Soil Fertility 101

With a focus on wheat producing areas

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Questions

- How many of you use a crop adviser for making fertilizer decisions?

- How many do your own soil sampling?

Goals Today

•Introduce basics of soil fertility

•Focus on nitrogen, phosphorus, potassium, and sulfur cycling and differences in their plant-availability

•Show nutrient deficiency symptoms and ‘test’ you

•Introduce soil sampling and explain yield response curves

•Show how to use Fertilizer Guidelines and soil lab results to estimate fertilizer needs

•Have you determine fertilizer rates given a soil test report

•Identify some differences between conventional and air drills

•HELP your bottom line!

There are 14 mineral nutrients that have been found to be essential for growth of most plants:

Macronutrients	Micronutrients
Nitrogen (N)	**Boron (B)**
Phosphorus (P)	**Chloride (Cl)**
Potassium (K)	**Copper (Cu)**
Sulfur (S)	**Iron (Fe)**
Calcium (Ca)	**Manganese (Mn)**
Magnesium (Mg)	Molybdenum (Mo)
	Nickel (Ni)
	Zinc (Zn)

The macronutrients are simply needed in larger amounts by the plant than the micronutrients.

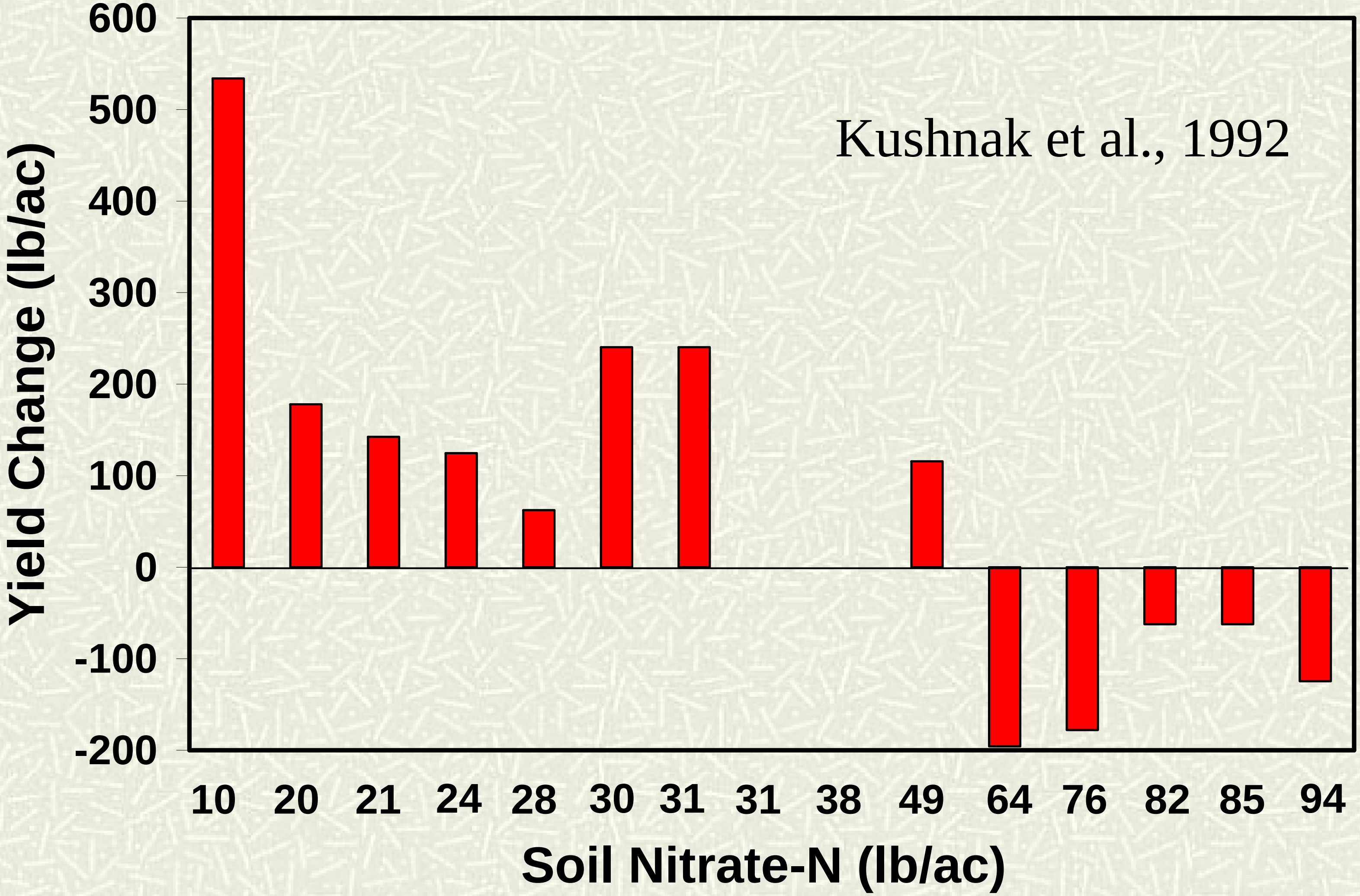
Nutrient deficiencies of the bolded nutrients have been observed in Montana

Mobility in soil of selected nutrients

Mobile (and soluble)	Relatively immobile	Very immobile (and insoluble)
Nitrogen (as nitrate) Sulfur Boron Chloride	Potassium	Phosphorus Copper Iron Manganese Zinc

Why important? **Can affect optimum fertilizer placement**

Effect of **subsurface banding** urea compared to **broadcast** urea in Golden Triangle on small grain yield



Banding Phosphorus

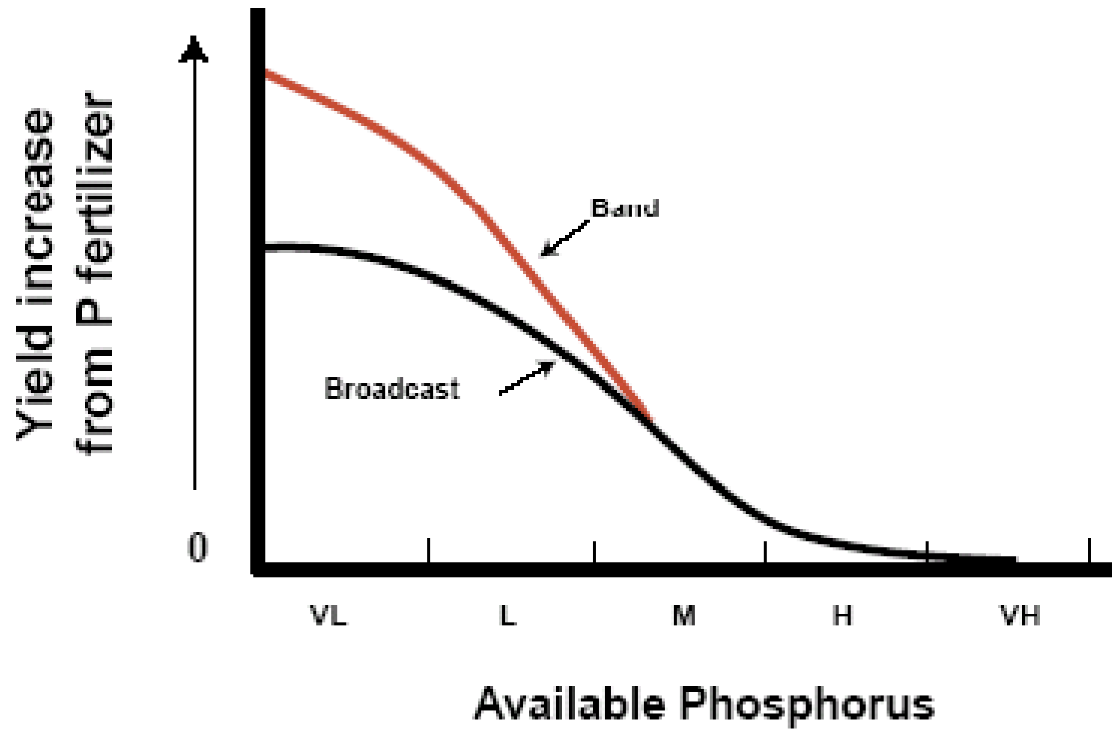


Figure 7. The advantages of P banding are greatest when STP levels are very low (VL) to low (L). From Randall and Hoeft (1988).

Banding P is much more effective than banding N, because P is much more immobile in the soil.

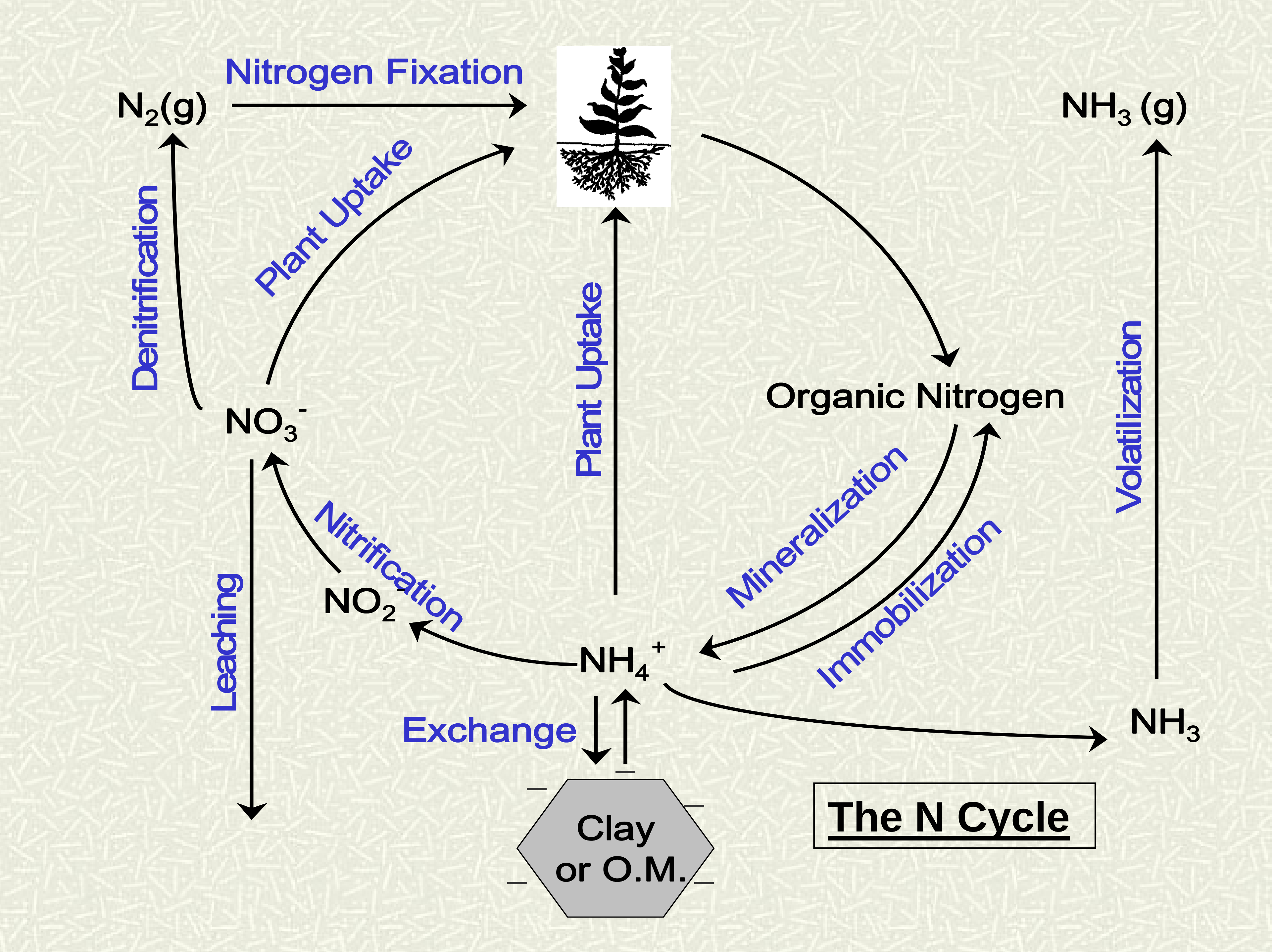
For more information on soil fertility and plant nutrition, refer to Nutrient Management Module 2, and for more information on Fertilizer Placement, look at Module 11:

