Soil Fertility, Testing, Amending

Master Farmer Course - Pondera County Extension

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Today's topics

- Soil properties and how they interact with plant nutrients
- What can be learned from a soil test
- The limitations of soil properties you can influence
- 4Rs of Fertilization
- Management for healthy soil

The Montana Fertilizer Advisory Committee and the Western Sustainable Agriculture Research and Education Program are major funding sources for MSU studies included in this talk.

Soil Quality vs Soil Health

Soil Quality = properties that change little, if at all, with land use management practices, often found on a traditional soil test

- Texture
- Cation Exchange Capacity

Where do SOM and soil pH belong?

On both lists

Soil Health = dynamic properties which may be subjective to measure

- Aggregation
- Microbial activity
- Tilth
- Nutrient availability
- Water holding capacity
- Compaction

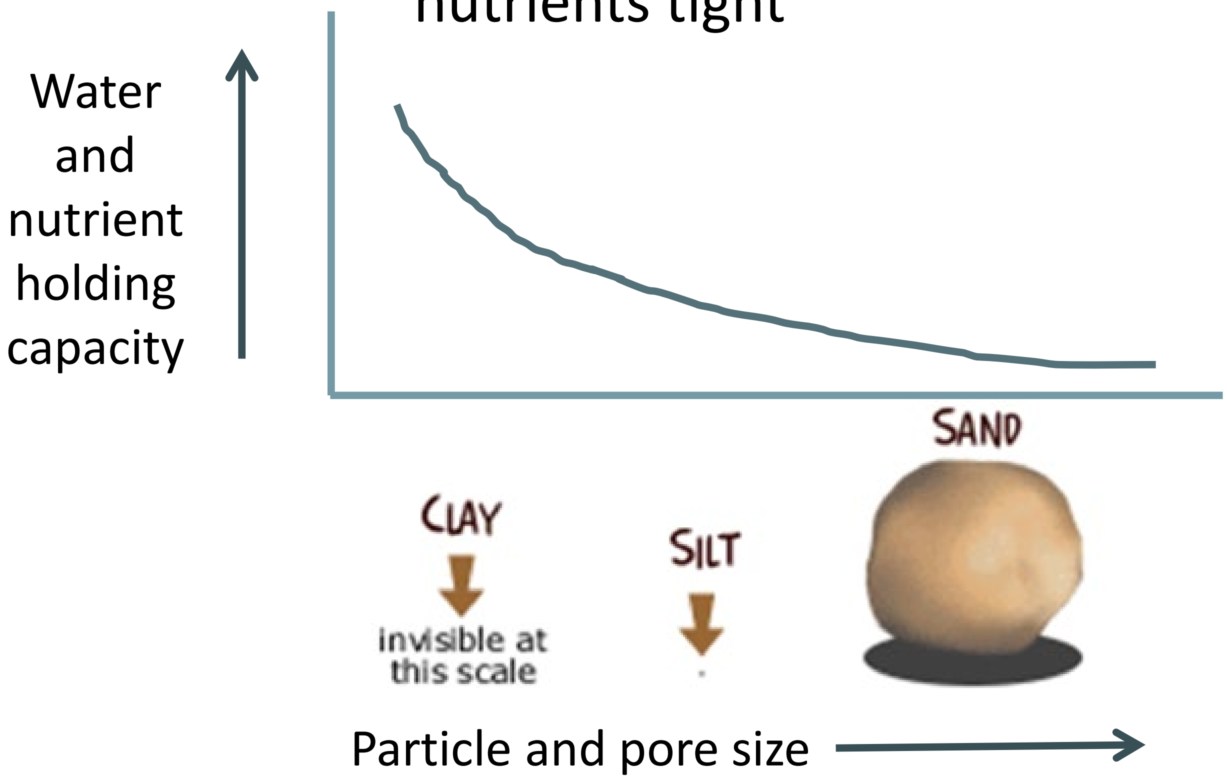
What to look for on a soil test report? Factors affecting plant health and production

Factor	Values of concern	Impact/consider
Nutrient content	Nutrient dependent	Too little = hungry plants, too much = contaminate water, burn plants
Soil organic matter	≤ 1 (%)	Minimize bare soil, increase N, add legumes
	> 3 (%)	N credit
Soil pH	< 5	Al toxicity
	< 6	Poor seedling establishment and legume nodulation
	> 8.3	Nutrients tied up, likely high Na
Soluble salts (EC)	> 4 (mmhos/cm)	Too saline, water stress, nutrient imbalance
Soil texture and CEC		Water and nutrient holding capacity

Soil texture

Sand: large pore space, low surface area = low water or nutrient holding capacity

Clay: small pore space, large surface area, often negative charge on surface = holds water and nutrients tight



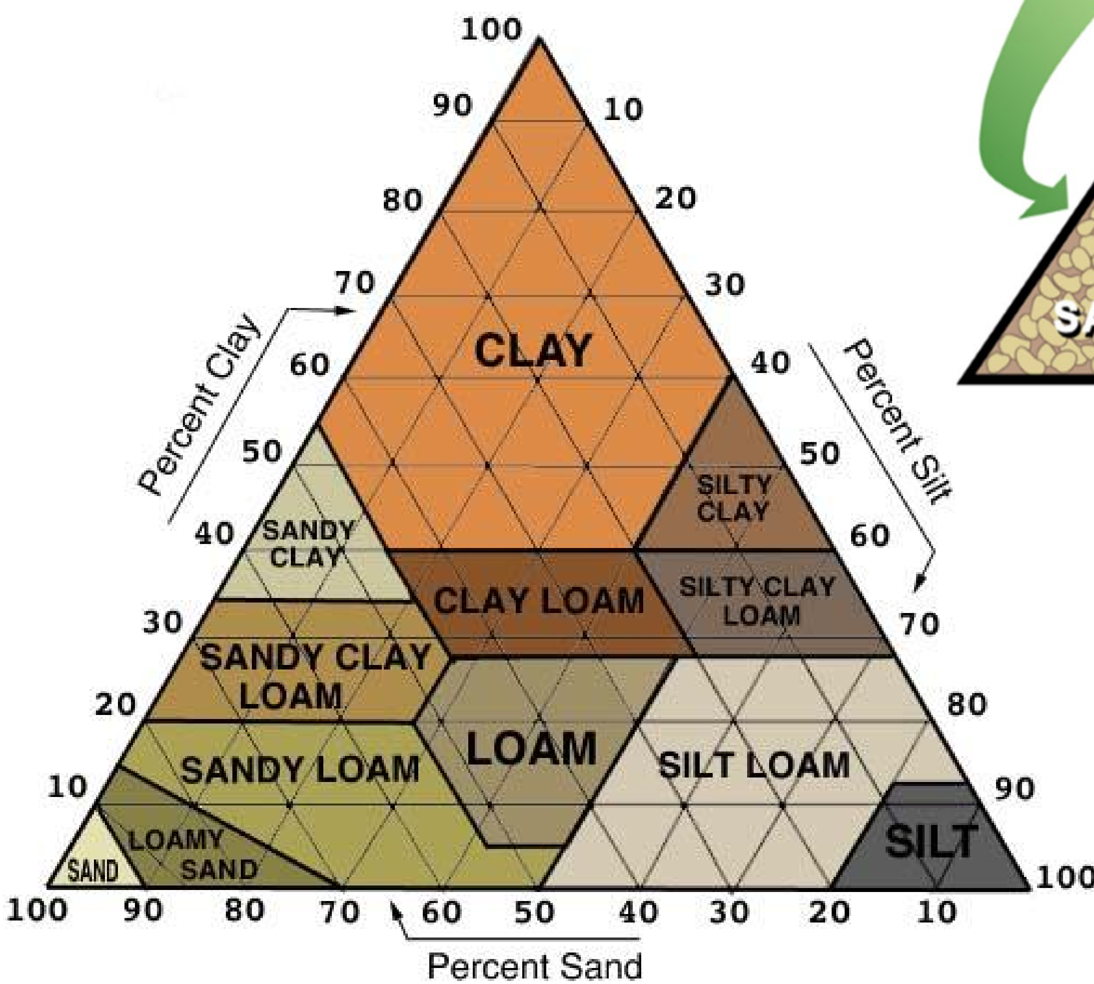
Ideal is **loam** to **clay loam** approx. equal parts of sand, silt, clay

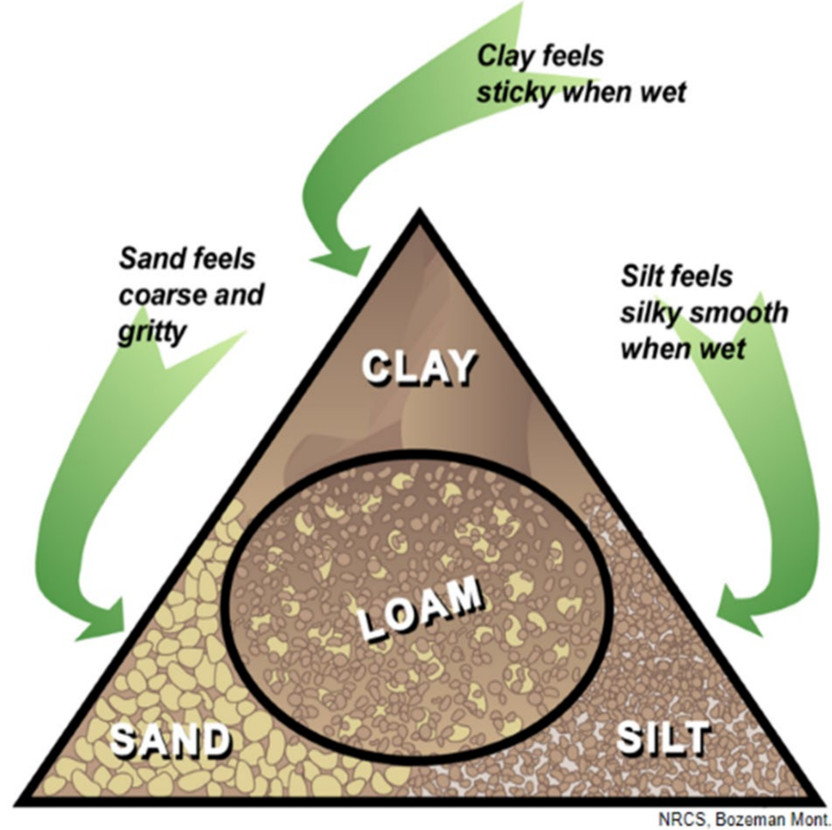
Mason jar texture test

- Fill a straight sided jar 1/3 with soil
- Add water until almost full
- Add 1 tsp dishwasher soap or water softener (why?)
- Shake and let settle
- Mark sand depth at 1 min.
- Mark silt depth after 6 hours (or by color/texture change with clay at 24 hr)
- Calculate clay by difference (or measure at 24 hours)

http://landresources.montana.edu/soilfertility/documents/PDF/SoilTextureJarTest.pdf

Using the soil texture triangle





Loam is a combination of all these

Texture Effects on Soil Properties

	Drainage Infiltration	Water holding capacity	Aeration	CEC
Sand	excellent	poor	excellent	low
Silt	good	good	good	medium
Clay	poor	excellent	poor	high

Soils with large surface areas, such as clay and organic matter, have more cation exchange capacity and surface area and therefore are generally more fertile.

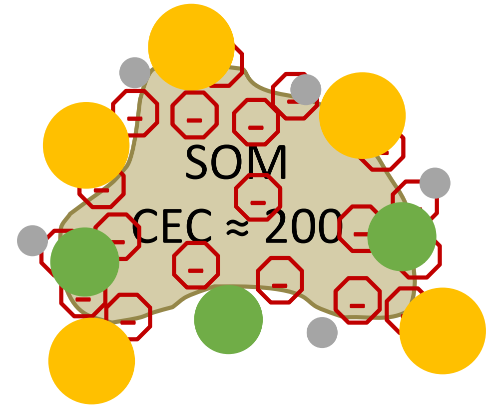
Cation Exchange Capacity CEC

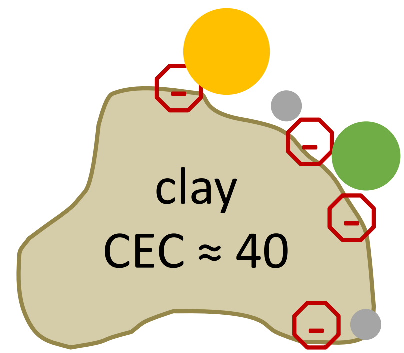
the parking spaces for nutrients in the soil

- CEC is the total neg. charge on a soil (meq/100g)
- A high CEC soil (> 15) has the capacity to attract and hold nutrients with positive charges, e.g. K^{+}, Zn^{+2}, NH_4^{+}
- Large surface area (clay, SOM) ≈ larger CEC ≈ generally more fertile.
- What else might high CEC soils hold onto?

