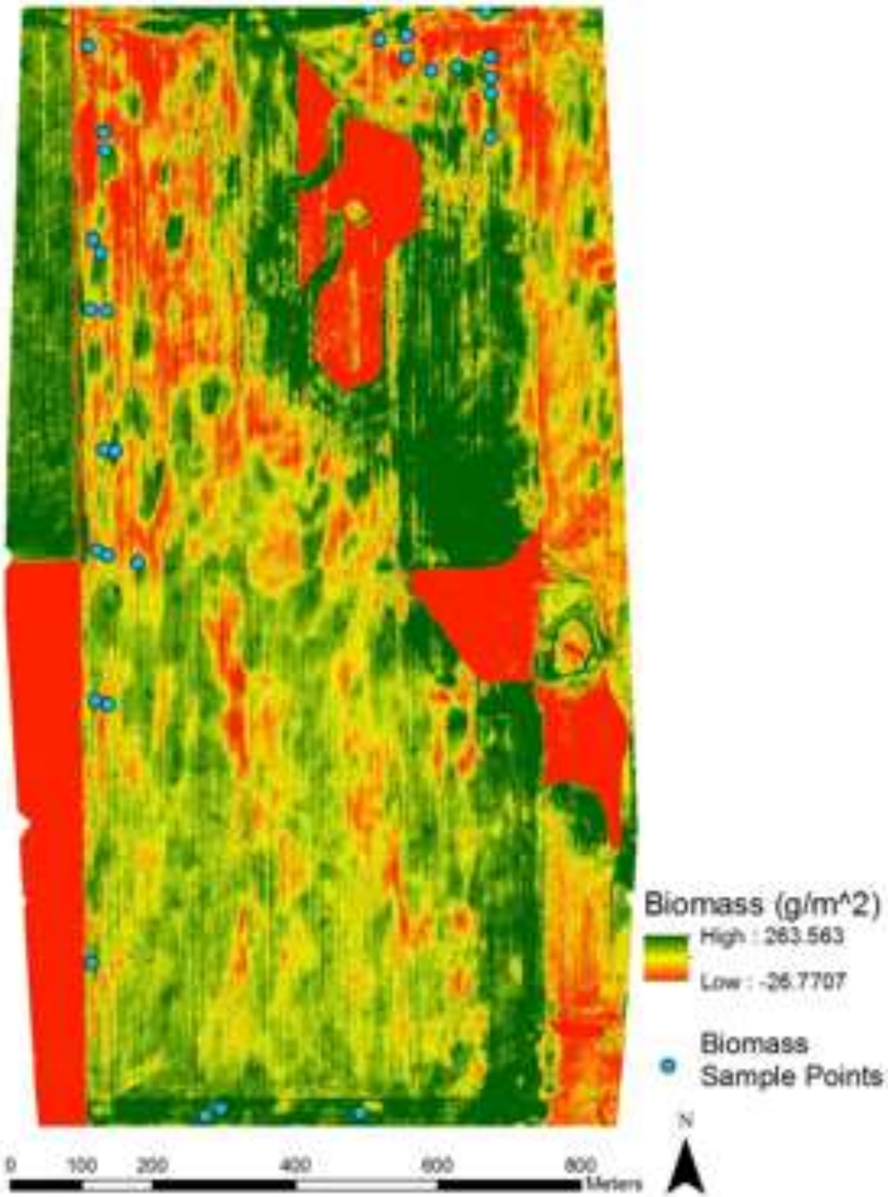
Data to be collected

- biomass & grain yield
- soil cores (0-5, 5-10,10-15, & 15-20 cm) at GPS referenced points
- time – 0, 6, 12, and 24 months
- record pH, extractable Al conc. exchangeable bases

Soil pH/Al toxicity mapping to reduce costs

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

NDVI Aerial Images (June 7)



<u>Soil pH analysis</u>

- **soil cores this spring at random locations in field**

or

- **soil mapping with Veris**

Summary

- Cropland soils in many dryland areas of Montana are becoming more acidic (e.g. Chouteau Co.)
- We are still trying to understand the extent of this problem (soil samples anyone?).
- N fertilizer inputs are a big reason
  - no-till has accelerated acidification process near the soil surface
  - problem is not unique to Montana
- Yield impacted – Al toxicity pH < 5
- Management options exist to cope with, slow down or reverse the trend of soil acidification


Thank you