http://www.montana.edu/wwwpb/pubs/mt4449.html

Nutrient Reactions and Cyling

- Will focus on N, P, K, and S because these have best chance of limiting yield and protein.

Nitrogen form	Molecular formula	Notes
Nitrogen gas	N_2 (g)	Represents about 80% of the air we breathe but not available to plants
Ammonia gas	NH_3 (g)	Generally cheapest form of N, toxic at high concentrations
Ammonium	NH_4^+	Plant available, attracted to exchange sites on clay particles
Nitrate	NO_3^-	Very mobile, requires more energy by plant than ammonium
Nitrite	NO_2^-	Mobile, generally low concentrations, toxic to young mammals
Organic N	-	Slowly supplies available N to soil solution



Nitrogen Fixation
$N_2(g)$
NH_3 (g)
Plant Uptake
Denitrification
Plant Uptake
Volatilization
Organic Nitrogen
NO_3^-
Mineralization
Immobilization
Nitrification
NO_2^-
Leaching
NH_4^+
Exchange
NH_3
Clay
or O.M.
The N Cycle

‘Mineralization’

Release of minerals as organic matter (O.M.) is oxidized, releasing available N

Organic-N → Plant-Available N

If have higher than normal O.M. (>3%), can back off on N fertilizer by 20 lb/ac.

‘Immobilization’

Incorporation of available N into microbial cells or plant tissue

Plant-Available N → Organic-N

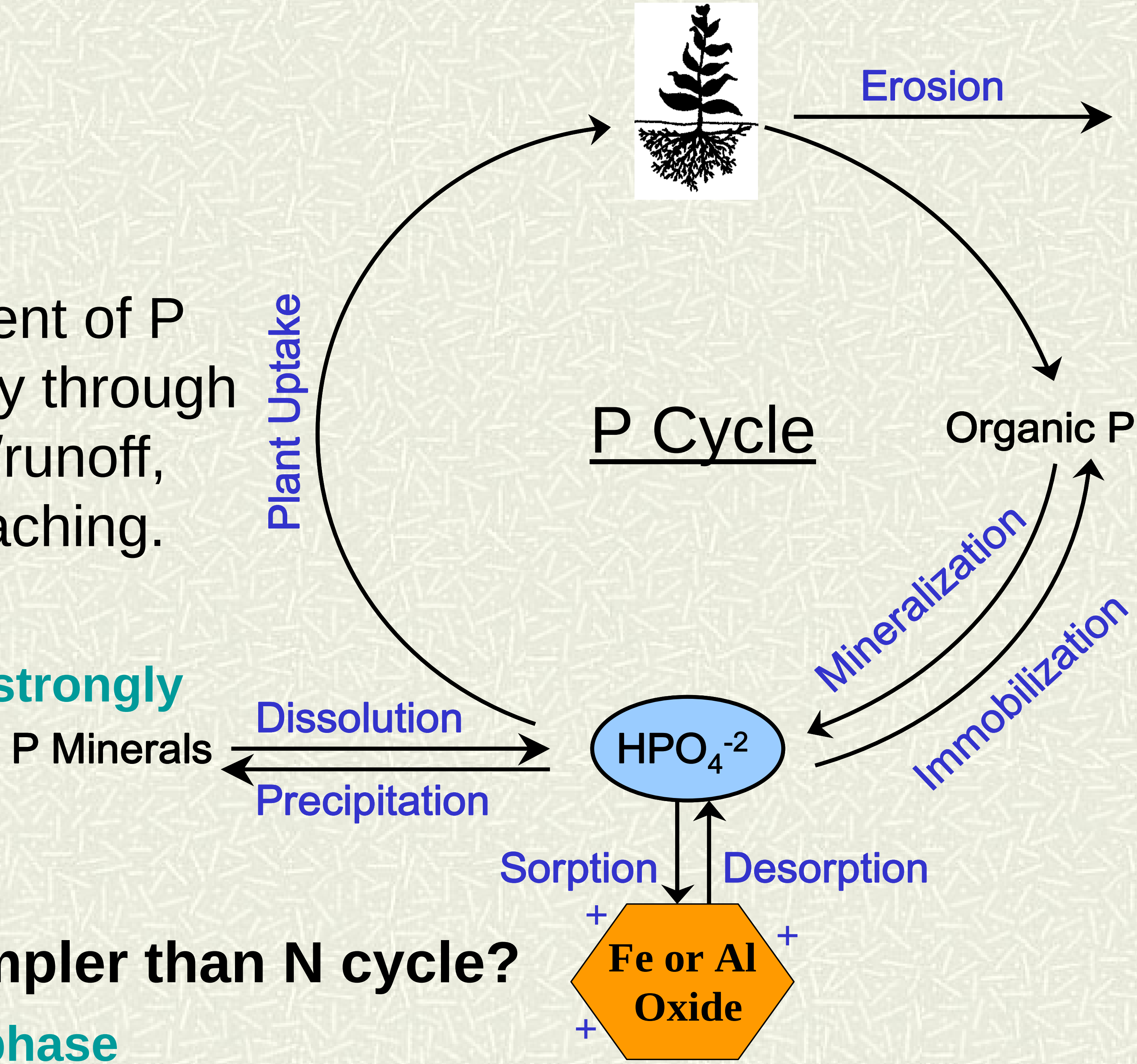
If leave more than ½ ton stubble, increase N fertilizer by 10 lb/ac.

If you want more information on N cycling, go to MSU Extension’s publication on the topic at:

http://www.montana.edu/wwwpb/pubs/mt44493.pdf

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

P binds strongly to soil



Why simpler than N cycle?

No gas phase

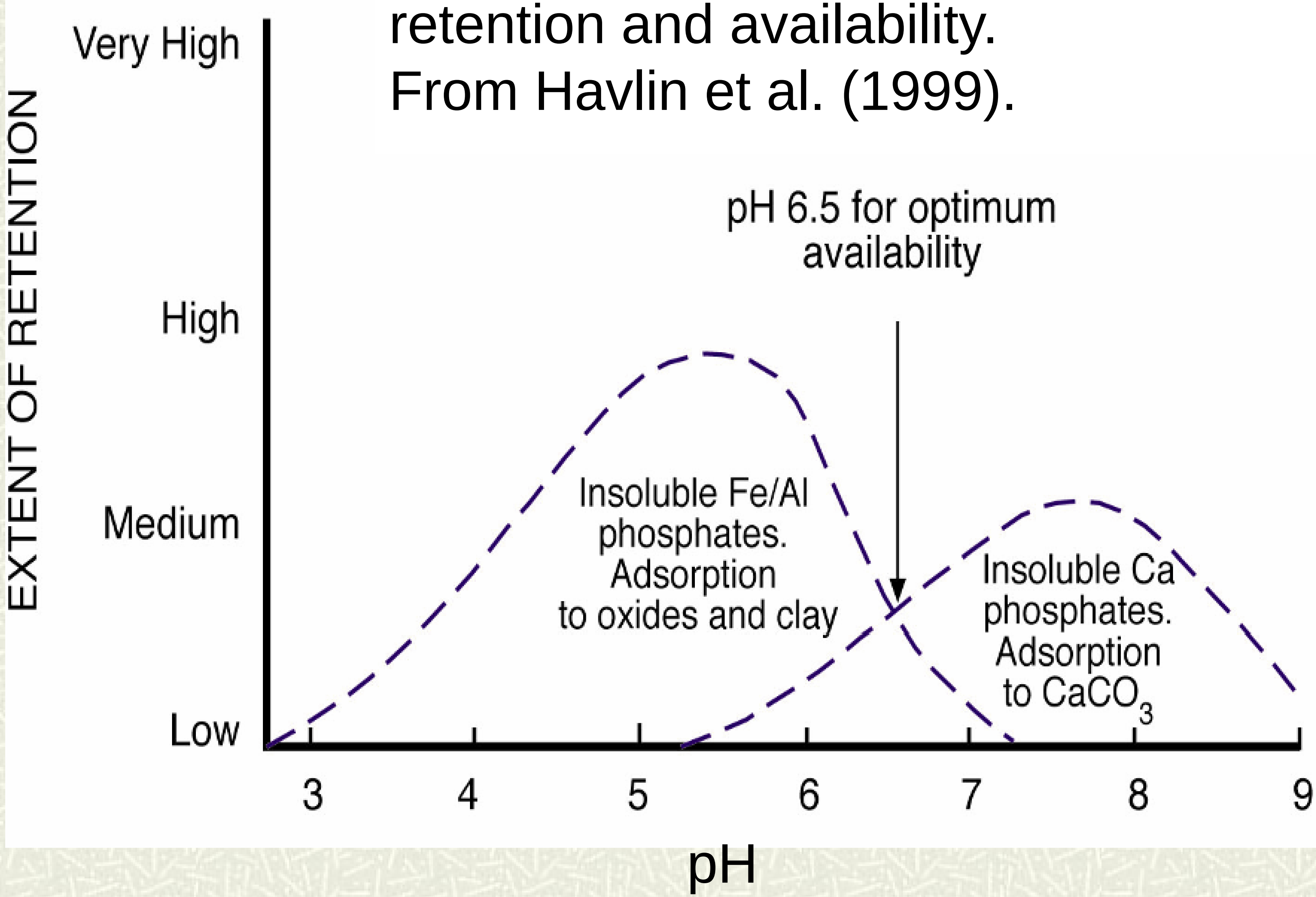
Soluble P concentrations in soil are generally very low (0.01 – 1 mg/L) due to:

1. Precipitation and low solubility of calcium phosphate minerals. This is very relevant in this region.

2. Strong sorption to manganese, aluminum, and iron oxides and hydroxides (example: rust). This process increases at low pH and is more of an issue in the Southeast U.S.

