SOIL NUTRIENT FUNDAMENTALS (SOIL FERTILITY 101)

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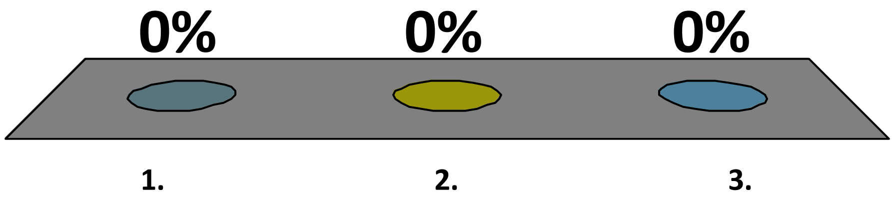
Objectives

- Present soil properties and how they interact with plant nutrients
- Illustrate the soil nutrient cycles of N, P, K, S and some micronutrients
- Understand plant available forms of nutrients and their relation to nutrient cycles

Why are clickers better than cell phones?

1. No monthly fee
2. They don’t ring in the middle of a talk
3. They never say “service not found”



Response Counter

An essential nutrient:

- Is required by plants to complete life cycle (seed to new seed)
- Cannot be replaced by another element
- Is directly involved in plant’s growth and reproduction
- Is needed by MOST plants

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

Plant nutrient uptake

- Plants obtain nutrients by direct root contact, mass flow (movement with water), or diffusion (random motion) - nutrient mobility influences placement and will be discussed later
- For plants to take up nutrients they need to be:
  - in the right form (soluble or weakly bound)
  - in soil solution

Available nutrient forms

+ Positive charge	- Negative/neutral charge
Ammonium - NH_4^+	Nitrate - NO_3^-
Potassium - K^+	Phosphate - $H_2PO_4^-$, HPO_4^{-2}
Calcium - Ca^{+2}	Sulfate - SO_4^{-2}
Magnesium - Mg^{+2}	Chloride – Cl^-
Iron – Fe^{+2}, Fe^{+3}	Borate – H_3BO_3, $H_2BO_3^-$, $B_4O_7^{-2}$
Zinc – Zn^{+2}	Molybdate – MoO_4^{-2}
Manganese – Mn^{+2}, Mn^{+4}	
Copper – Cu^{+2}	
Nickel – Ni^{+2}	

For now notice the + and -. This relates to mobility in the soil.

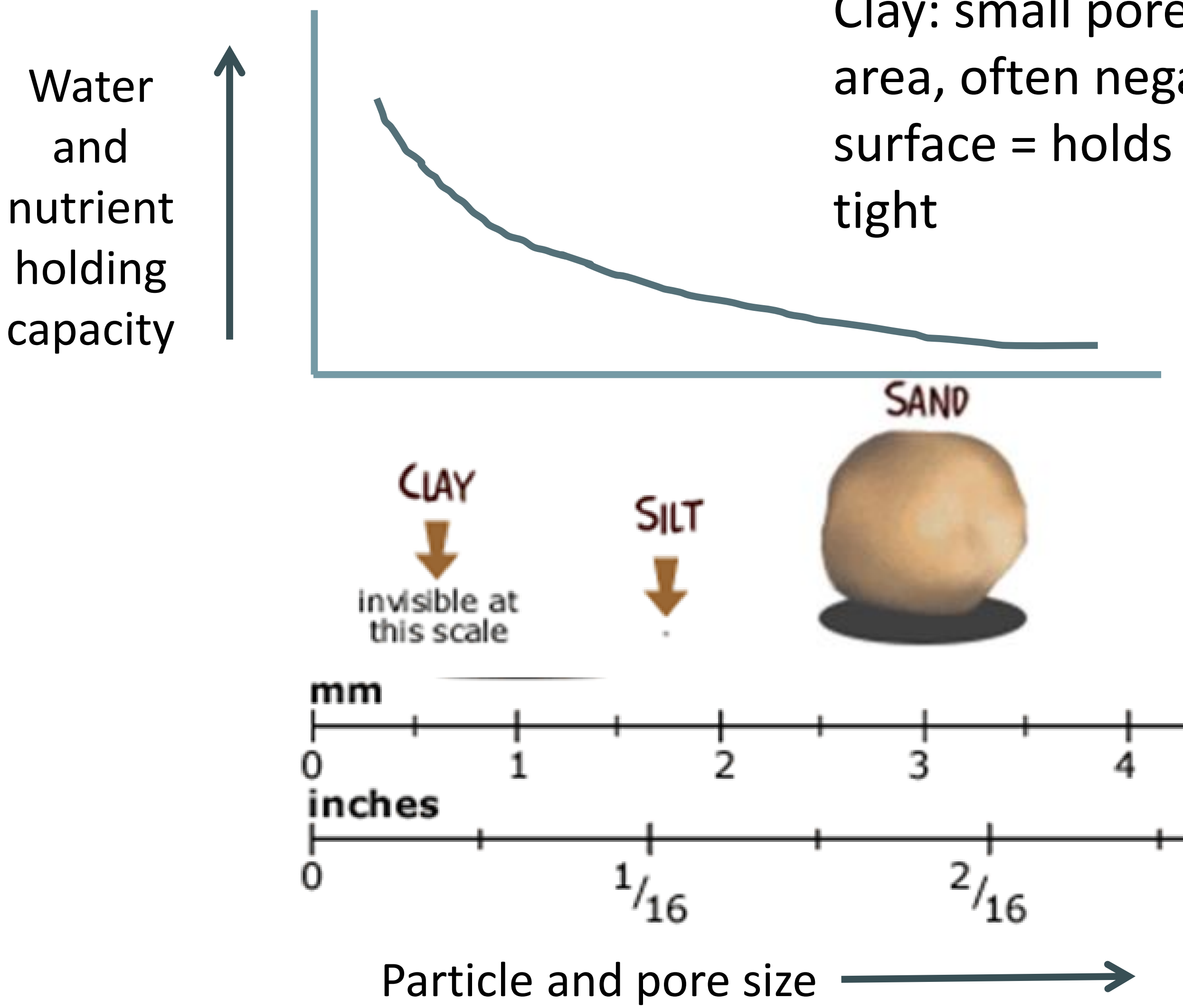
Soil properties that influence nutrient availability