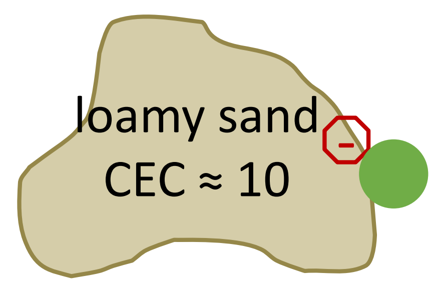
Herbicides

- CEC of mineral soil is hard to change but can slowly change SOM





1 Tbsp has surface area of a football field

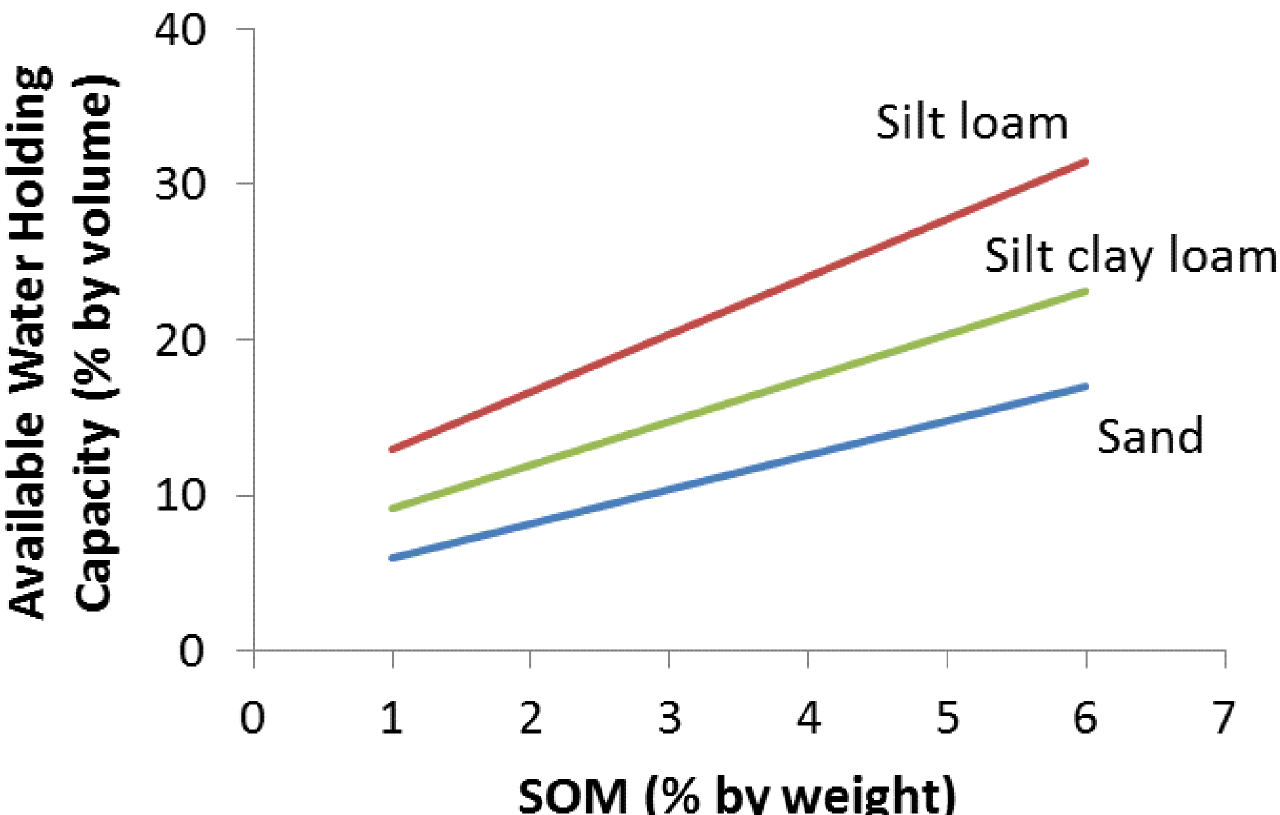


1 Tbsp sand has surface area of a kitchen table

SOM = Soil organic matter

What does SOM do for soil?

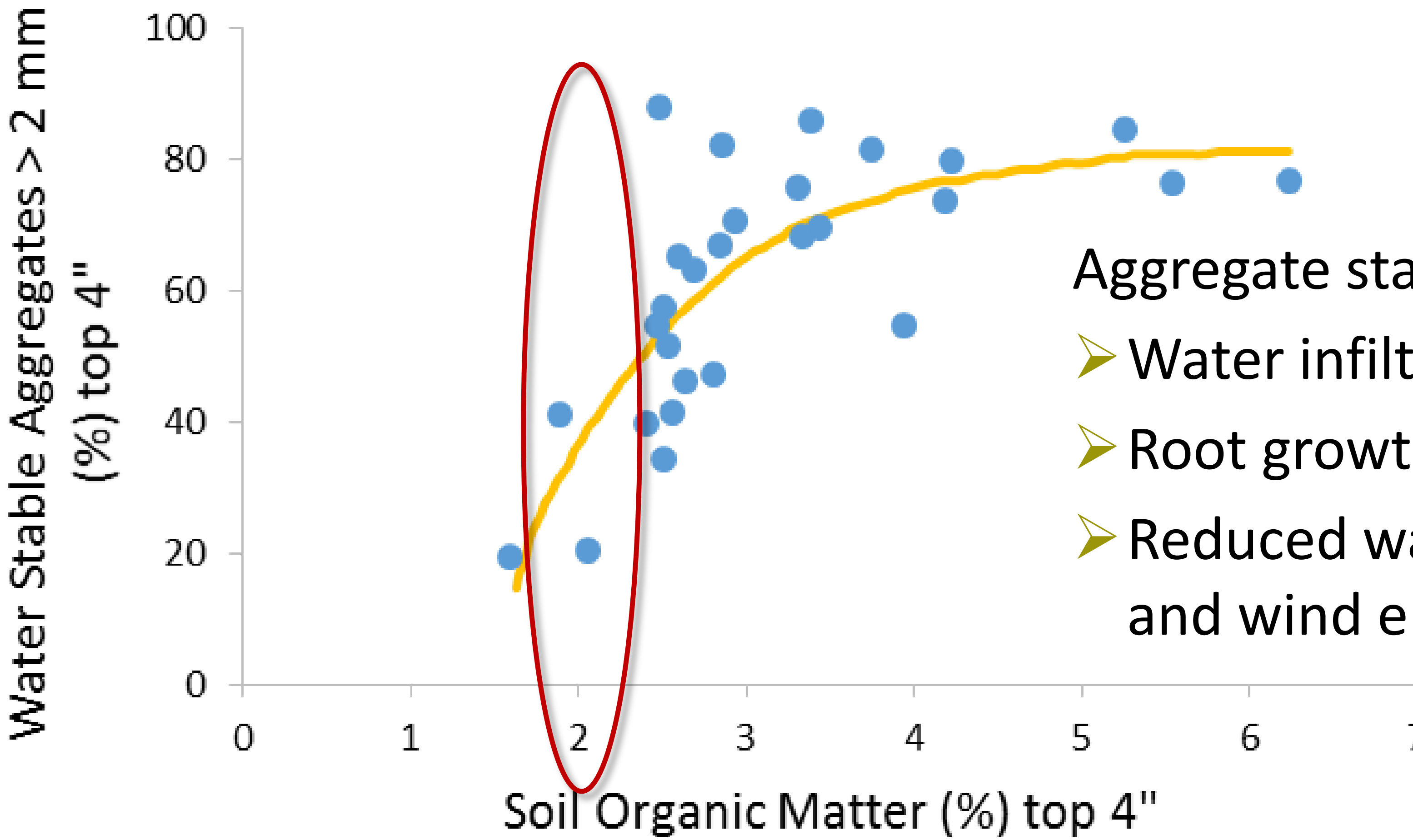
- As decomposes it releases nutrients bound in OM structure



Hudson 1994

- Increases water holding capacity which helps nutrients move from soil to plant roots and should increase yield

Small increases in SOM lead to potentially large improvement in soil structure



Aggregate stability

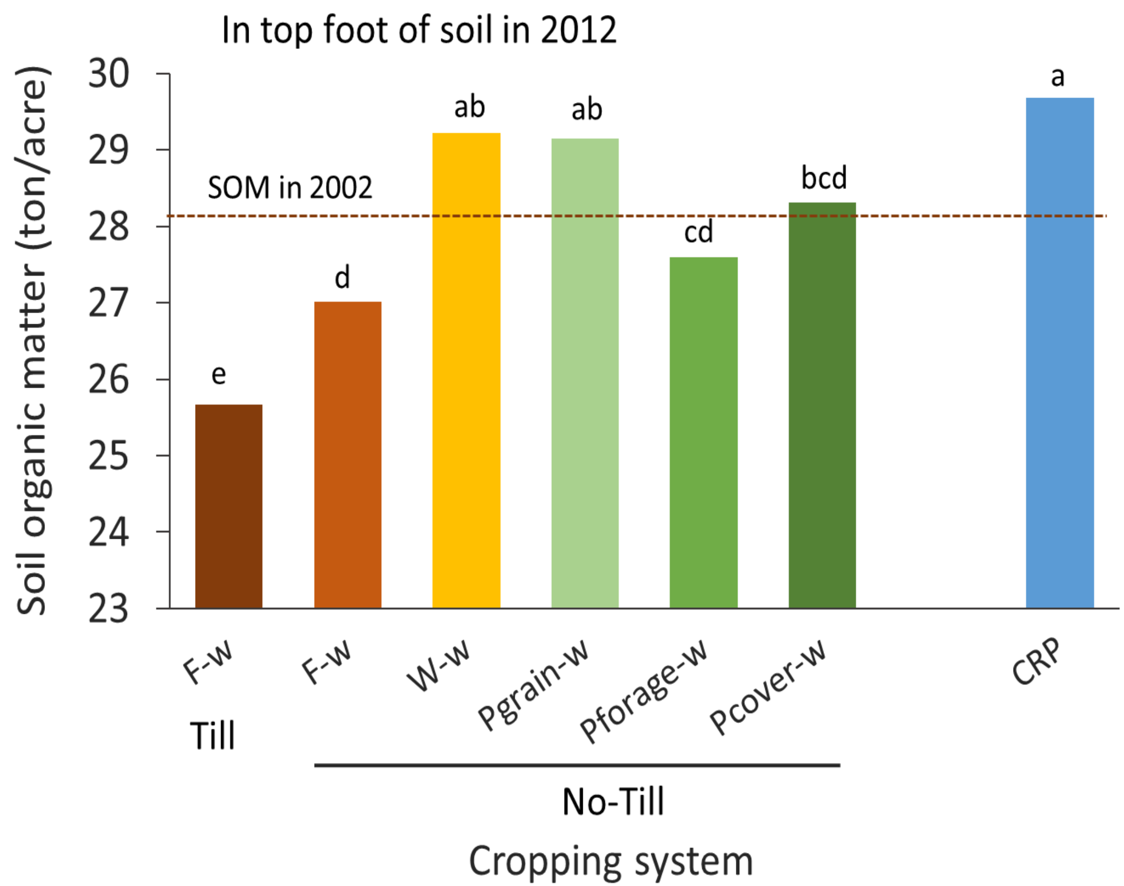
- Water infiltration
- Root growth
- Reduced water and wind erosion

Fisher et al., 2007
Australia, irrigated, variety of soil types

Changing SOM?

- Guesses on how long to increase soil organic matter (SOM) from 1.4 to 1.5%?

- A long time. MSU study, CRP increased SOM from 1.4% to 1.5% in 10 years in top foot.
- Fallow, especially tilled – loses SOM!
- Hay, or heavily grazed pasture maybe maintaining, likely losing SOM



Engel et al. 2017

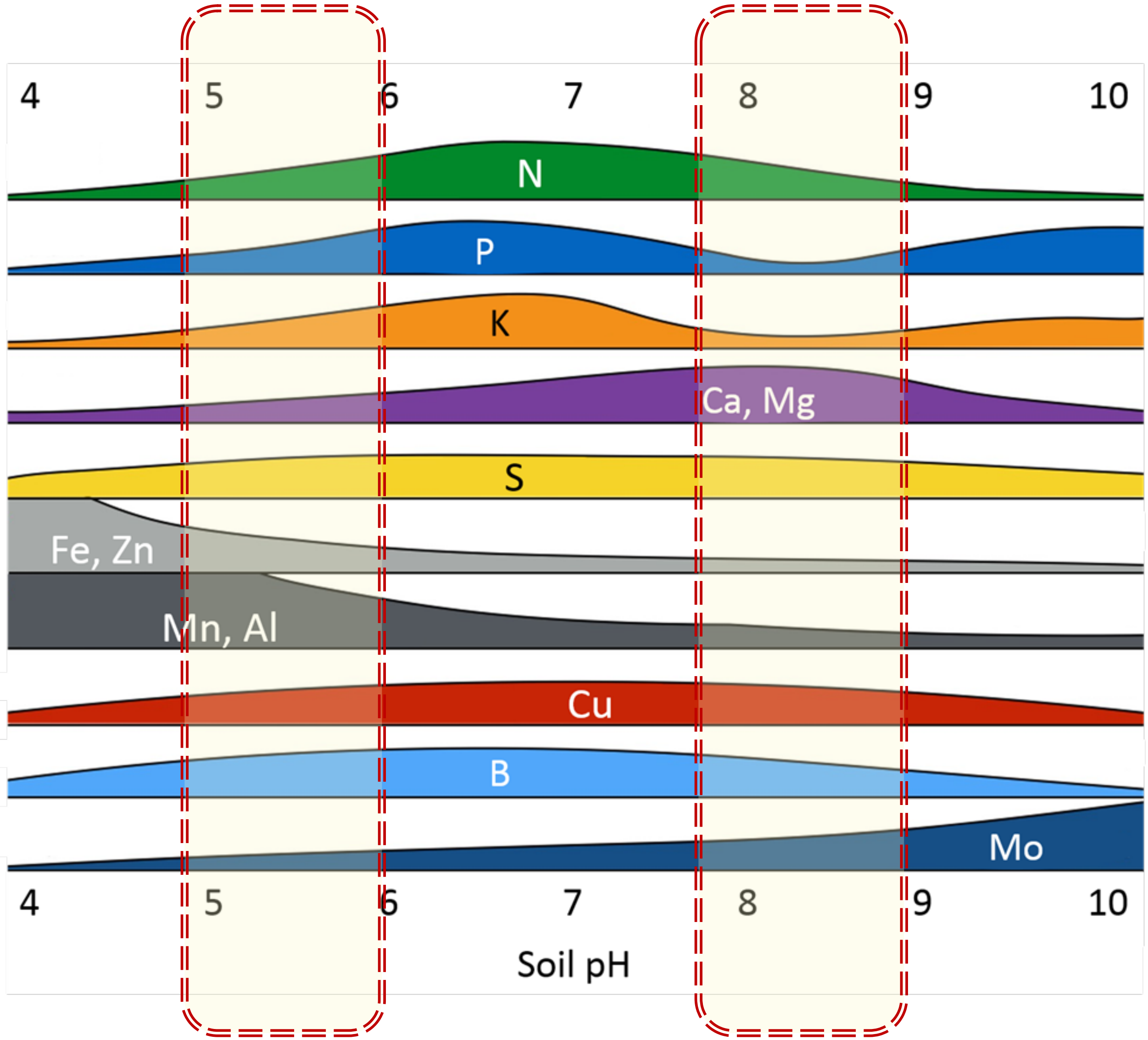
Questions?