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

The effect of soil pH on P retention and availability. From Havlin et al. (1999).



If you want more information on P cycling, go to MSU Extension’s publication at:

http://www.montana.edu/wwwpb/pubs/mt44494.pdf

Questions so far?

Potassium (K)

Needed in Montana?

Table 2. Responses to K fertilizer when included in fertilizer program (Skogley and Haby 1981).

Crop	Response Frequency (%)	Average Yield Increase*	Average Application Rate* (lb K_2O/ac)
Winter wheat	47	5.5 bu/ac	20
Spring wheat	30	4.8 bu/ac	20
Barley	44	3.9 bu/ac	32
Barley (irrig.)	70	9.2 bu/ac	43
Alfalfa hay	50	694 lb/ac	75-200
Sugar beets (irrig.)	30	220 lb/ac	86-107
Native range	17	315 lb/ac	70

*For sites that showed positive response to K fertilizer

Which crops have largest K needs?

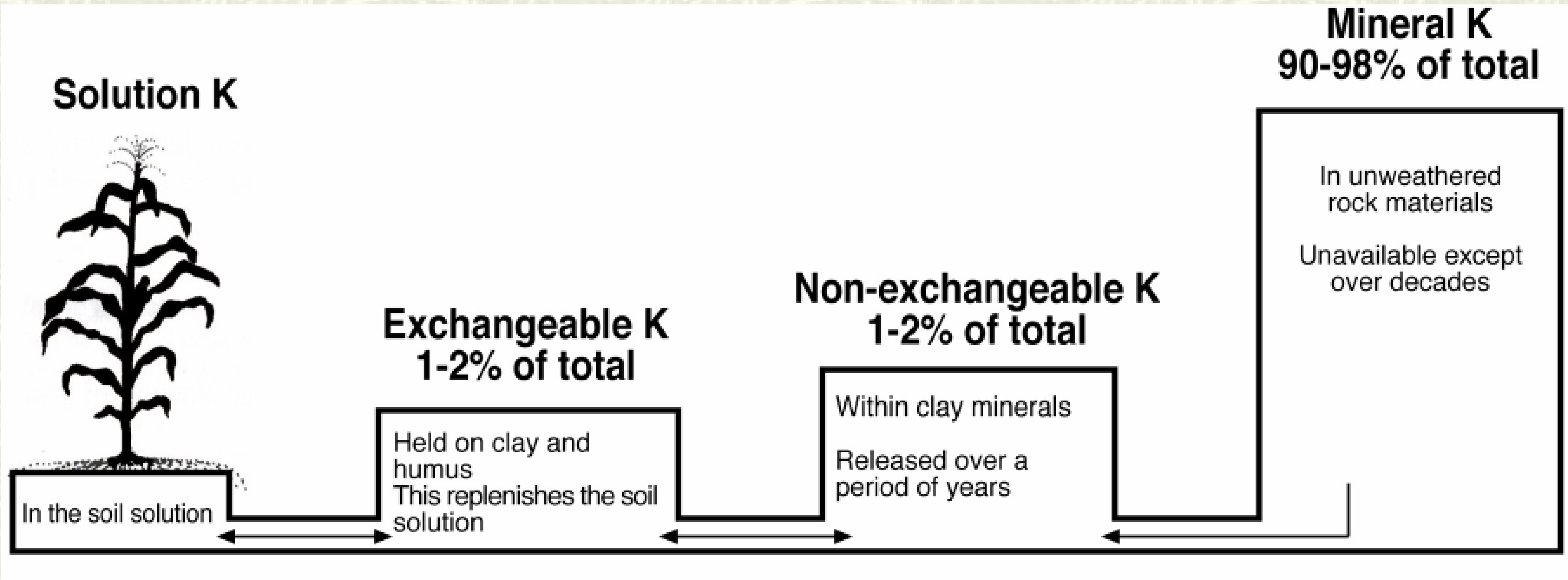
Table 1. K removal amounts in harvested portions of selected agricultural crops.

Crop	Assumed yield per acre	K_2O removal (lb/ac)
Alfalfa	2.5 t	150
Barley	50 bu	80
Brome	1.5 t	95
Corn silage	20 t	167
Orchard grass	1.5 t	75
Potatoes	300 cwt	330
Sugar beets	25 t	460
Timothy	1.5 t	94
Wheat	40 bu	80

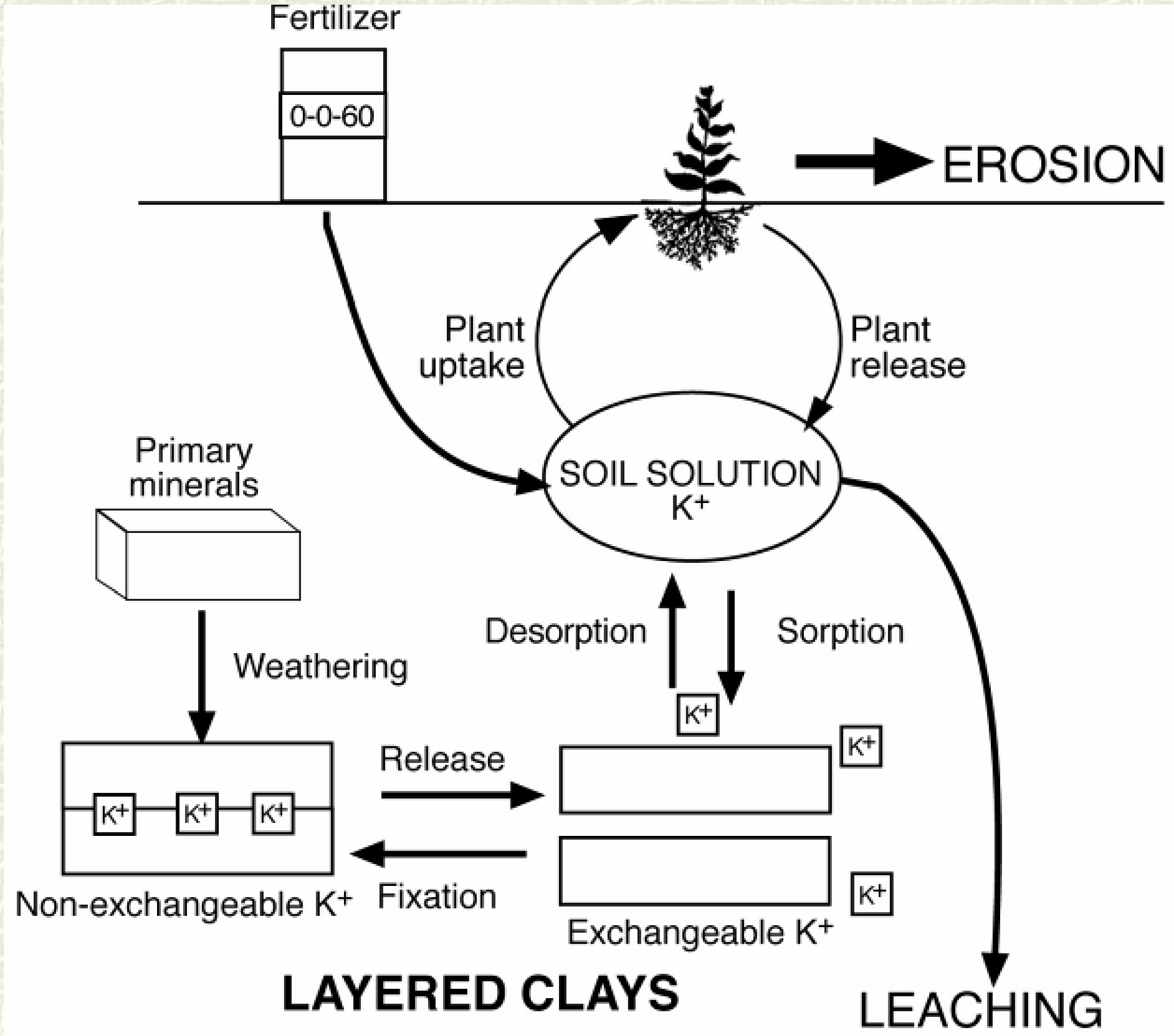
From CFA (1995). Wheat and barley removal include head and straw.

How might K, or lack of K, affect an alfalfa-hay field?

Potassium Forms

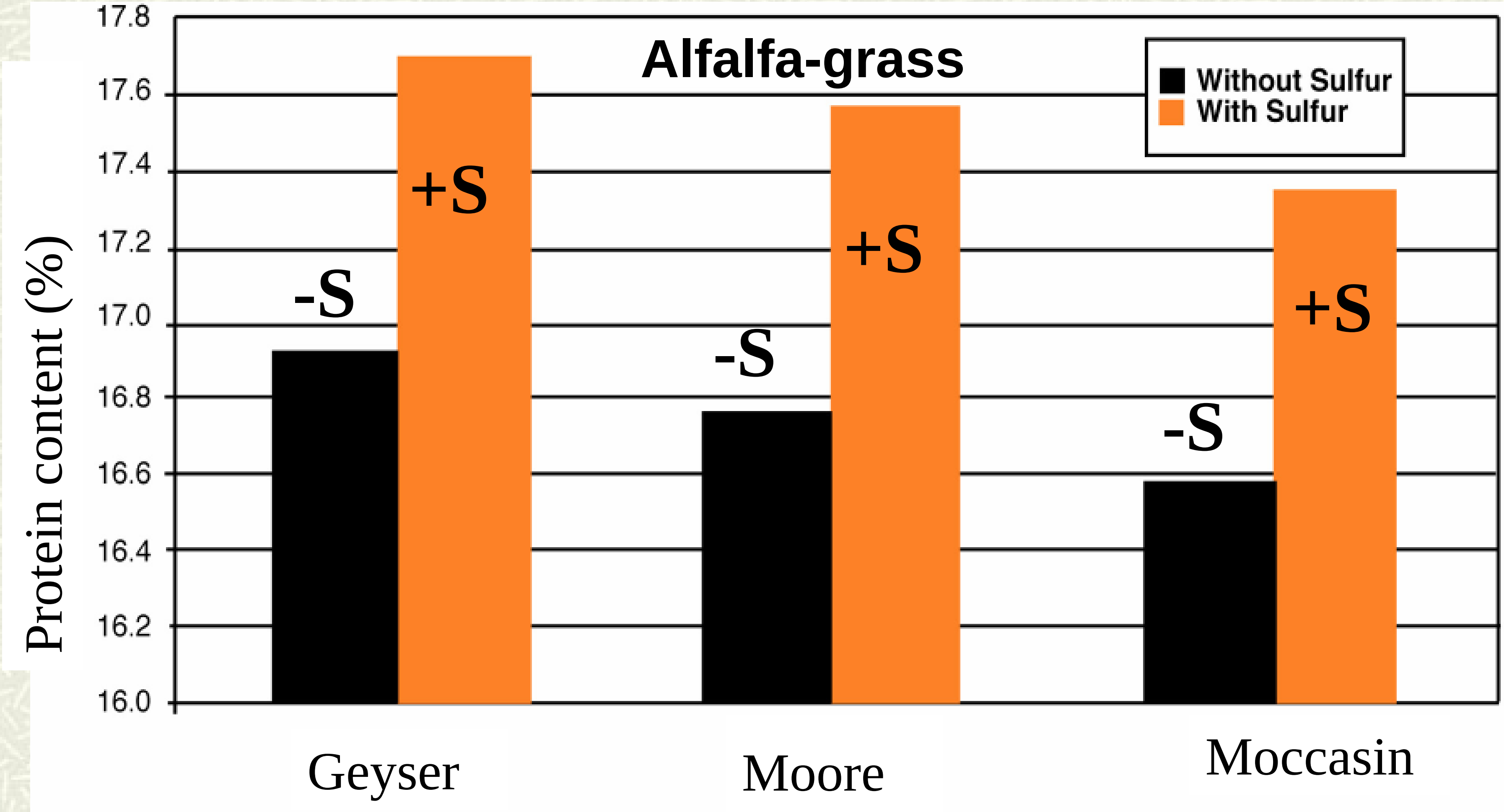


Potassium Cycling



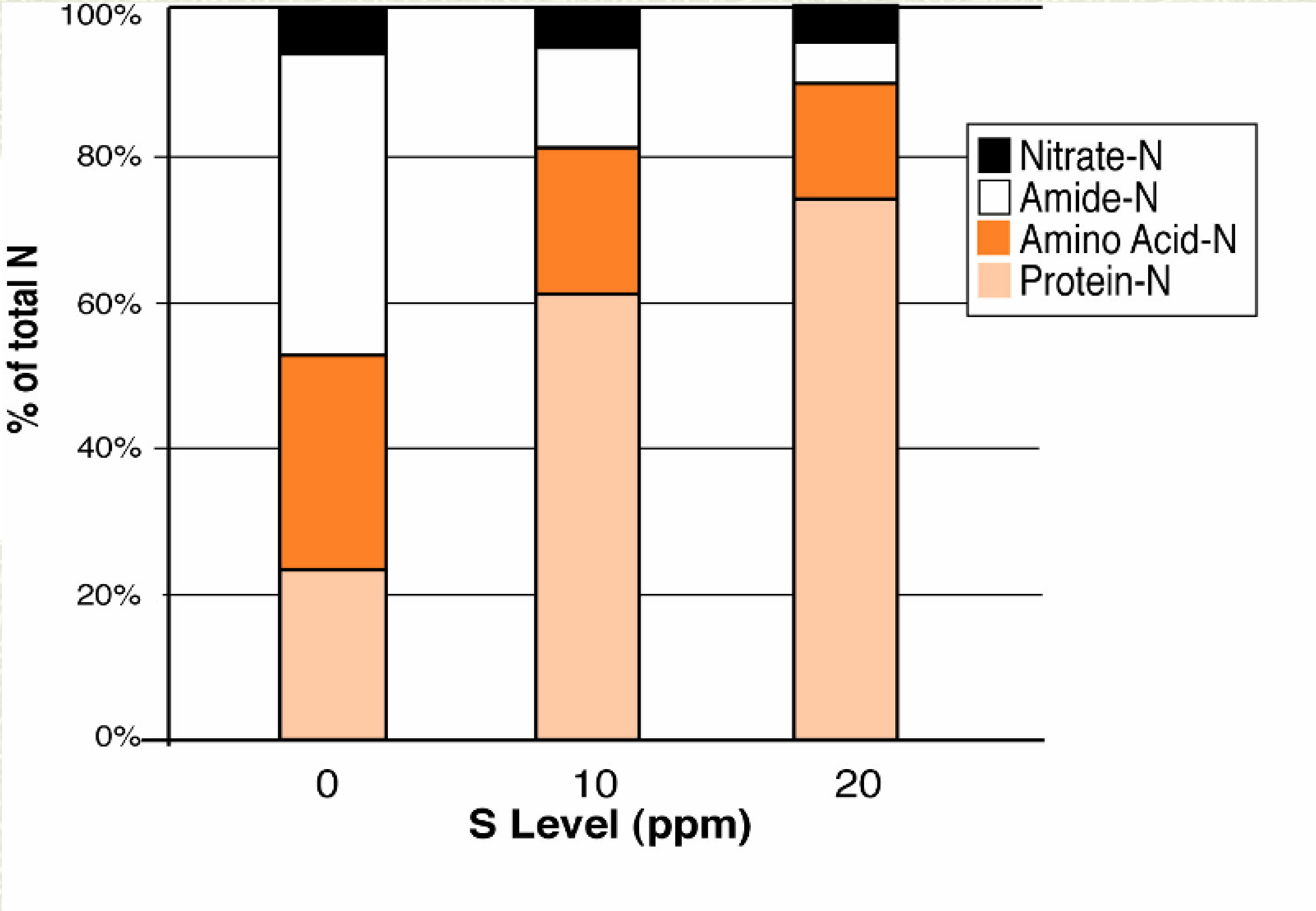
Sulfur (S)

Responses seen in Montana?

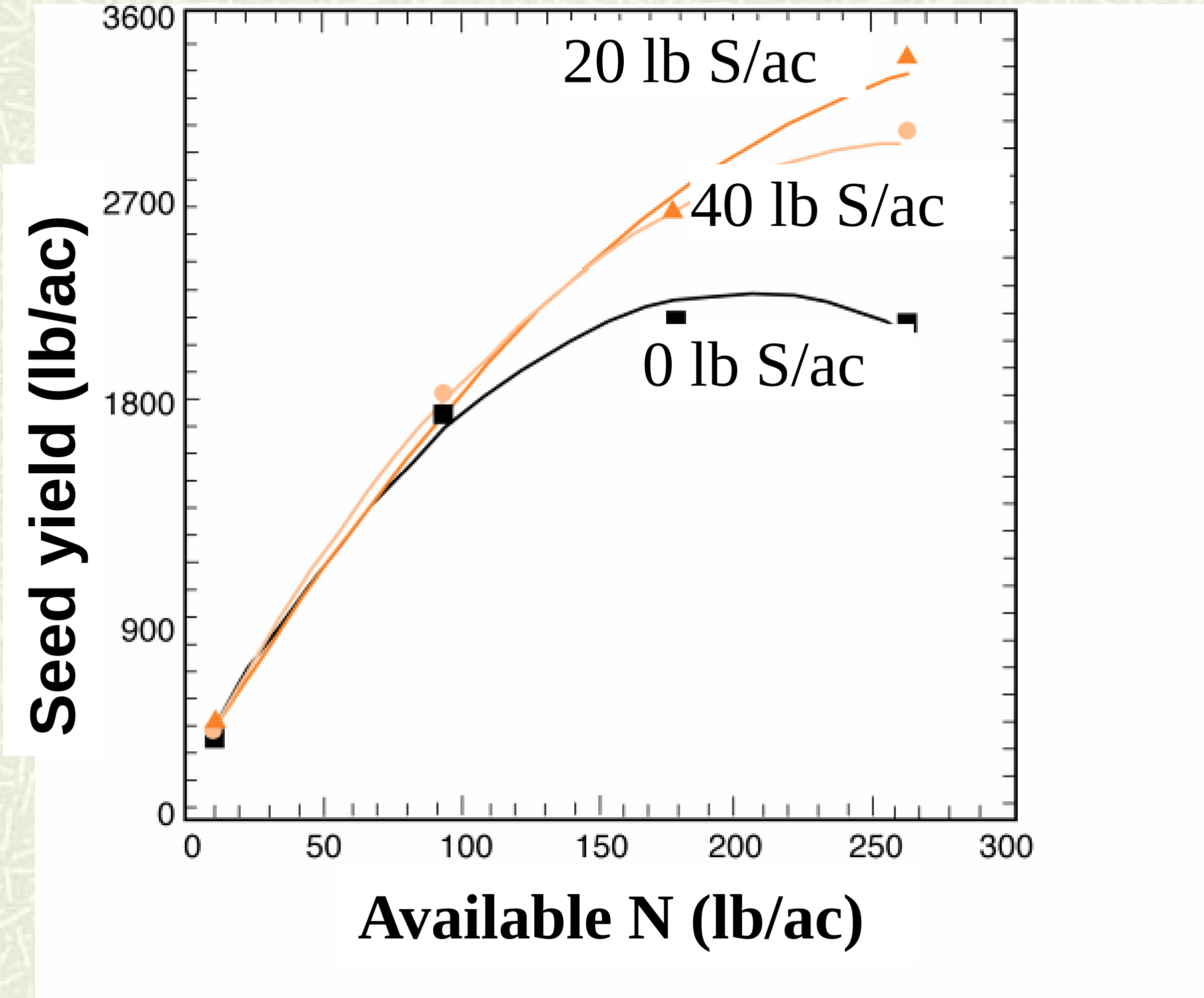


Note: Yield increased 30% at Moccasin (Wichman, 2001)