On to pH

pH affects soil nutrient availability

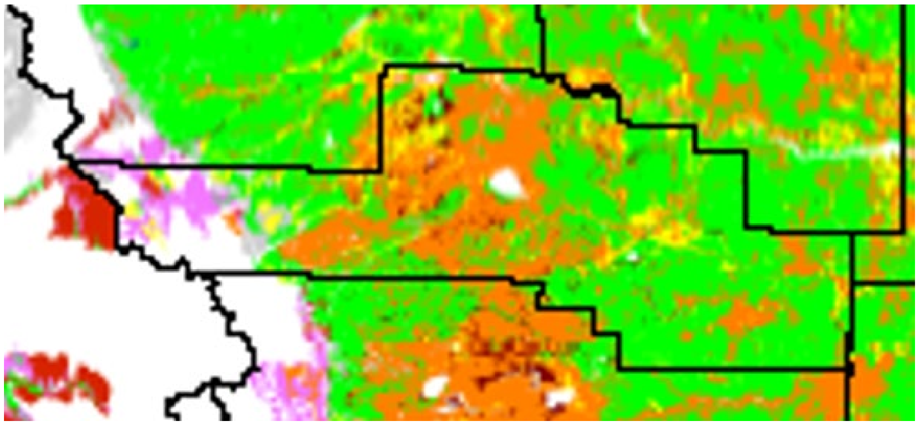
Low pH, acidic soils – may limit N, and eventually Ca, Mg, K, Mo because they don't stick tight and can leach away (Fe) or form minerals (P), Al toxicity

High pH, alkaline calcareous soils – may limit P, Fe, Mn, B, Cu, Zn, plant can't get them

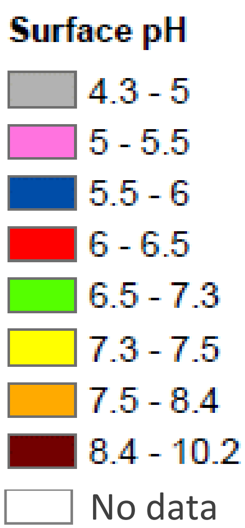


Troeh and Wegner, 2013

What were historical surface horizon pH values in this region?



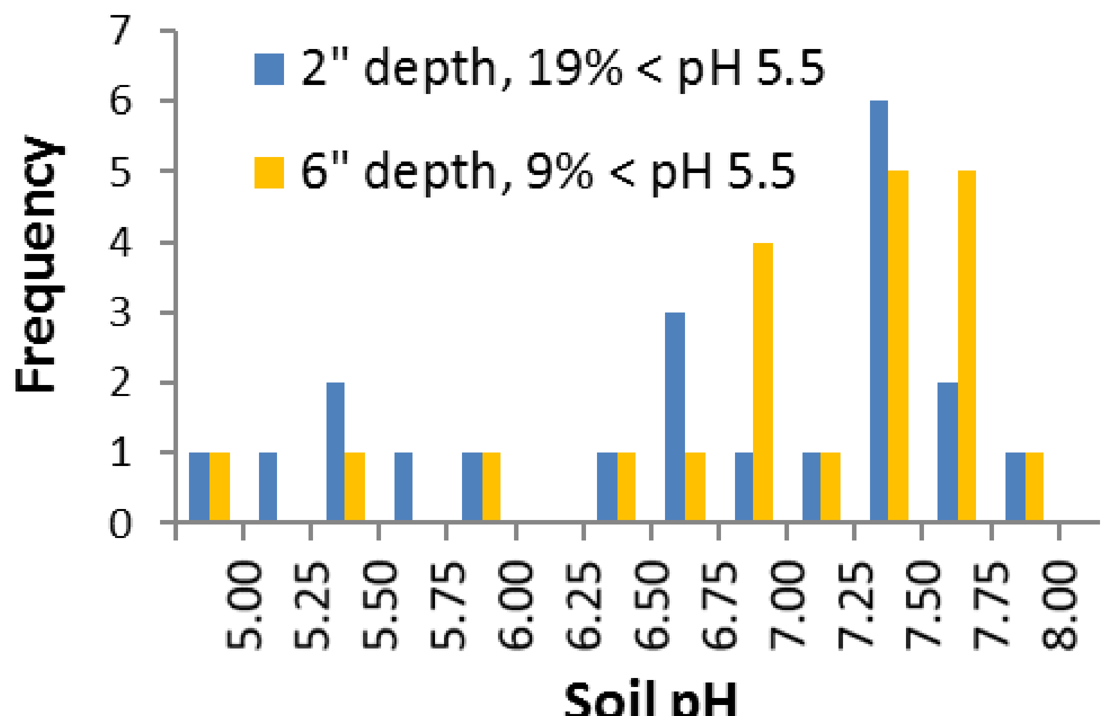
Map courtesy of NRCS



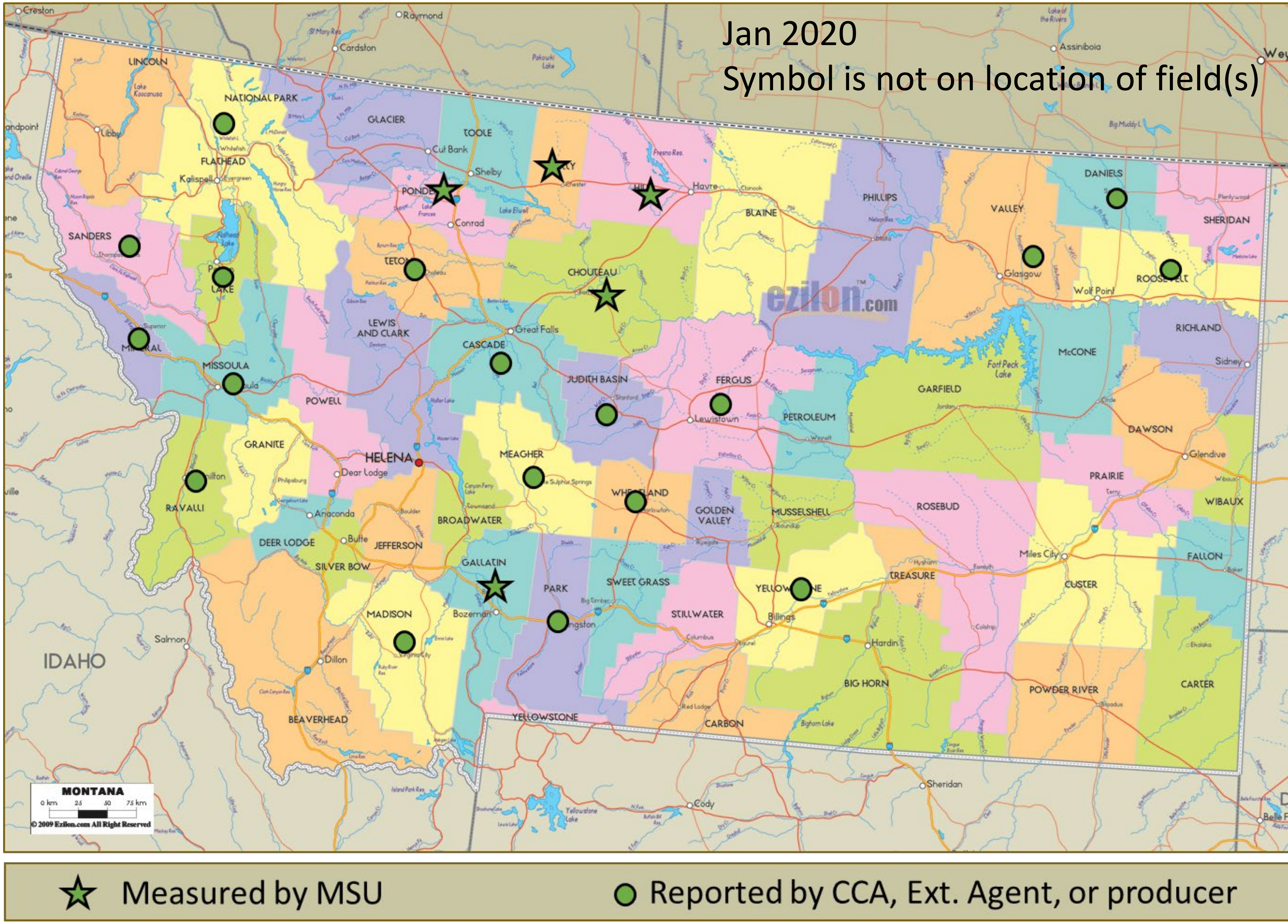
Many arable soils in our region are high pH because of a calcium layer

Is that changing?

21 samples in Pondera Co. by Adriane Good, May 2018



Soil acidification: MT counties with at least one field with pH < 5.5



40% of 20 random locations in Chouteau County have pH < 5.5 in top 2”

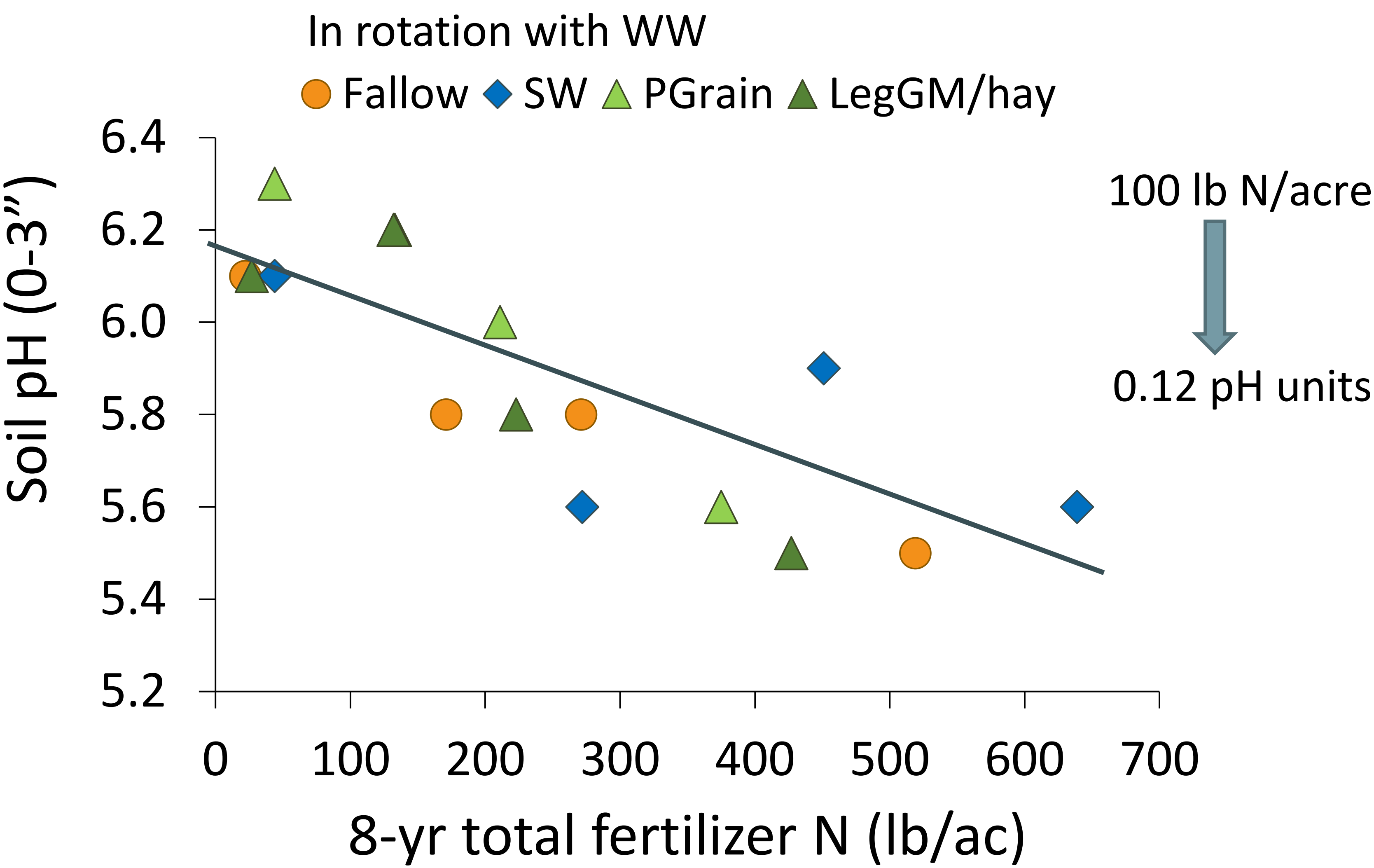
Agronomic reasons for soil acidification

- 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 – less nitrate uptake and less root release of basic anions (OH^- and HCO_3^-) to maintain charge balance.
- Crop residue removal – removes Ca, Mg, K ('base' cations).
  6x the lime to replace base cations removed by oat straw harvest than just oat grain harvest (NE Ext G1503)
- Lack of deep tillage 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).
  Yet apparently much less than fertilization of wheat.