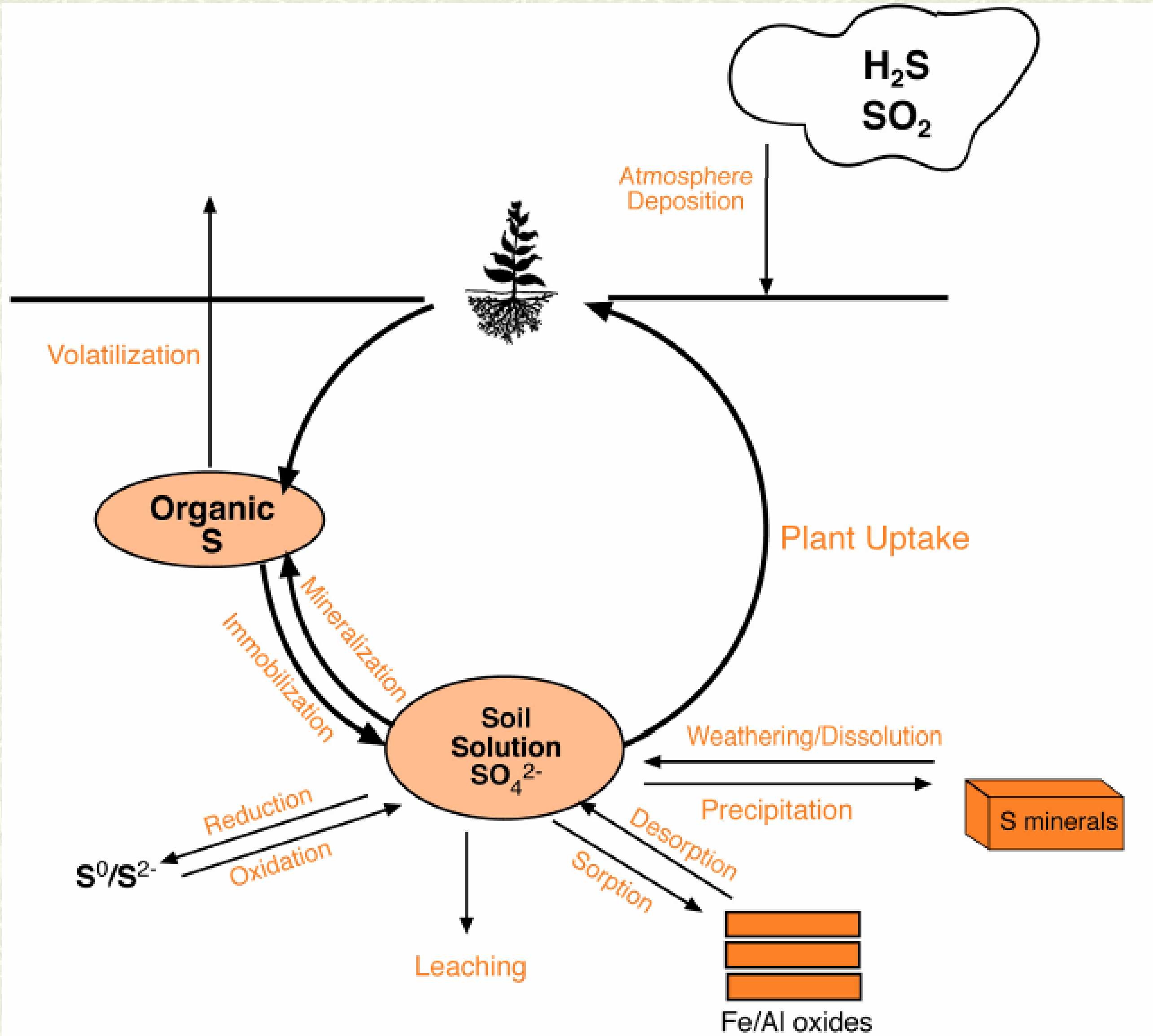
Effect of S on Protein in Wheat



Effect of S on Canola Seed Yield



Sulfur cycling



Questions so far?

Nutrient Deficiency Symptoms

Nutrients that are mobile in plant will affect lower leaves first

Mobile nutrients (in plant)

Nitrogen

Phosphorus

Potassium

Chloride

For nutrients that are sometimes deficient in Montana crops

Pseudo-deficiencies

What else can cause symptoms that look like nutrient deficiency symptoms?

1. Herbicides
2. Disease
3. Insects
4. Moisture stress
5. Salinity

How verify nutrient deficiency?

1. Soil Testing

2. Tissue Testing

3. Apply fertilizer test strip

What else would you look at other than shoot tissue?

1. Roots – healthy (white), distribution?
2. Soil – compacted, texture, moisture?
3. Distribution on field – near edges, patchy, in strips…?
4. ?

Factors decreasing N availability

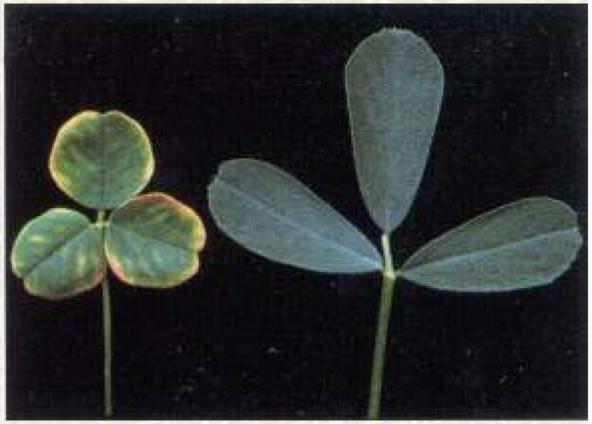
1. Low organic matter
2. Poor nodulation of legumes (ex: alfalfa)
3. Excessive leaching
4. Cool temperatures, dry

In general, N, especially nitrate, is very mobile in soil.

N Deficiency Symptoms

1. Pale green to yellow lower (older) leaves
   Why lower leaves? N is MOBILE in plant
2. Stunted, slow growth
3. Yellow edges on alfalfa

Alfalfa



Corn

Spring Wheat

Phosphorus (P)

Why often deficient in Montana soils?

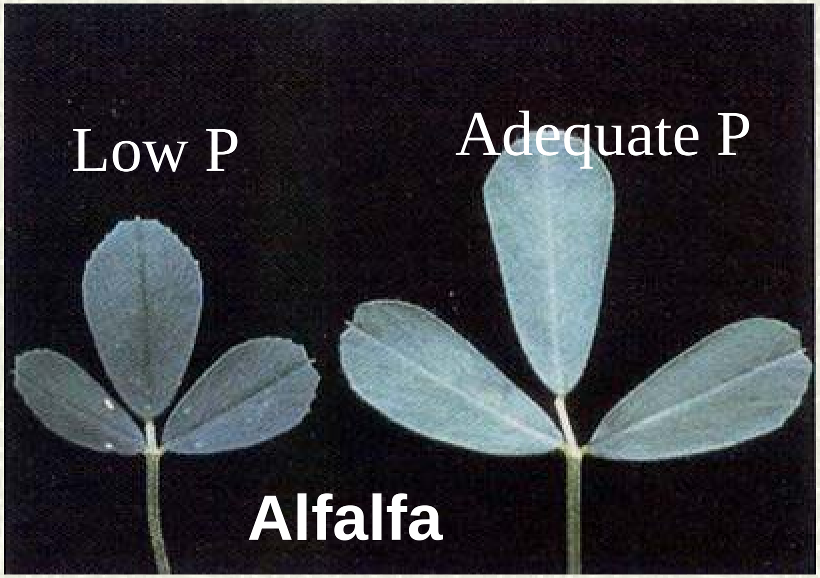
Binds with calcium to form poorly soluble calcium phosphate minerals

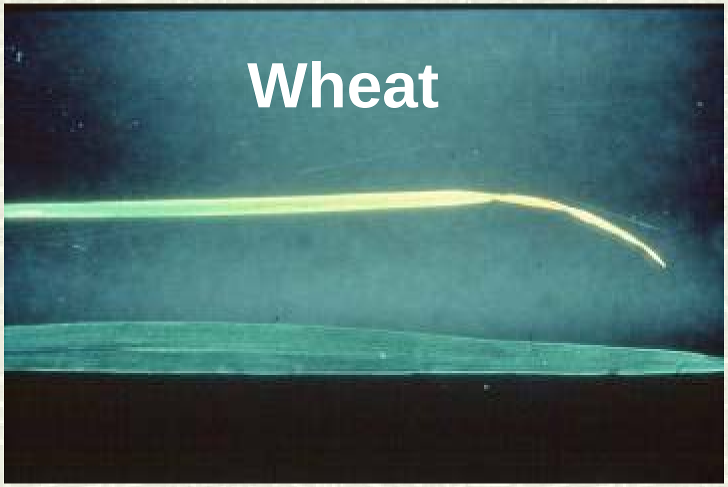
Factors decreasing P availability

1. Soil pH below 6.0 or above 7.5
2. Cold, wet weather
3. Calcareous soils
4. Leveled soils
5. Highly weathered, sandy soils

P Deficiency Symptoms

1. Dark green, often purple
2. Lower leaves sometimes yellow
3. Upward tilting of leaves may occur in alfalfa
4. Often seen on ridges of fields





Lettuce

Factors decreasing K availability

1. Cold, dry soils
2. Poorly aerated soils
3. High calcium and magnesium levels
4. Sandy, low clay soils
5. Low soil organic matter, or high amounts of available N

K deficiency symptoms

1. Alfalfa – white spots on leaf edges
2. Corn and grasses – chlorosis and necrosis on *lower* leaves first. WHY?

   K is mobile in plant

3. Weakening of straw-lodging in small grains, breakage in corn.

4. Wilting, stunted, shortened internodes.

Factors decreasing S availability

1. Irrigated with low S in irrigation water
2. Sandy, acidic, or low organic matter soils
3. Cold soils
4. Soils formed from minerals low in S or far from industrial sources

S deficiency symptoms

1. Upper leaves light green to yellow. WHY?

   S is immobile in plant
2. Small, thin stems
3. Low protein
4. Delayed maturity
5. No characteristic spots or stripes

Questions so far?

What nutrient is deficient?

SULFUR

Options: Nitrogen, Phosphorus, Potassium, Sulfur

What nutrient is deficient?

NITROGEN

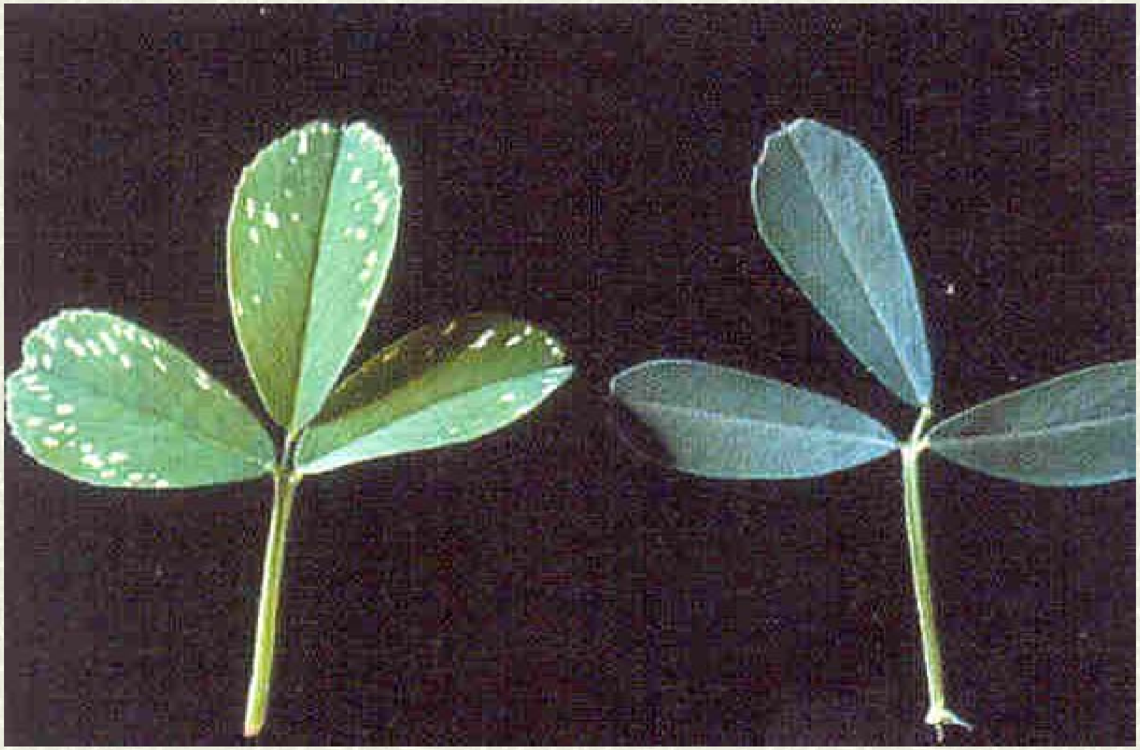
Options: Nitrogen, Phosphorus, Potassium, Sulfur

What nutrient is deficient?

PHOSPHORUS

Options: Nitrogen, Phosphorus, Potassium, Sulfur

What nutrient is deficient?



POTASSIUM

Options: Nitrogen, Phosphorus, Potassium, Sulfur

See Nutrient Management Module 11 for more info on Nutrient Deficiency Symptoms

Let’s take a 5 minute break

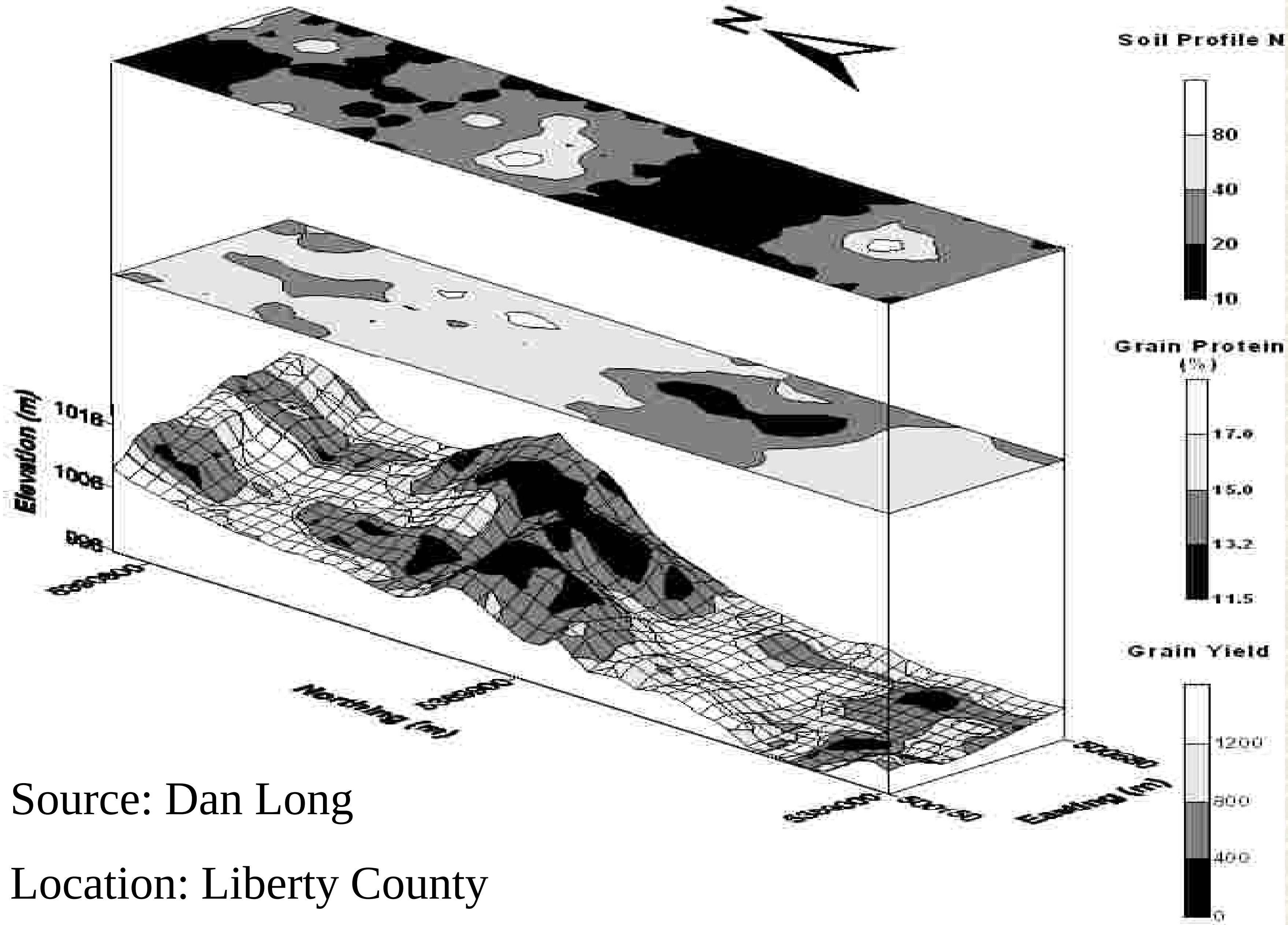
Soil Testing

Advantages of soil testing (even if only occasionally)

- Allows you to optimize fertilizer rates, especially in case where soil nutrient availability has been depleted or is in excess
- Can increase yield and/or save on fertilizer costs (which have gone up in last year)

Why are more samples better when it comes to soil sampling?

- Variability can be large!



Source: Dan Long

Location: Liberty County

Why is N tested to 2 feet and P and K to only 6 inches?

- N can easily move to 2 feet (and beyond) and the lower depths often have substantial amounts of N.
- P and K fertilizer generally stay in upper ½ foot and amounts are often very low below there.

What do ‘Olsen P’ and ‘soil test K’ mean on my lab results?

- They are measures of ‘plant-available’ P and K and are determined by adding extractants to the soil and measuring P and K in solution. The result is the sum of soluble nutrient PLUS weakly bound nutrient.

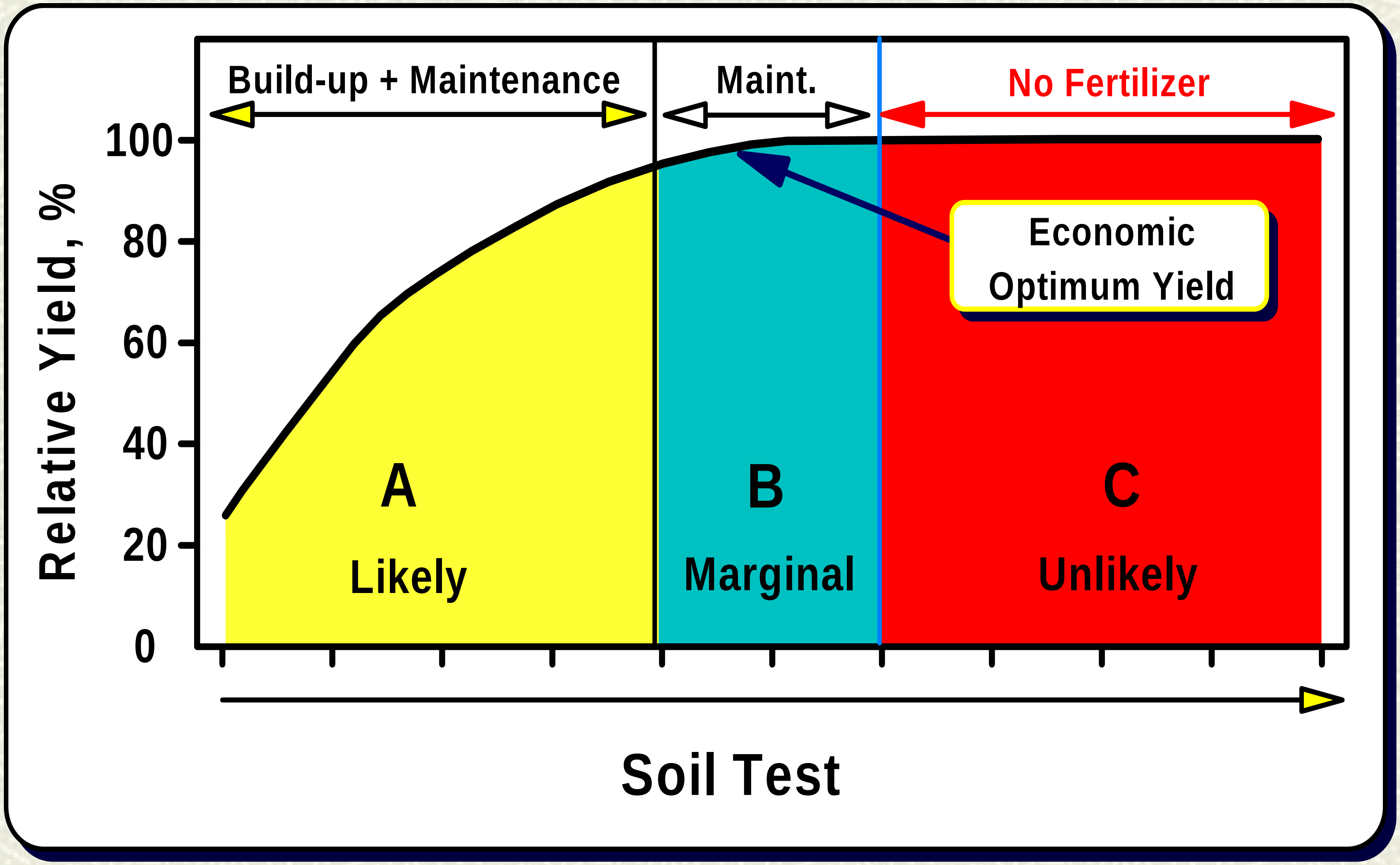
Why is ‘soluble’ N measured, rather than extracted like P and K?