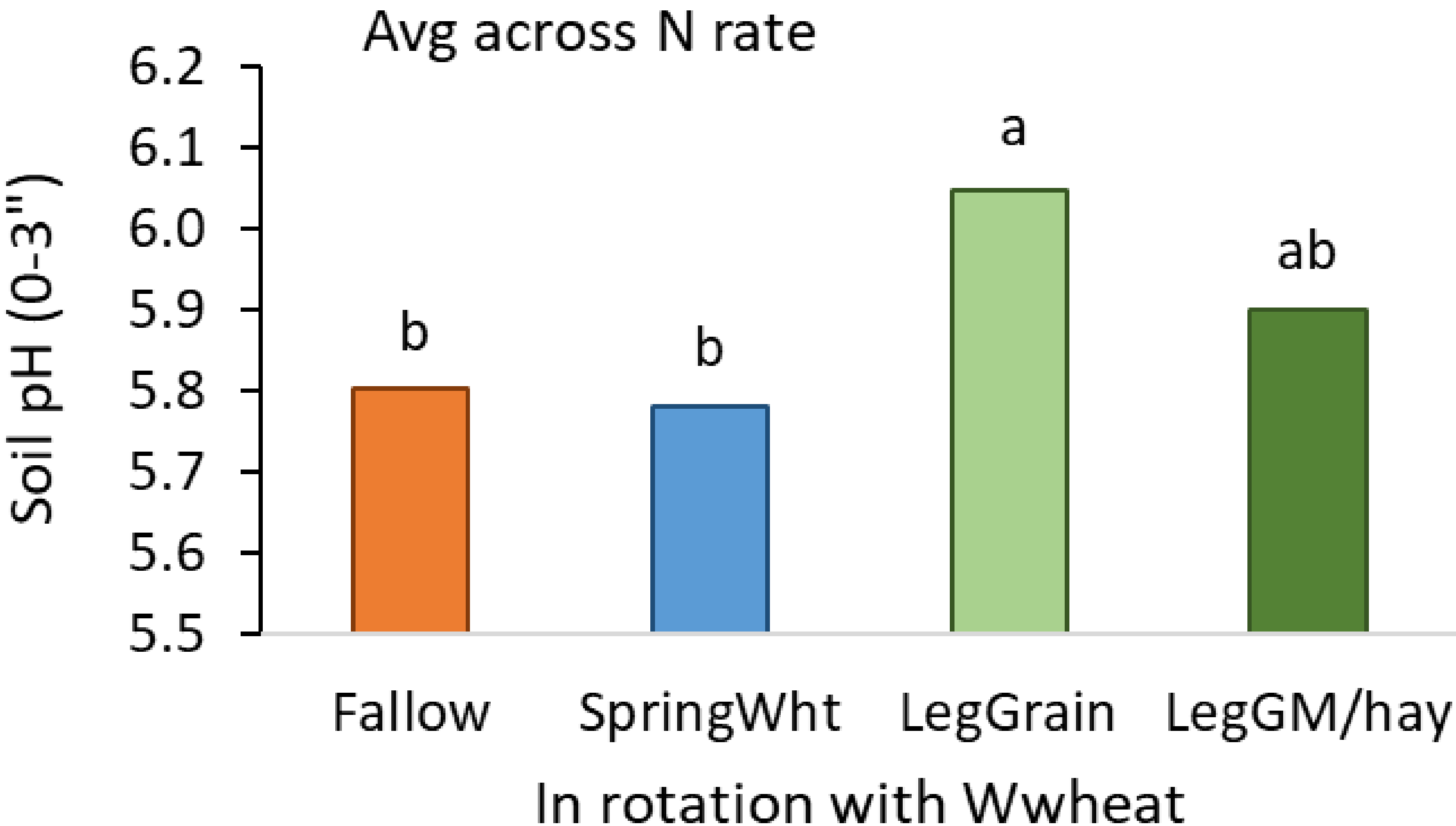
8-yrs of N (0, ½, full, 1 ½ recommended rate) reduced top 4-inch soil pH in dryland near Big Sandy



sandy clay loam, 1.1% OM

Jones and Miller unpub data

8-yrs of pea in rotation slowed pH reduction



sandy clay loam, 1.1% OM

Jones and Miller, unpub data

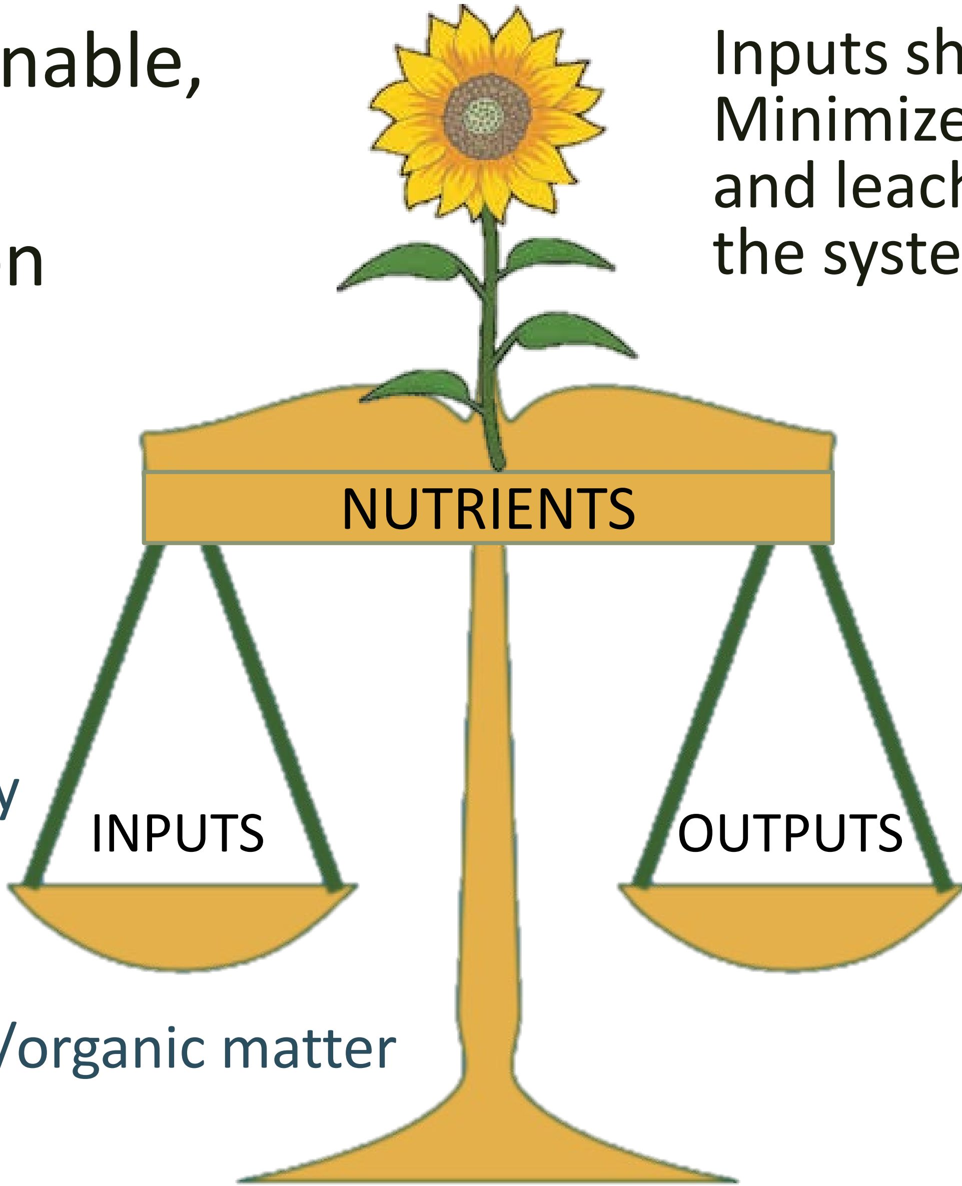
Is this a real issue or Rick and me looking for more work?

Questions?

On to soil nutrients

For sustainable, healthy production

Inputs should = Outputs
Minimize erosion, runoff and leaching losses from the system

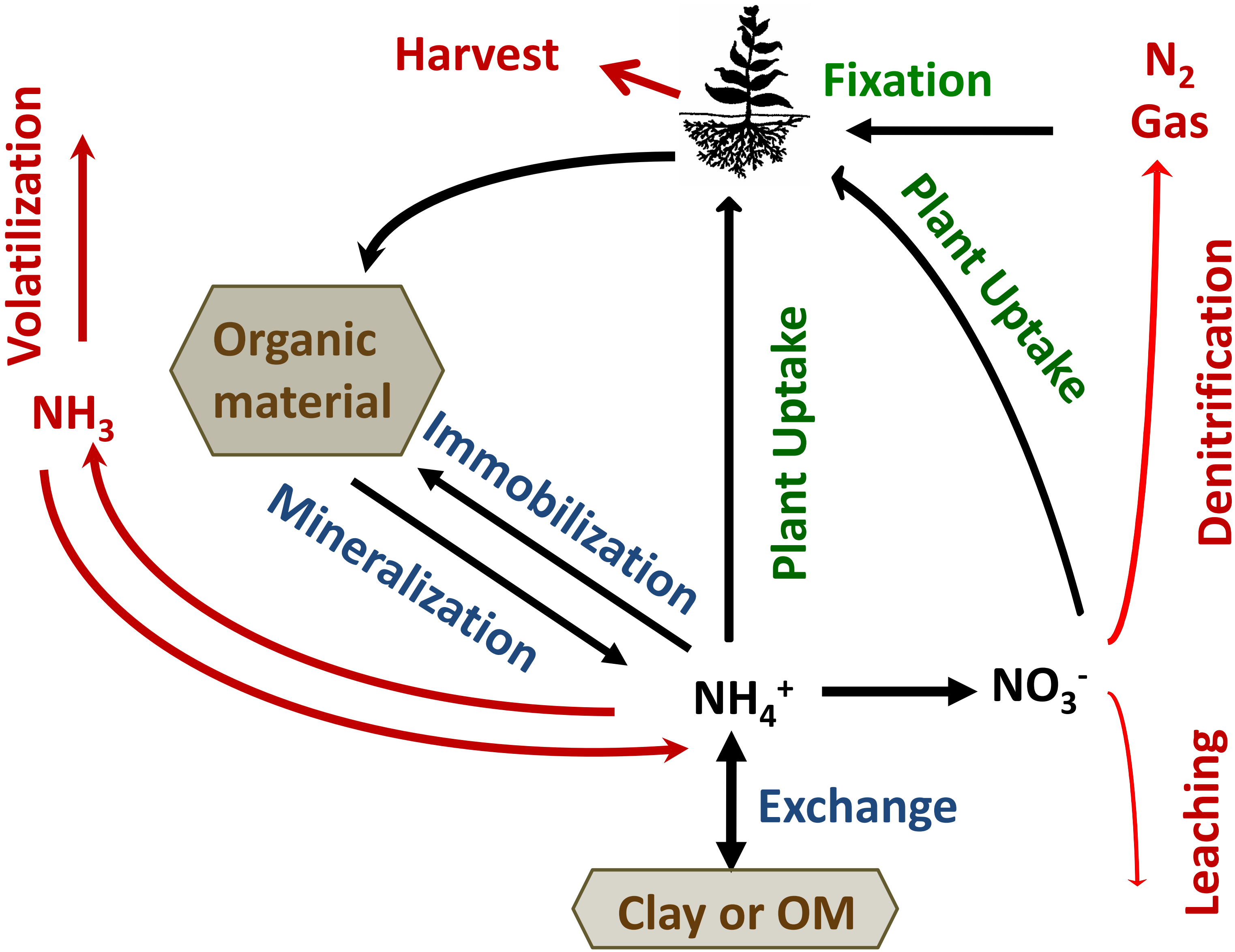


Fertilizer
Manure
N-fixation by legumes
Mineral soil/organic matter

Harvest
Erosion
Runoff
Leaching

In many ag systems, outputs > inputs = mining the soil for nutrients
Loss of soil productivity leads to financial loss

Most common lacking nutrient is nitrogen (N)

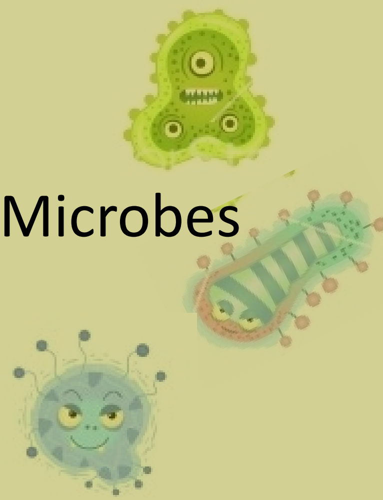


Nutrient **cycles**: microbes and N

Mineralization = decomposition of SOM by microbes, releasing available N

Plant-Available N

Microbes



+

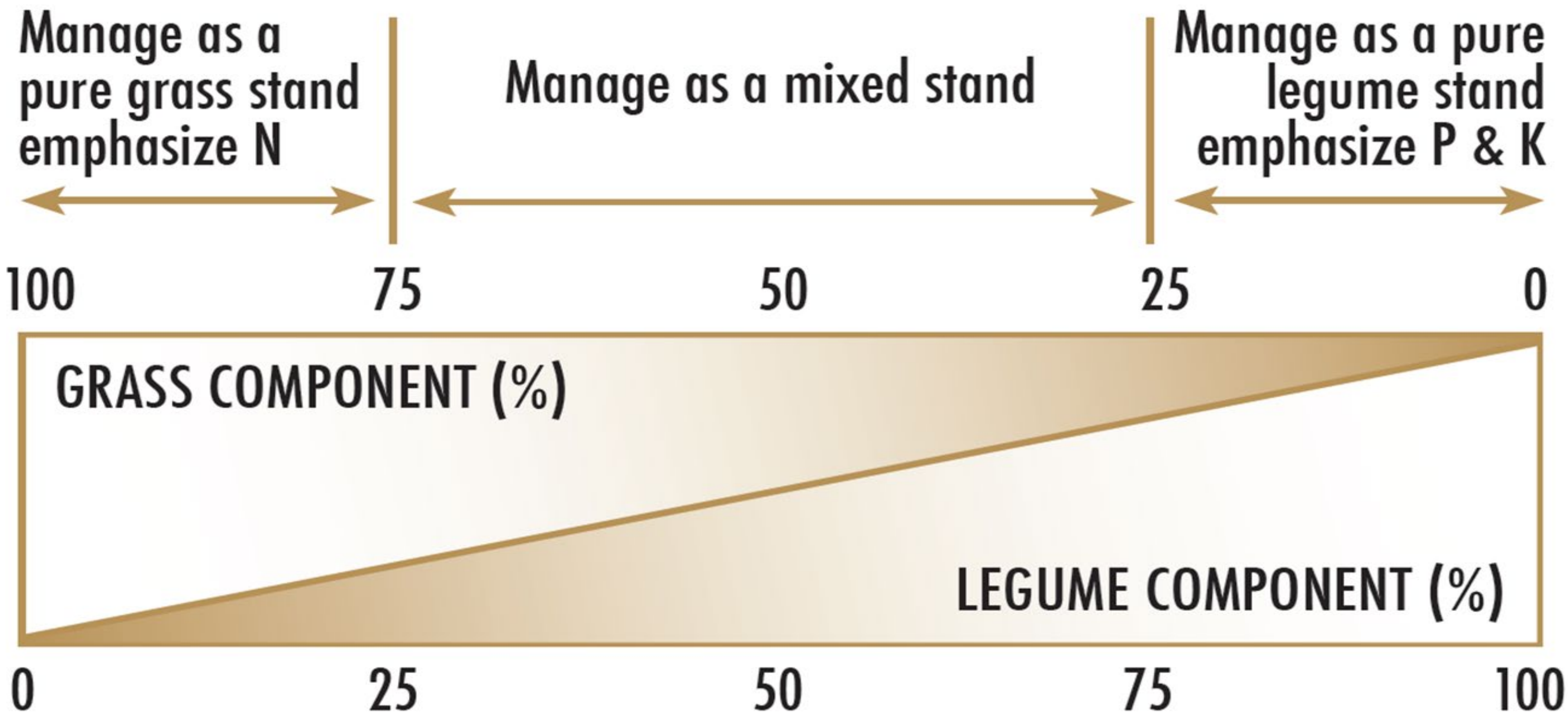
Organic-C in plant residue

Immobilization = uptake of available N and C by microbes to live and reproduce

Is immobilized N lost from the system?