- Nitrate-N is so soluble, that the concentration in solution is about equal to what is plant available (‘with N, what you see is what you get’).

Why is soluble N tested but a ‘soil test’ used for P and K?

- N fertilizer can easily move to 2 feet (and beyond) and these lower depths often have the majority of N.
- P and K fertilizer generally stay in upper ½ foot and are often very low below there.

Generalized Crop Yield Response Curve



FINALLY!!!!

- How do I determine N fertilizer amount?

First, need yield potential. How determine?

1. Average yield from past records, can be adjusted for soil moisture
2. Average yield x 1.05 (optimistic or realistic?)
3. From available water:

   Available water = April soil water + growing season rain

Determining Available Soil Water

- Generally done in late March to mid April
- Soil water depends on soil texture. How determine texture?

1. NRCS Soil map
2. Lab measurement
3. Hand texture

Texture-Available Water Relation

Soil texture	Water/moist ft. soil
Coarse (loamy fine sand)	1.25 in.
Moderately coarse (sandy loam)	1.5 in.
Medium (silt loam)	2.0 in.
Fine (clay, clay loam)	2.0-2.2 in.

<u>Example</u>

Texture: sandy loam
Moist soil depth (determined by Brown probe): 3 ft.

Soil water = (1.5 in./ft) x 3 ft.= **4.5 in**.

How determine depth of 'moist soil'?

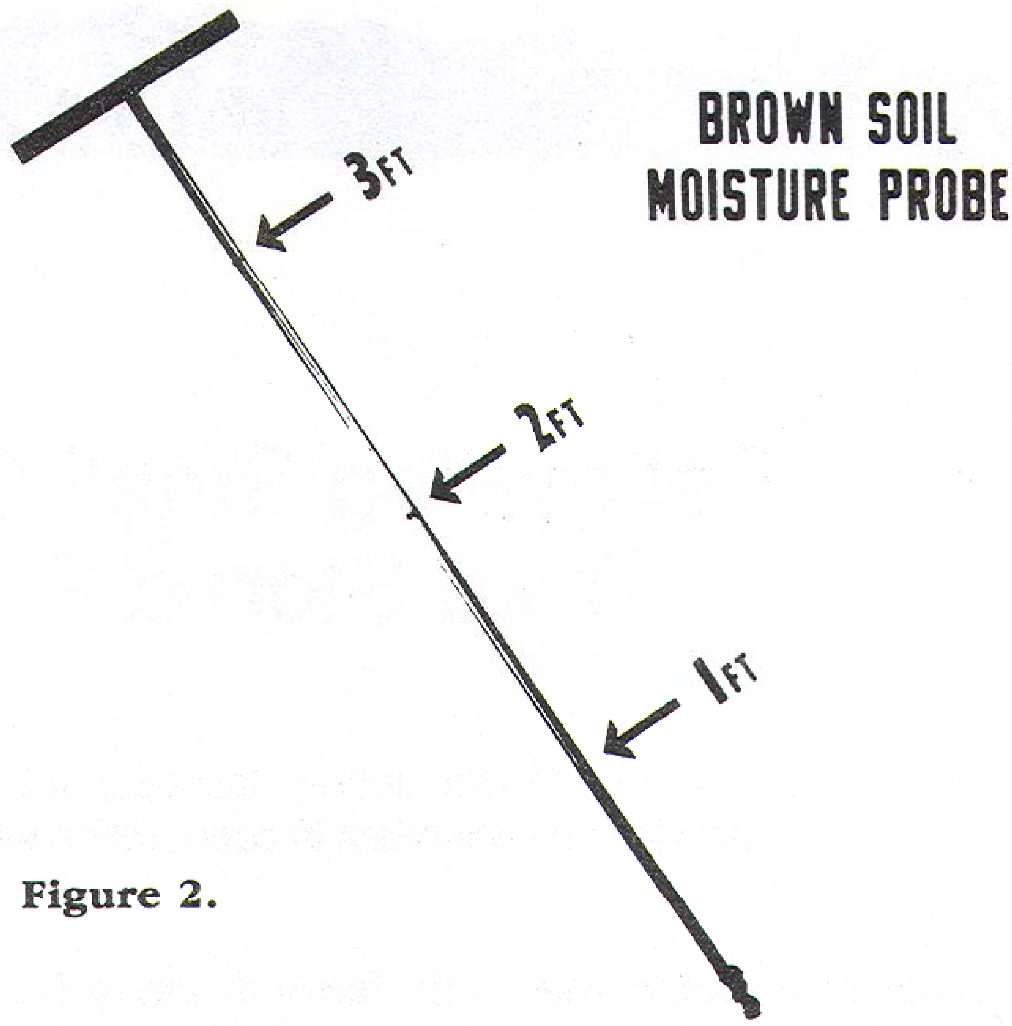


Figure 2.

Precipitation Maps

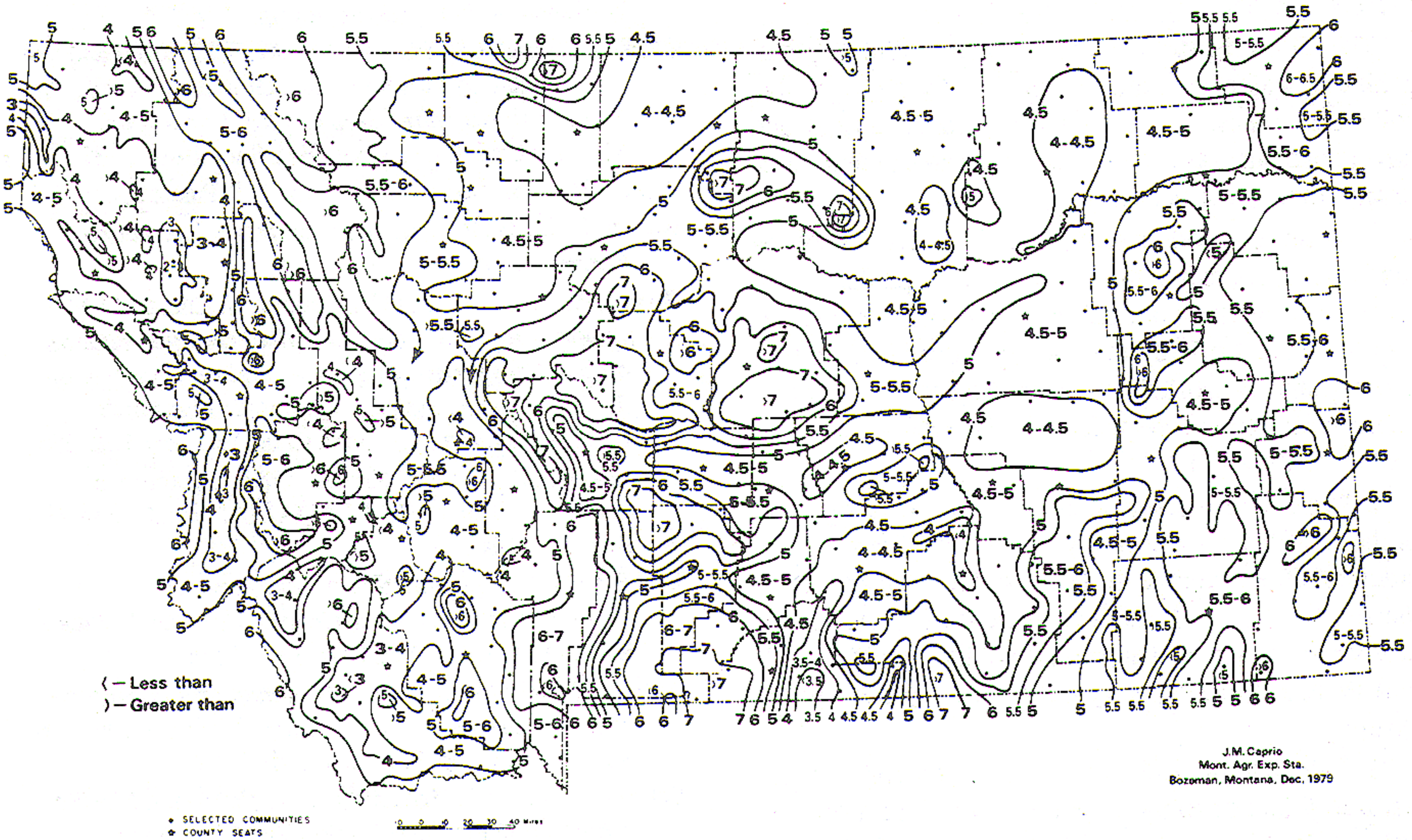


Figure 3. Amount of precipitation that is equalled or exceeded in 70 percent of the years May 1–July 31 (inches).

Plant-Available Water = April soil water + growing season rain

Table 4. Approximate yield of dryland winter wheat at several locations in Montana, based on estimates of stored soil water on April 15 and growing-season rainfall from April 15 until 3 weeks prior to harvest.

	Plant-Available Water (inches)*							
Location	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
	Yield Potential (bu/a)							
Bozeman	9	21	33	45	57	65	72	—
Conrad	9	20	31	42	52	61	—	—
Havre	9	20	31	42	52	61	—	—
Huntley	7	15	23	31	39	46	52	—
Kalispell	4	18	32	46	58	68	76	84
Moccasin	9	20	31	42	52	61	—	—
Sidney	7	17	27	37	47	55	62	—

**Plant-available water equals the sum of stored soil water (inches)to 4 feet in mid-April plus expected rainfall between April 1 and approximately July 15 (inches).*

From MontGuide 8325

Table 17. Spring and winter wheat N guidelines based on soil analysis.

WHEAT- SPRING***	
Yield Potential (bu/a) *	Available N (lbs/a) **
30	99
40	132
50	165
60	198
70	231
80	264
90	297
100	330

WHEAT- WINTER	
Yield Potential (bu/a)*	Available N (lbs/a) **
30	78
40	104
50	130
60	156
70	182
80	208
90	234

* Attainable yield with ***all*** growth factors optimized.
** Fertilizer N = Available N - soil analysis NO_3-N.
***Includes durum and hard red and hard white spring wheat at 13% and 14% protein, respectively.

EB 161: http://www.montana.edu/wwwpb/pubs/eb161.pdf

Special Conditions

- Drill-row applications of $N+K_2O$ should not exceed 20 lbs/a. When using urea as the N source, drill-row application of $N+K_2O$ should not exceed 10 lbs/a with a 6-7 inch row spacing. When using a wider row spacing, do not apply any urea with the seed. With newer drills and openers, the mixture of seed, fertilizer and soil is much greater, so more fertilizer can be placed in the "row" due to the dilution of potential detrimental impacts from salts and ammonia on germination and growth.
- If 14% protein is desired in winter wheat, use spring wheat guidelines.

WHEAT - WINTER	
Yield Potential (bu/a)*	Available N (lbs/a) **
30	78
40	104
50	130
60	156
70	182
80	208
90	234

Example

- Winter wheat
- Yield potential = 40 bu/ac
- Soil test N = 54 lbs/ac (top 2 ft.)

Fertilizer N = Available N – soil test N

Fertilizer N = 104 lbs/a – 54 lbs/a = **50 lbs/a**

If 50 lbs per acre of N needed, how much urea (46-0-0) is needed?

The 46-0-0 means this fertilizer is 46% N, 0% P_2O_5, and 0% K_2O. So the fraction of N in urea is 0.46 (46/100).

$$\text{N fertilizer} = \frac{(50\ \text{lbs/acre})}{0.46}$$

$$= \boxed{\textbf{109 lbs urea/acre}}$$

Phosphorus

Table 18. Phosphorus fertilizer guidelines based on soil analysis.

Crop	Olsen P Soil Test Level (ppm)				
	0	4	8	12	16*
	P Fertilizer Rate (lbs P_2O_5/a)				
Alfalfa	140	110	75	40	0
Alfalfa-Grass	55	50	40	25	10
Barley-Feed/Malt	50	40	30	20	10
Bean	30	25	20	15	5
Buckwheat	45	35	30	20	10
Canola	45	40	35	30	25
Corn-Grain	100	80	60	40	20
Corn-Silage	80	65	50	35	25
Flax	35	30	20	15	10
Grass	45	35	30	20	5
Lentil, Chickpea and Pea	35	30	25	20	15
Millet	40	35	25	20	5
Oat	45	35	30	25	20
Potato	170	145	115	75	20
Safflower	50	40	30	20	10
Soybean	60	50	40	25	5
Sugarbeet	85	70	55	40	10
Sunflower	35	30	25	20	15
Wheat-Spring	50	45	35	30	20
Wheat-Winter	55	50	45	40	35

Phosphorus

Crop	Olsen P Soil Test Level (ppm)				
	0	4	8	12	16*
	P Fertilizer Rate (lbs P_2O_5/a)				
Wheat-Spring	50	45	35	30	20
Wheat-Winter	55	50	45	40	35

Example

Winter wheat

Olsen P = 10 ppm

P_2O_5 needed = **42.5 lb/ac**

How much MAP (11-52-0) do you need to get 43 lb P_2O_5/ac?

The 52 means MAP is 52% P_2O_5 so fraction is 0.52

$$\text{MAP} = \frac{43 \text{ lb } P_2O_5/\text{ac}}{0.52}$$

MAP needed = $\boxed{\textbf{85 lb/ac}}$

Potassium table (Table 19) and calculations are essentially identical to P

Questions so far?

Your turn!!!

- Use Fertilizer Guidelines-Keep in mind these are guidelines-may need to adjust for your region and field history. (If you know you won't use again, <u>please</u> return)

Crop: Spring wheat

Yield pot. = 50 bu/ac

Soil N = 35 lb/ac
Olsen P = 14 ppm
Soil test K = 200 ppm

Nutrient	Amount (lb/ac)
Nitrogen	**130**
P_2O_5	**25**
K_2O	**40**

If you would rather use a web based calculator (avoids needing to interpolate), Montana fertilizer guidelines are at:

www.agry.purdue.edu/mmp/webcalc/fertrec.asp

Conventional vs. Air drills

- Conventional: place seed in a single narrow row (less than 3 inches)
- Air drills: can spread seed (and fertilizer) out by up to about 8 inches depending on opener

Biggest problem Grant Jackson has seen with air drills is planting seed too deep, reducing stand. Need to check seed depth for each seed row frequently.

Wide Band Width

What advantages can you think of for wide banding of seed?

Any disadvantages?

Narrow Band Width

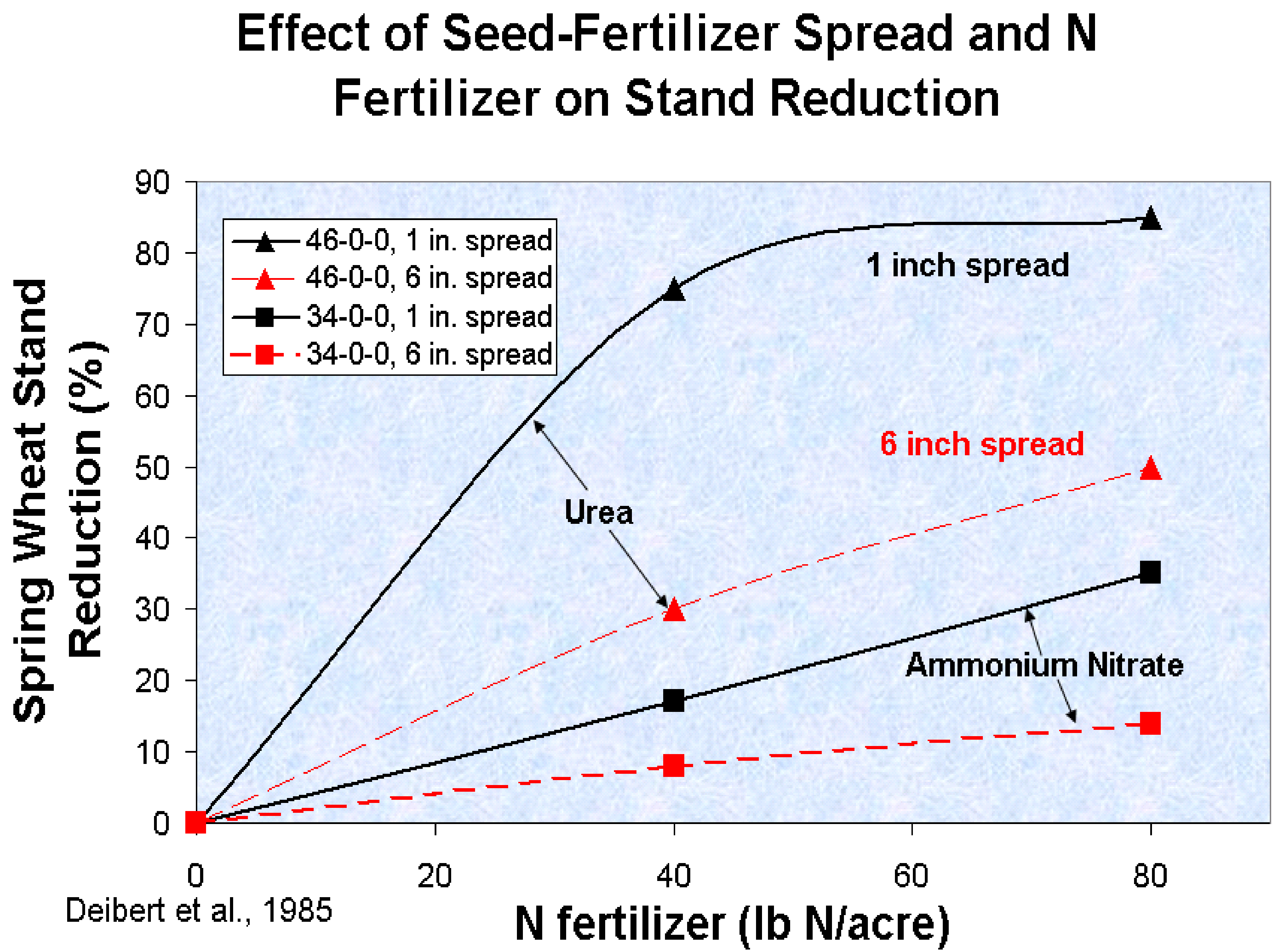
Deep Banding of Fertilizer near seed

- Advantage – fast uptake in spring
- Disadvantage– dry out soil and can cause poor germination

Solution: With low amounts of P (< 20-30 lb P_2O_5/ac, can place fertilizer <u>directly</u> with seed)

Effect of opener width on stand reduction

- Premise: Fertilizer is salty and can prevent germination if too close to seed
- A larger opener spreads out fertilizer, decreasing salt concentrations


Effect of Seed-Fertilizer Spread and N Fertilizer on Stand Reduction
Spring Wheat Stand Reduction (%)
90
80
70
60
50
40
30
20
10
0
46-0-0, 1 in. spread
46-0-0, 6 in. spread
34-0-0, 1 in. spread
34-0-0, 6 in. spread
1 inch spread
6 inch spread
Urea
Ammonium Nitrate
0
20
40
60
80
Deibert et al., 1985
N fertilizer (lb N/acre)

Conclusions

- Nitrogen is much more soluble and mobile than phosphorus and potassium.
- Nitrogen levels are largely dependent on breakdown of organic matter (and fertilizer).
- Phosphorus levels are low in Montana due to insoluble calcium-P minerals.
- Fertilizer needs can be determined if know soil test levels of N, P, and K, and yield potential.
- Air drills with large (> 6 in.) openers can increase yield due to less germination problems when fertilizer is applied with the seed, increased efficiency of fertilizer use, and decreased weed pressure.