N is the most common lacking nutrient except with legumes, e.g. mixed alfalfa/grass forage

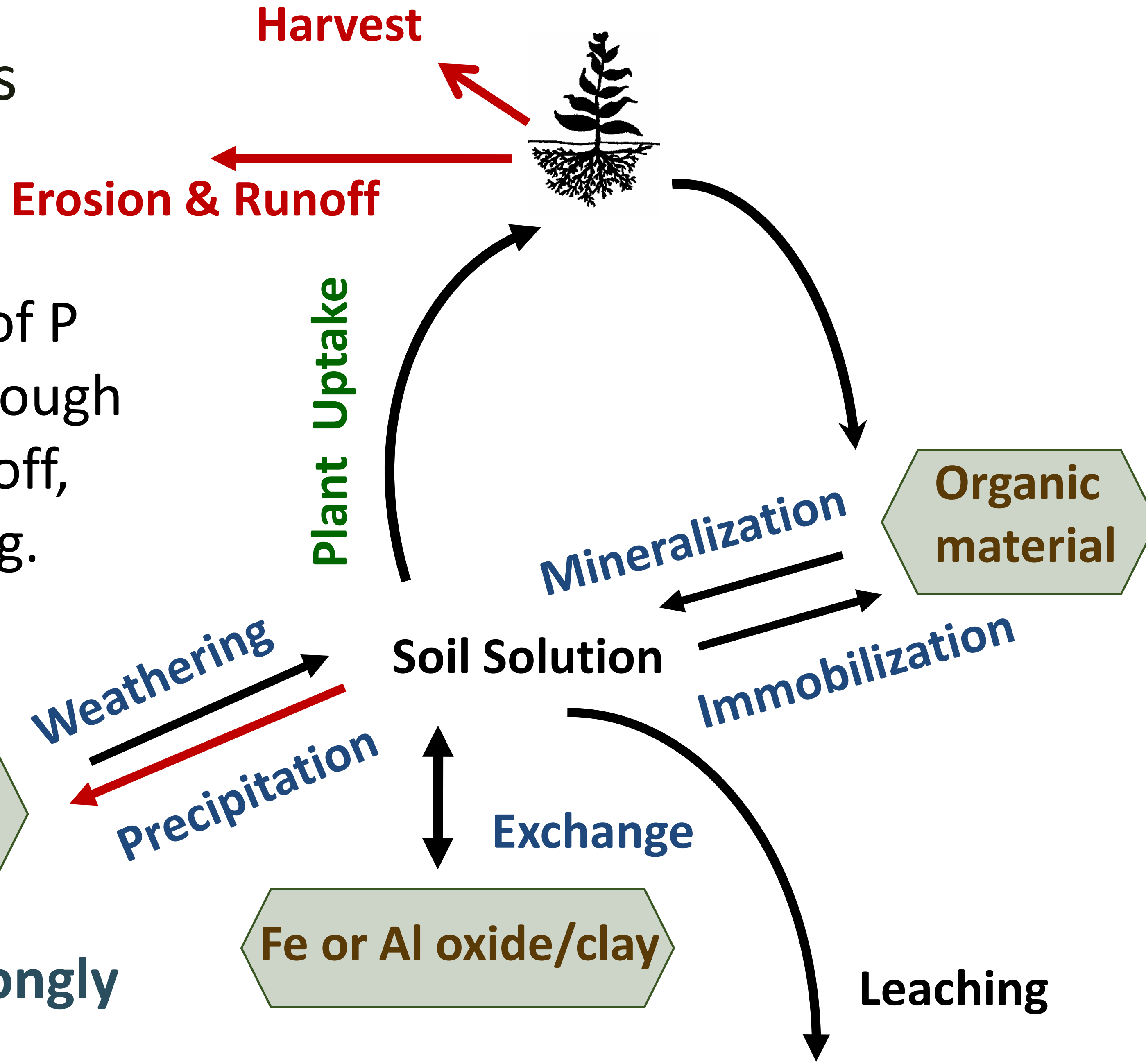
Focus of N vs P & K fertilization in forages depends on % legume in stand.



Fertilizing with nutrients other than N favors legumes over grass

Phosphorus cycle

Movement of P is largely through erosion/runoff, NOT leaching. Why?

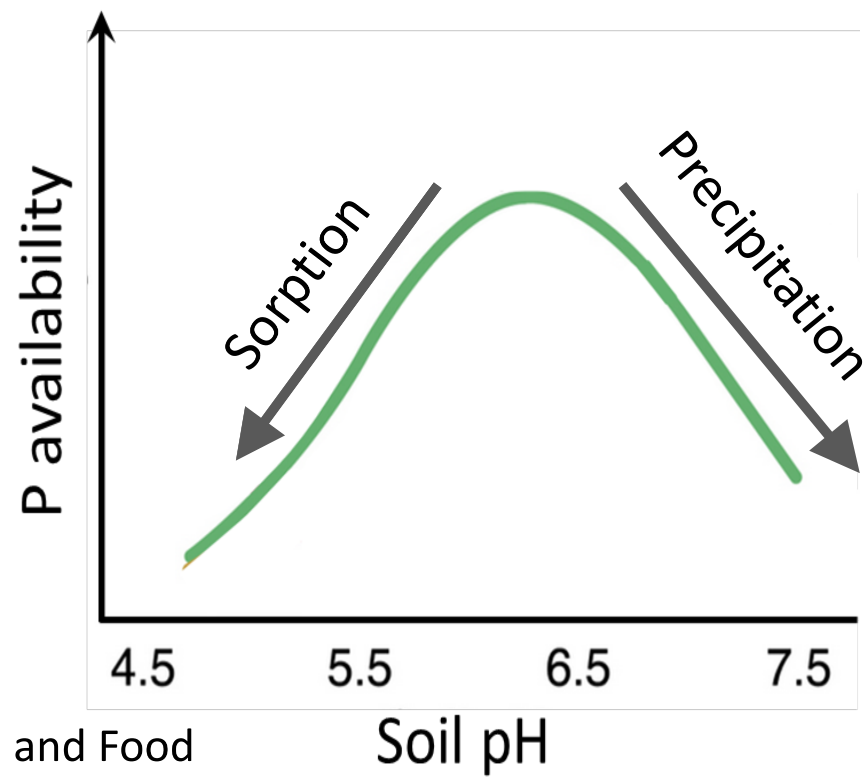


P binds strongly to soil

Low soluble P concentrations due to:

- Precipitation and low solubility of calcium phosphate minerals. This is very relevant in Pondera's lime-rich soils.
- Sorption (binding to minerals) and precipitation with iron and aluminum increases at low pH and may becoming a concern in parts of MT

At what pH levels would you likely need to fertilize with more P?

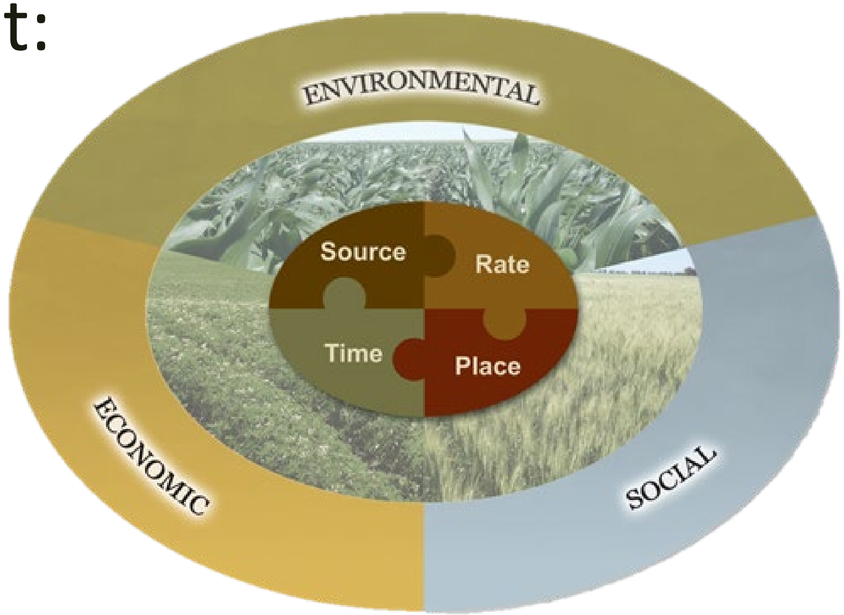


Gov. W. Australia, Dept of Ag. and Food

How do I know what to add to my soil???

Questions to ask before you add fertilizer

1. Which elements do I need? (e.g. N, P, K, S, Zn)
2. 4R Stewardship, the right:
    - Rate
    - Source
    - Time
    - Placement



3. Will I get a return ($ or environmental) on my investment?

Soil test

- To identify nutrient deficiency or imbalance
- To help calculate fertilizer rates
- Can increase yield and/or save on fertilizer costs, and decrease environmental risks
- Best done in early spring, but not when soil is wet, therefore in our climate perhaps best done in late fall
- See publications listed at end for details on 'how-to'

Example soil test report

Location: Sample date:

Desired crop	Prior crop	Nitrate-N			P ppm		K ppm	OM %	pH	CEC	Salts
		ppm	lb/ac	Depth (in)	Bray	Olsen					
Forage		2	4	0-6	13	5	161	2.0	7.5	10.2	0.3
Wheat	Fallow Cereal Legume ?		12	0-6	14	9	353	1.7	6.5	12	6
			15	6-24							
			9	24-36							
Ideal		Crop dependent				16 - 30	250 - 500	3 - 10	6-7.5	15-30	< 4

- Ideally an actual number, rather than a rating (low, medium, high, very high or deficient, sufficient) is provided.
- Drawback of soil test kits is usually rating only, no numbers
- Sometimes a recommendation is provided. Make sure it is based on DESIRED CROP and MT GUIDELINES

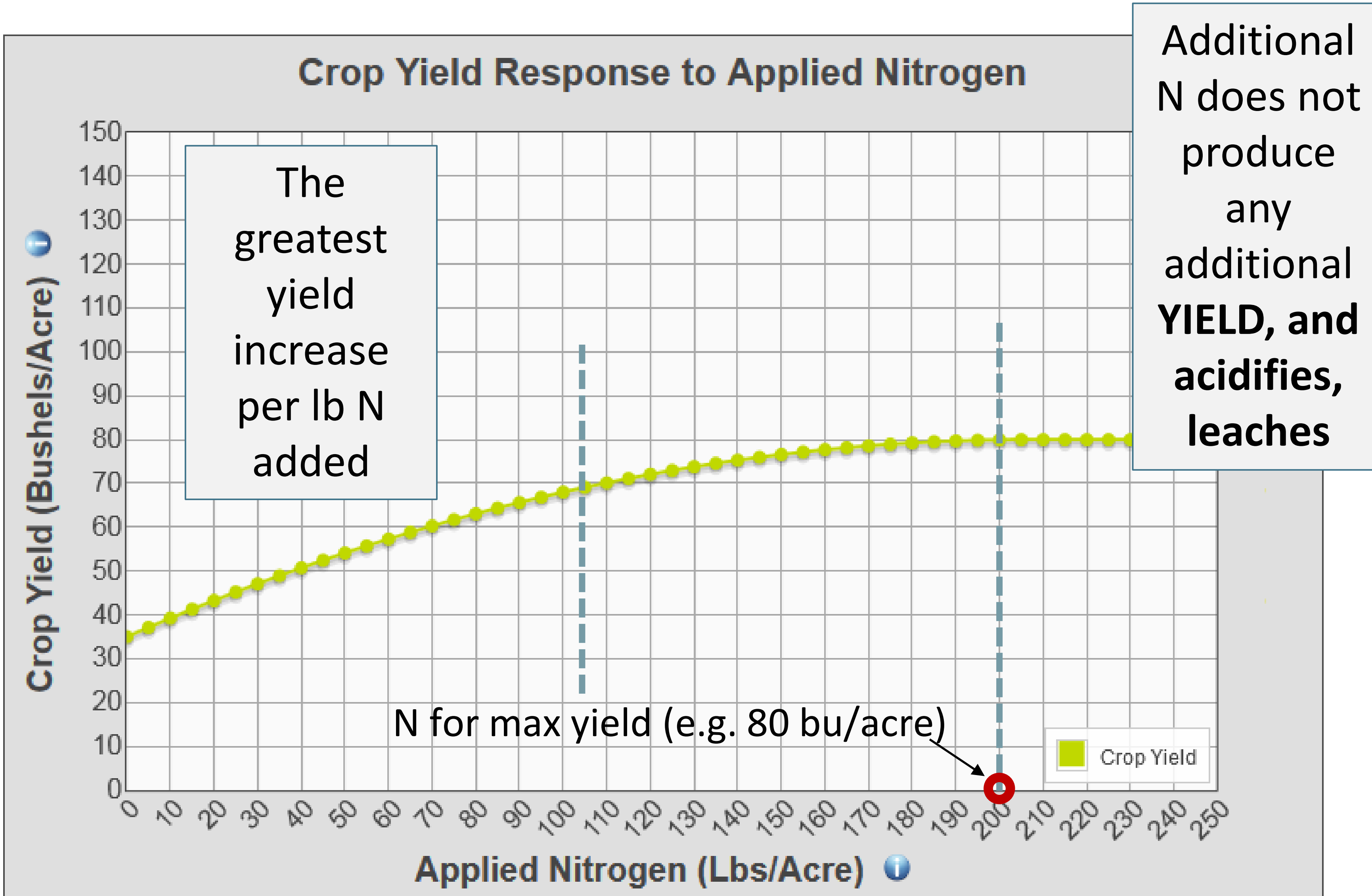
How much fertilizer do I need to apply?

- Fertilizer rate based on soil test results:
  - Need reasonable crop yield goal for N rates
  - MSU guidelines are based on Olsen P.
    Bray works in pH < 7.3, Olsen works pH > 6.
- Rates:
  - Provided by lab (check if they use MT rate guidelines)
  - Guidelines & calculations in MSU MontGuides MT200702AG and 03AG and bulletins

http://landresources.montana.edu/soilfertility/publications.html

  - MSU fertilizer rate calculator
    http://www.sarc.montana.edu/php/soiltest/

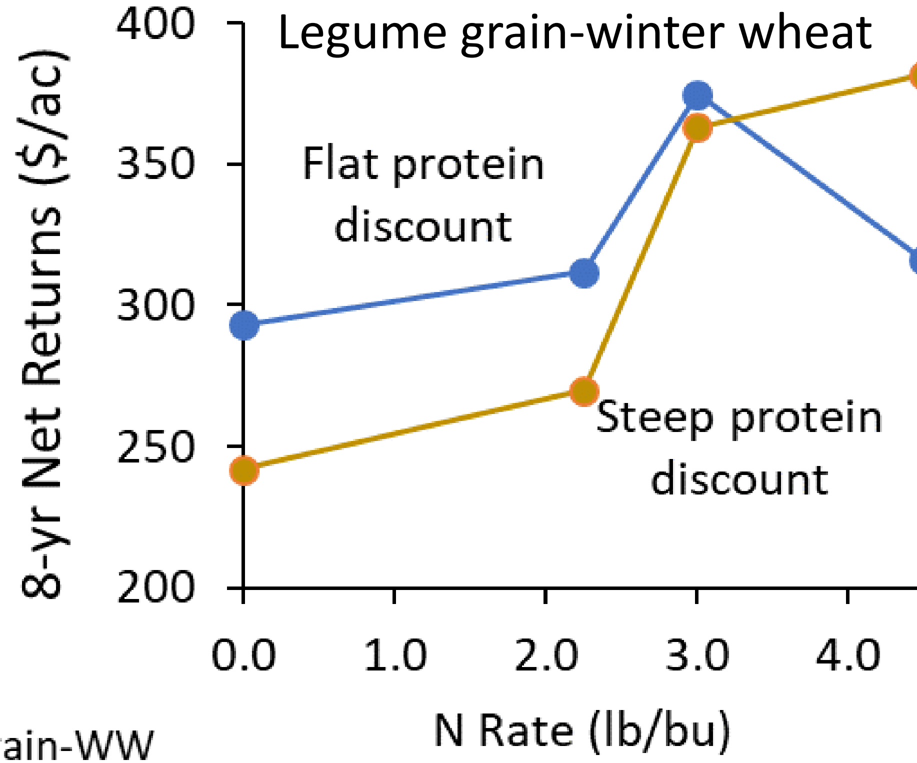
More is **NOT** better: Law of diminishing returns

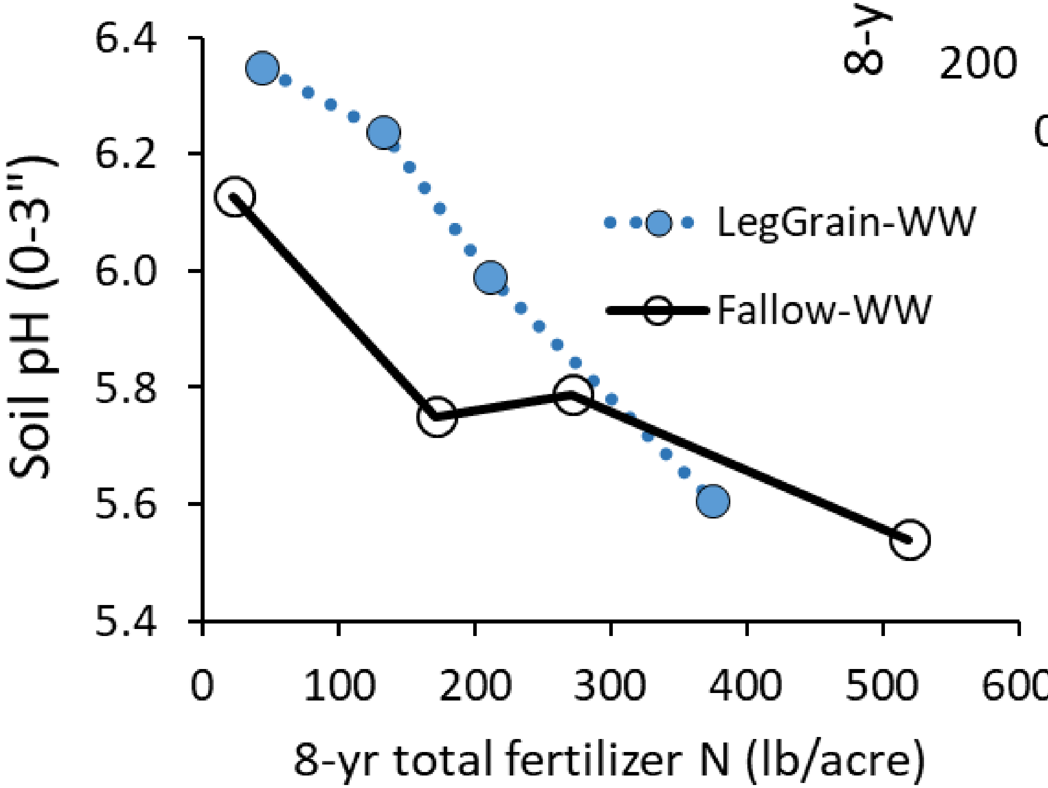


http://econtools.msuextension.org/nitrogen/

High N rates are costly

1. In lower net returns when discounts low





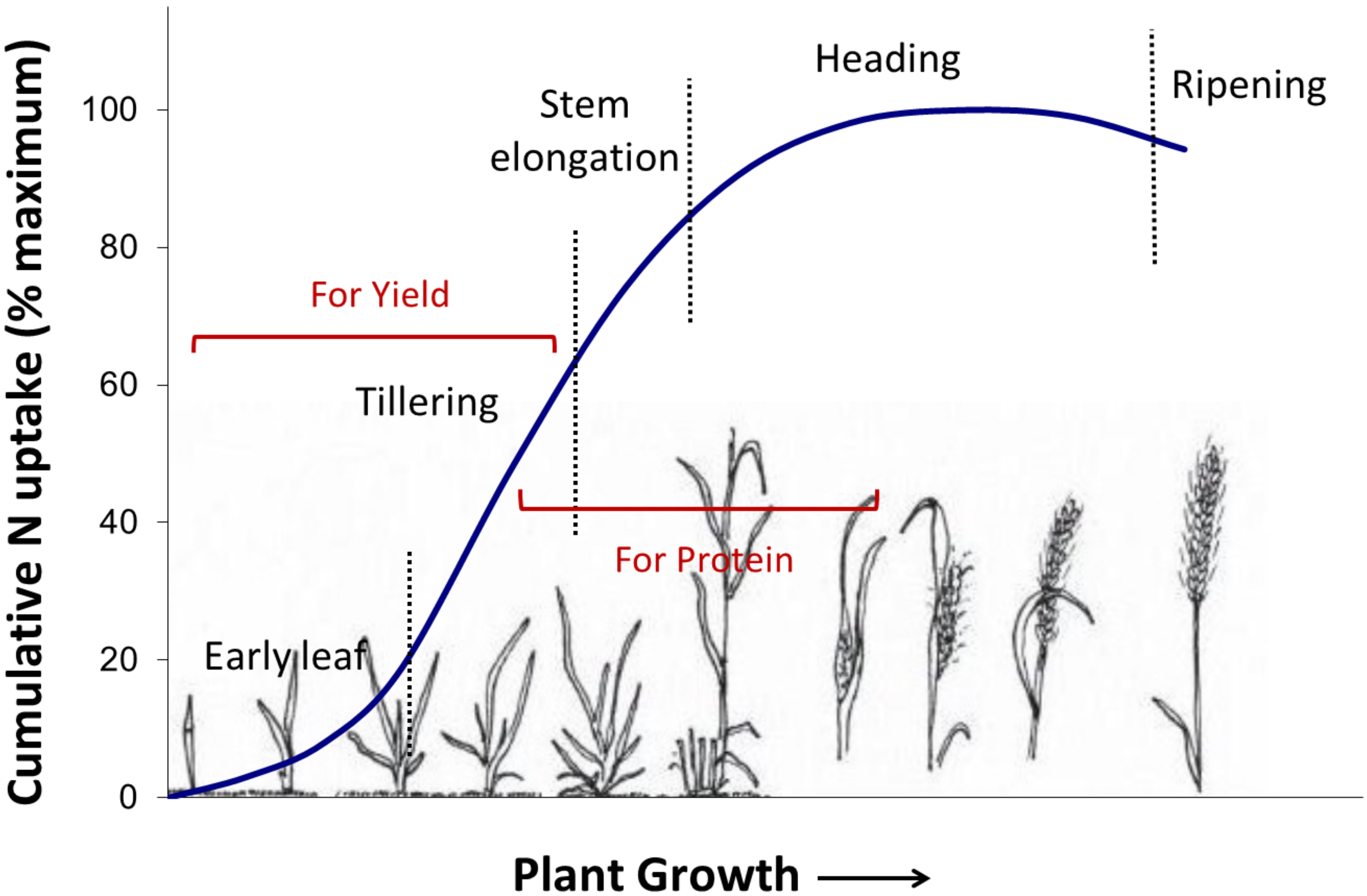
2. And by lowering soil pH to near toxic levels (~5.2)

Miller et al. unpub data. Big Sandy, MT

Timing depends on source

- Readily available; e.g. urea (46–0–0), urea ammonium nitrate (28–0–0), MAP (11-52-0), sulfate
  - N shortly before seeding up to mid-tillering/stem elongation. See *Nutrient uptake timing by crops*
  http://landresources.montana.edu/soilfertility/nutuptake.html
  - P, K, and S at or before seeding
- Slowly available (slow-release N, manure, rock phosphate, elemental-S)
  - take time to become available
  - apply well before needed – e.g., fall or build with prior crop(s)

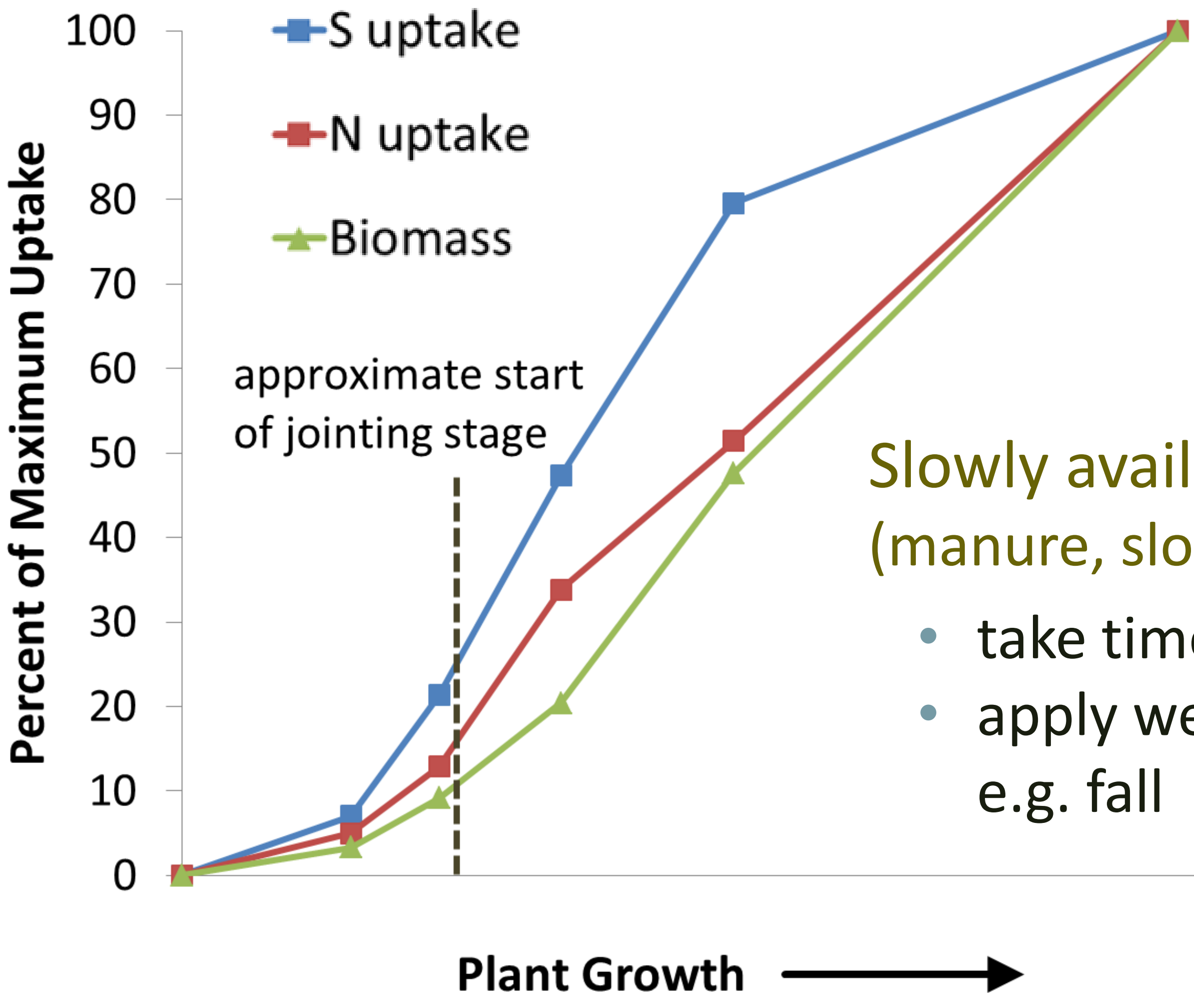
N timing for optimal uptake by wheat for yield



See *Nutrient uptake timing by crops*
http://landresources.montana.edu/soilfertility/nutuptake.html

N timing on forage depends on source

Readily available N (urea, UAN): shortly after **GRASS** green-up

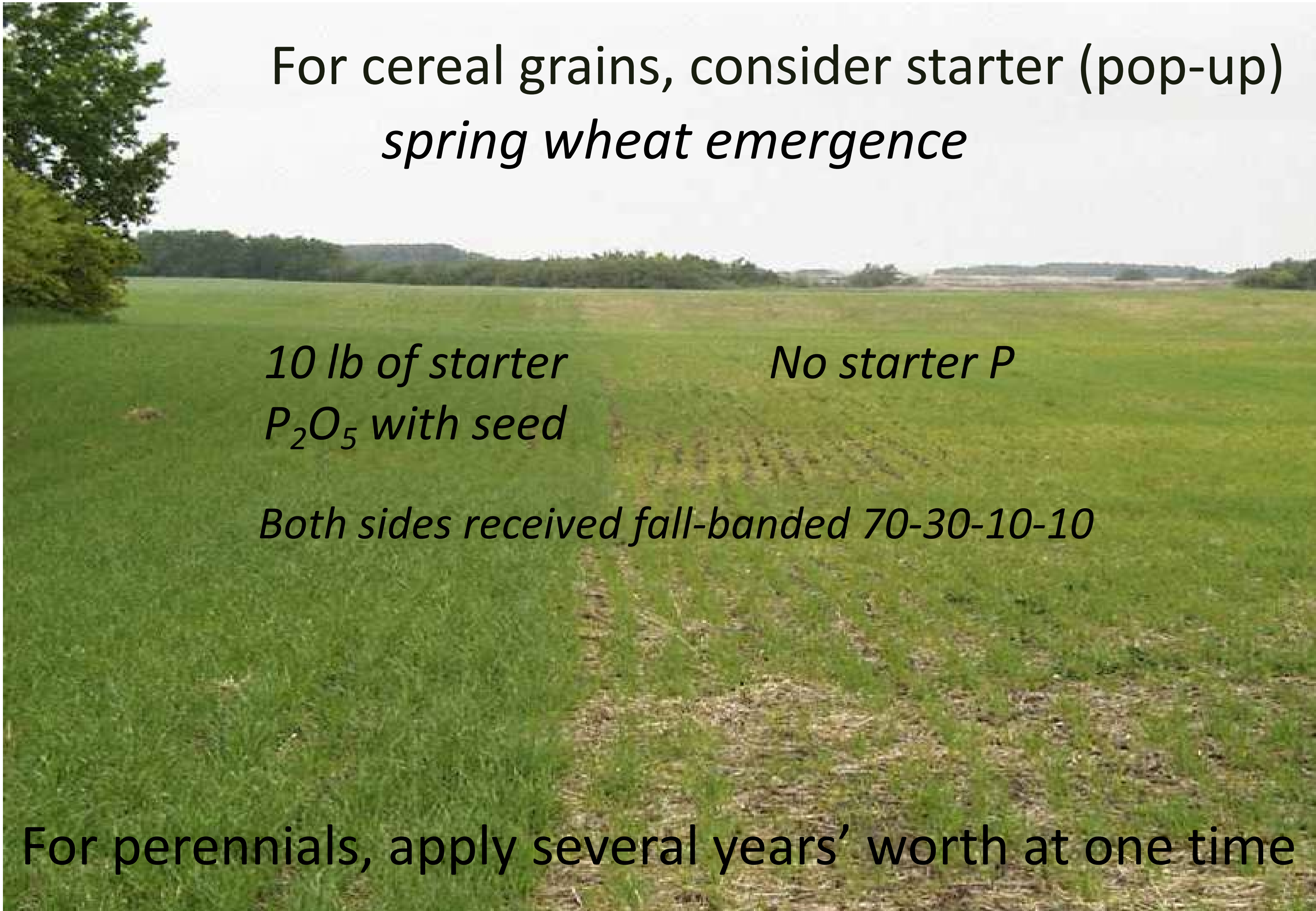


Slowly available N (manure, slow-release N)

- take time to become available
- apply well before needed, e.g. fall

Willamette Valley, Oregon, Hart et al. 1989

Phosphorus is immobile, gets tied up in soil



K timing

Is relatively immobile – what is best timing?

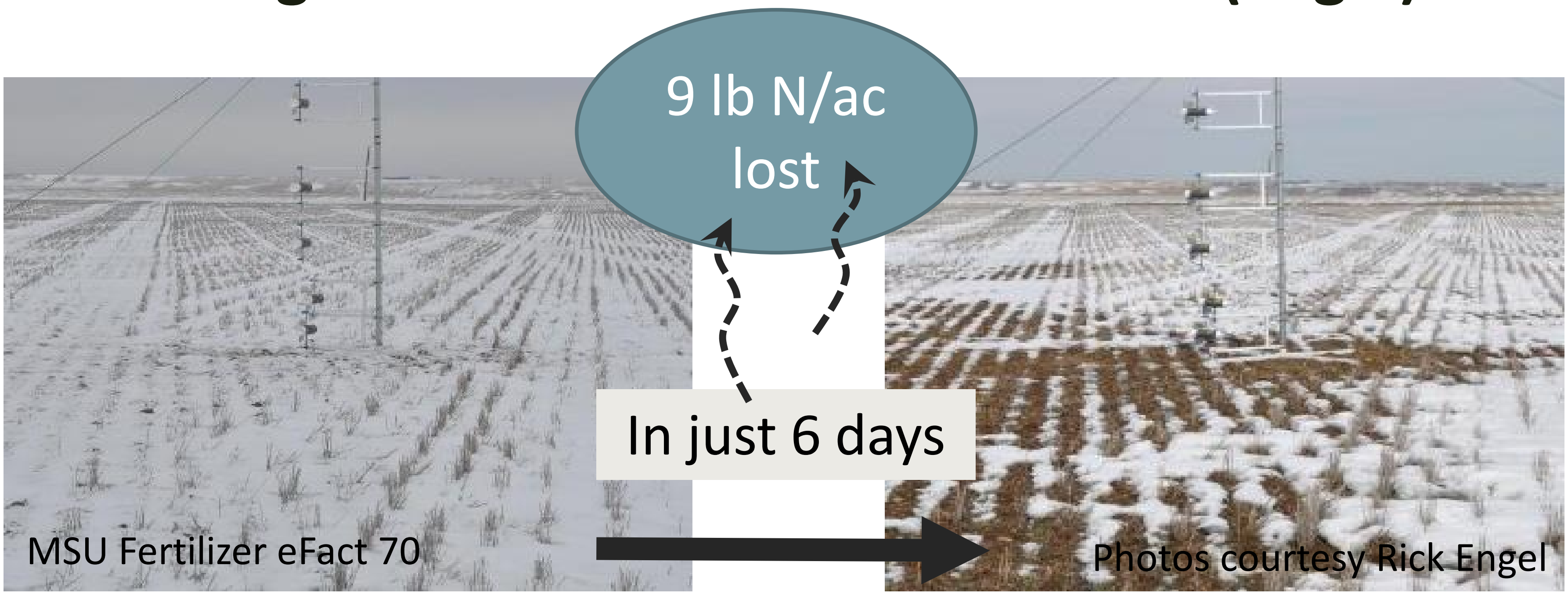
- For cereal grains: subsurface band or broadcast at seeding
- For forage:
  - split between first and after last cutting to minimize luxury consumption of first harvest
  - apply after last cutting and before fall period of re-growth to feed root reserves

Placement: N

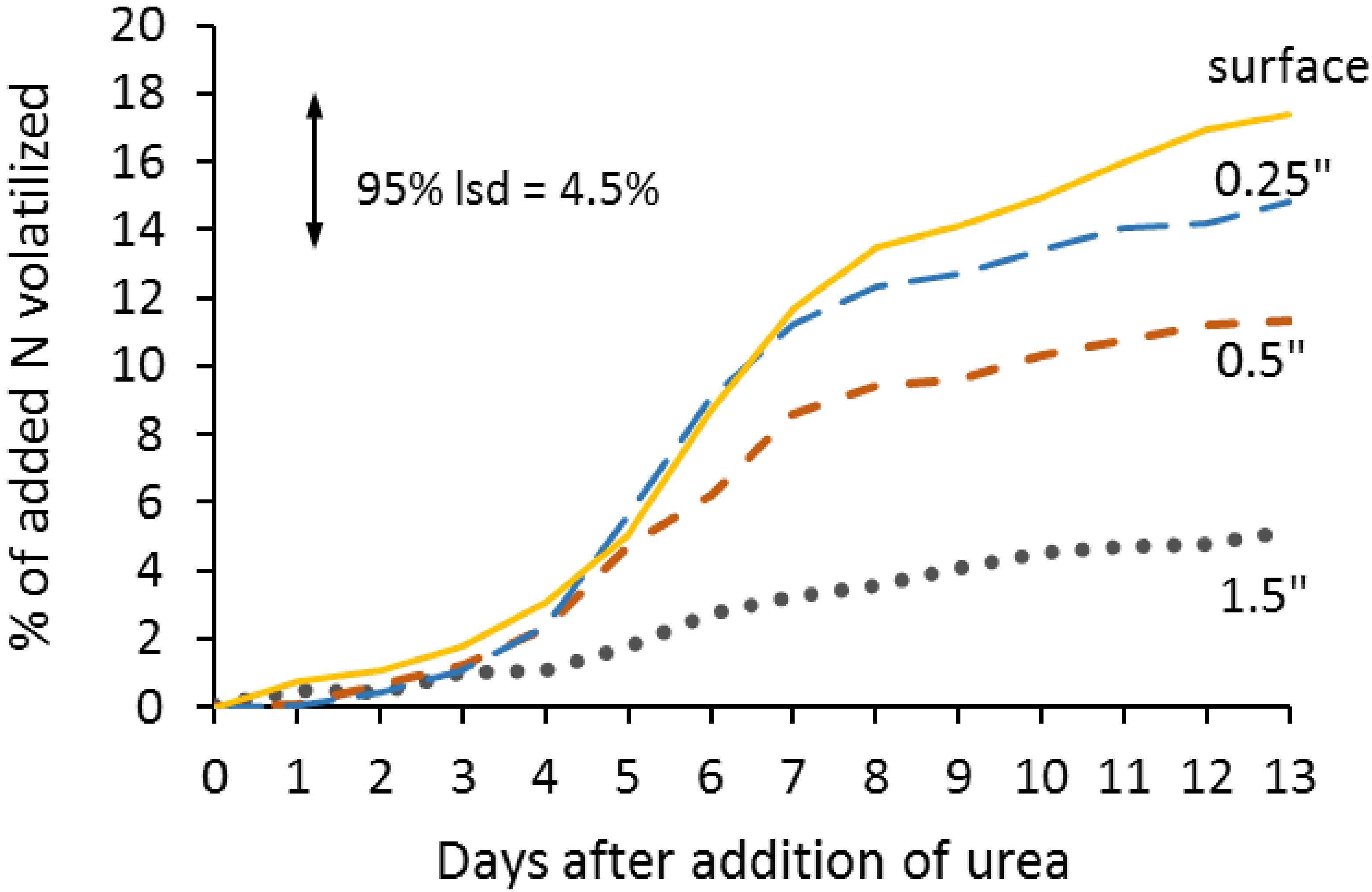
- In general, subsurface placement/incorporation of N fertilizer decreases losses and increases availability
  - Broadcast N fertilizer needs to be incorporated by tillage or ½” water ‘event’ to prevent volatilization
  - Do not apply on snow or frozen ground
- Fertilizer is salty and can damage germination if placed too close to seed at too high rates

Most important factors affecting urea volatilization

- Surface soil moisture at time of fertilization
- Precipitation the week or 2 after
- Worst-case – moist soil surface w/ only sprinkles for the next few weeks.
- **Average urea loss over 23 trials = 16% (Engel)**



Depth of incorporation reduces volatilization

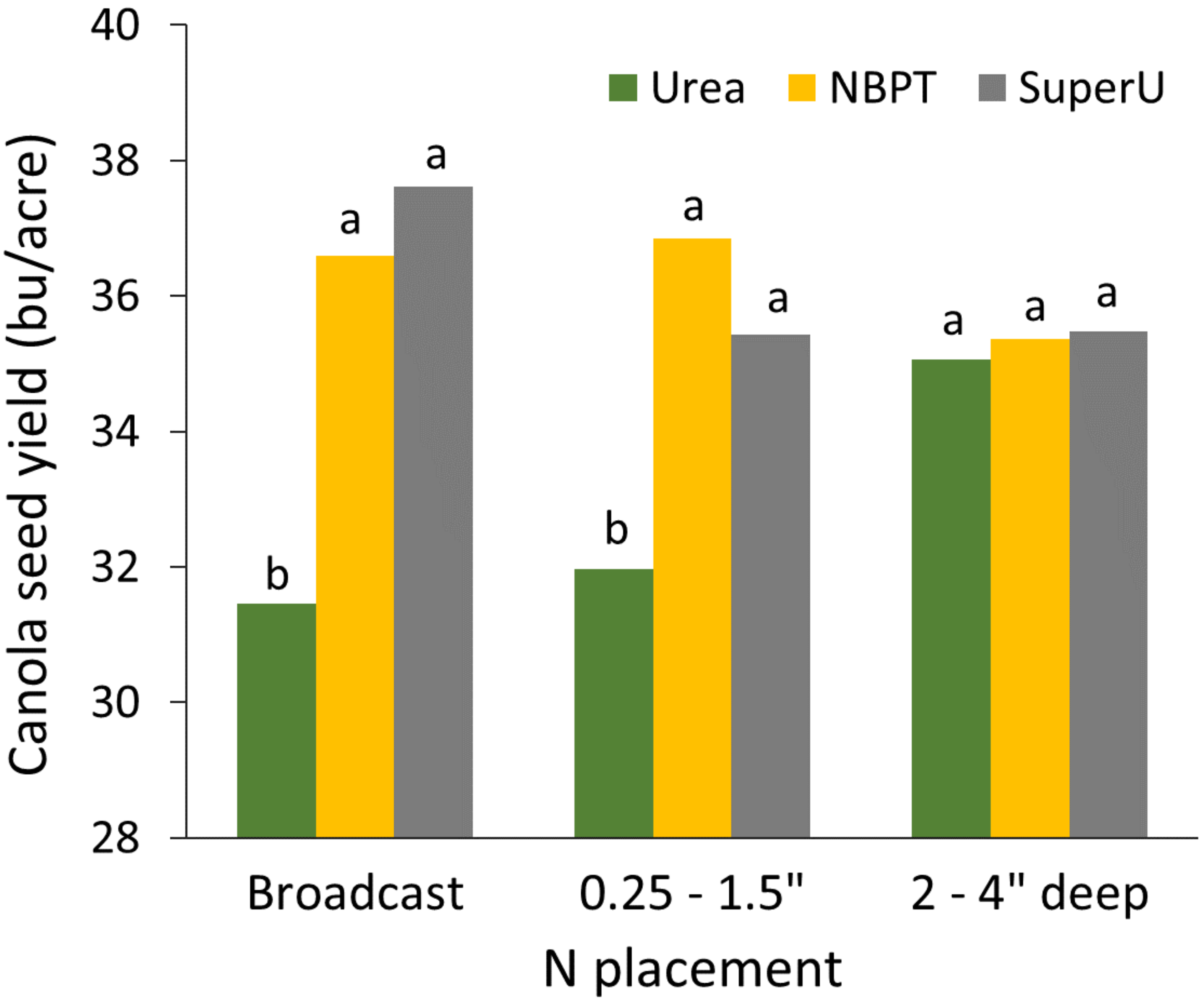


100 lb N/ac as urea

Silt loam, soil pH 6.5, Temp 75F

Ernst & Massey 1960, lab

Best-case – subsurface band at least 2” deep, packed, OR use ‘urease inhibitor’ like NBPT



Karamanos, Barker 2016 Top Crop Manager

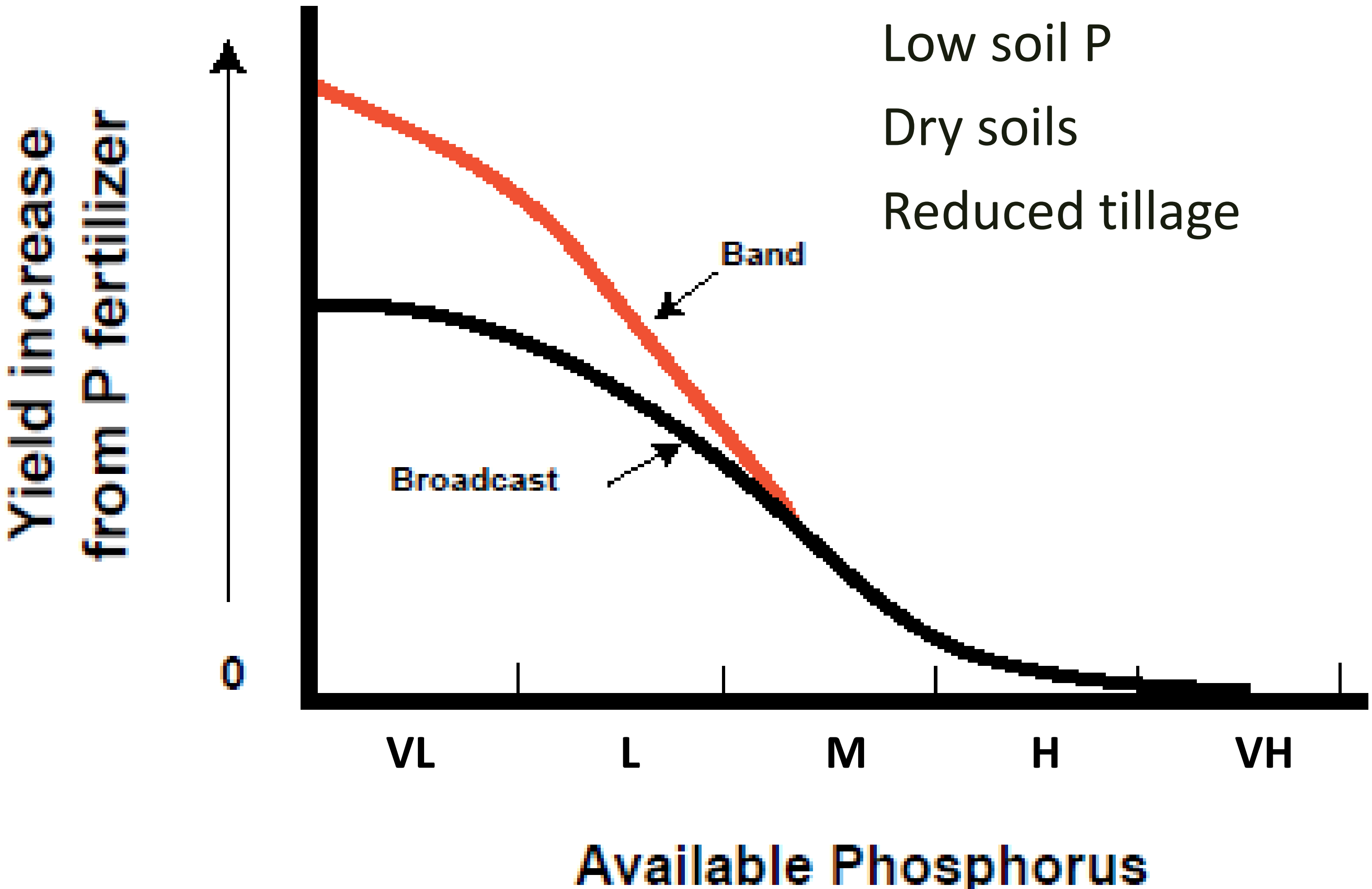
Placement of phosphate and KCl

- Incorporate prior to seeding (in tilled fields)
- Place in-furrow (single shoot) but at low rates
  - <20 lb P_2O_5/acre 11-52-0
  - <10-15 lb N plus K_2O with seed
- Place below and to side of seed (double shoot)
  - Advantage – fast uptake
  - Disadvantage – dry out soil and can cause poorer germination

P band vs. broadcast

Band better than broadcast:

- Low soil P
- Dry soils
- Reduced tillage



(Randall & Hoeft 1988)

Questions?

On to healthy soils

What describes a good soil?

- Good aeration, drainage and tilth
- Organic matter and organisms (per acre they can consume as much as 1 elephant!)
- Doesn’t crust after planting
- Soaks up heavy rains with little runoff
- Stores moisture for drought periods
- Has few clods and no hardpan
- Resists erosion and nutrient loss
- Produces healthy, high quality crops

How can I manage for healthy soils?

- Know your soil's properties and only add fertilizer and amendments as needed
- Avoid compaction by:
  - Reducing tillage and traffic when wet
- Increase the organic matter content by:
  - Minimizing fallow, possibly adding cover crops
  - Moderate grazing
- Maintain cover with vegetation or residue
- Scout for problems, such as low pH

The ‘problem’ is not always clear

- Ex: Unexplained poor health in low or mid-slope areas
- Low soil pH → Al toxicity
  - stubby club roots, no fine branching (similar to nematode damage)

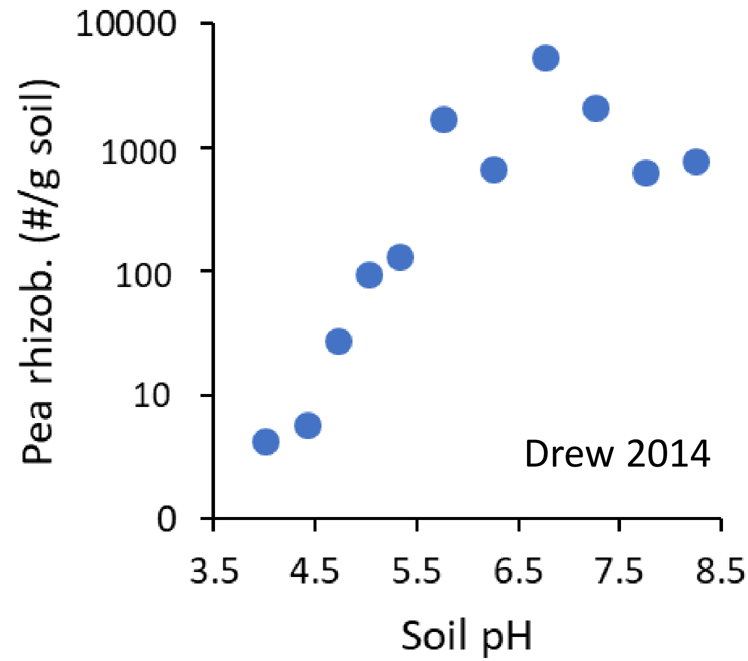
photo sources: Engel

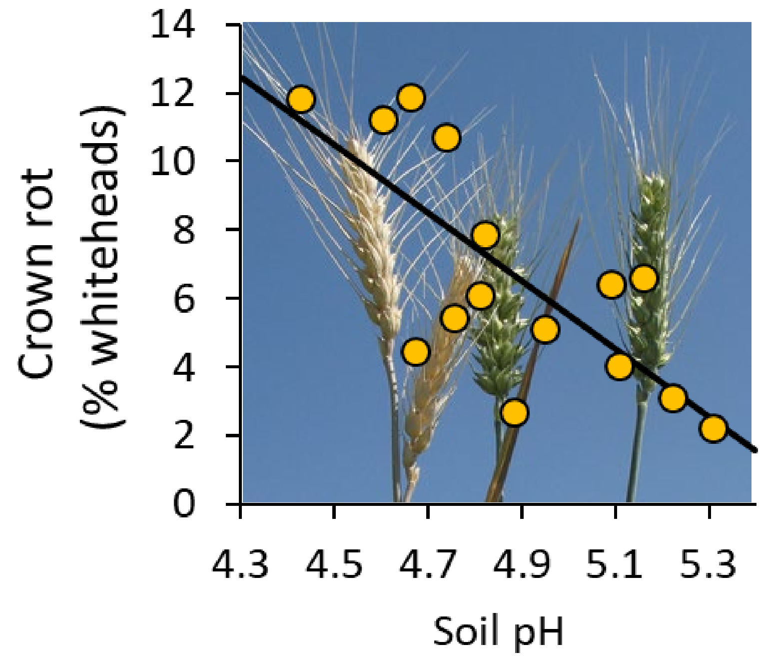
A. Robson,
https://agric.wa.gov.au/n/4487

What's happening?

- Change in herbicide efficacy and carry over (Raeder et al., 2015)
- Poor N fixation by legumes
- Increase in some fungal diseases (e.g., Cephalosporium stripe, root rots)

These may be caused by low soil pH and appear before Al toxicity





Smiley et al. 1996, Fusarium crown rot, image by M. Burrows

Evaluate and adjust:

- Indicators of soil nutrients: yield, quality (protein, forage nitrate), nutrient deficiencies or toxicities
- Use this year’s observations to fine tune rates next year, e.g. wheat grain protein levels
- Use and develop maps, keep records
- Experiment with strip trials
- Use variable, site specific rates
- Manage to reduce N leaching and volatilization

Summary

- Understanding soil properties guides proper fertilization
- Soil tests, the online economic N calculator and MSU Extension publications are important tools to calculate fertilizer rates, maximize plant heath, protect environment
- The right rate, source, placement and timing leads to optimal fertilizer use and plant health
- Observe and adjust to your specific conditions

Resources

On soil fertility website under *Extension Publications*

http://landresources.montana.edu/soilfertility/

- *Soil Sampling Strategies* (MT200803AG)
- *Interpretation of Soil Test Reports for Agriculture* (MT200702AG)
- *Developing Fertilizer Recommendations for Agriculture* (MT200703AG)
- More bulletins for specific crops
- *Soil Sampling and Laboratory Selection* (4449-1) http://landresources.montana.edu/NM/
- *The Soil Scoop* http://landresources.montana.edu/soilfertility/soilscoop.html
- Cropland Soil Acidification

http://landresources.montana.edu/soilfertility/acidif/index.html

Photo by Ann Ronning

Thank you!
Questions?

This presentation and more information on soil fertility is available at http://landresources.montana.edu/soilfertility