- Texture/surface area
- CEC (cation exchange capacity) and AEC (anion exchange capacity)
- SOM (soil organic matter)
- pH

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

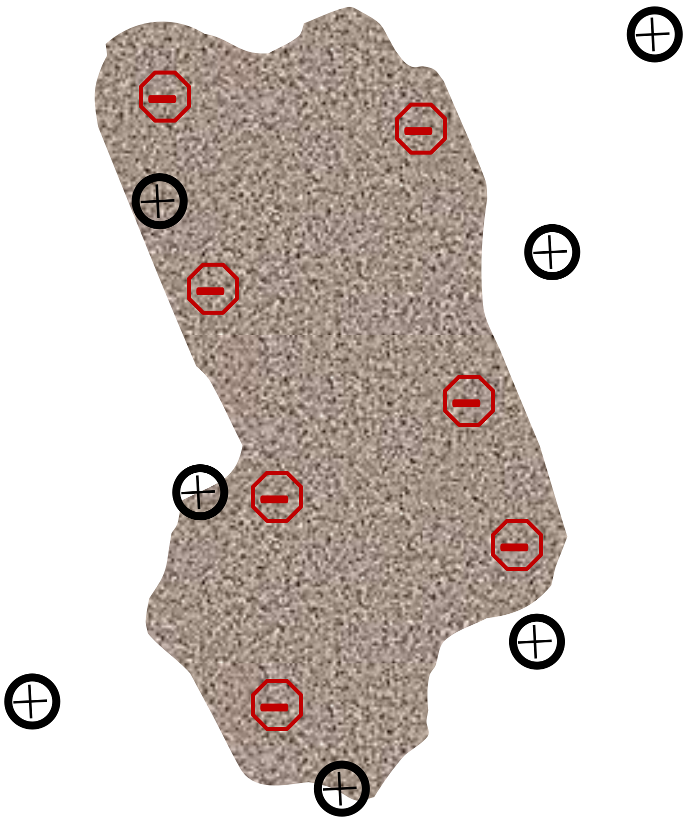


CEC and AEC

- Cation Exchange Capacity (CEC) - Total negative charge on a soil
- A measure of the soil’s ability to hold onto and supply positive ions (e.g. NH_4^+) to a crop.
- Anion Exchange Capacity (AEC) – Total positive charge to hold onto nutrient anions such as SO_4^{-2}
- Generally weak bonds that release as concentration of nutrient in solution drops
- AEC is generally smaller than CEC.

Which nutrients are soils better able to hold onto?

1. Cations, + charge 25%
   e.g. NH_4^+
2. Anions, - charge 25%
   e.g. NO_3^-
3. Neutral 25%
   e.g. H_3BO_3
4. The sticky ones 25%
   e.g. honey

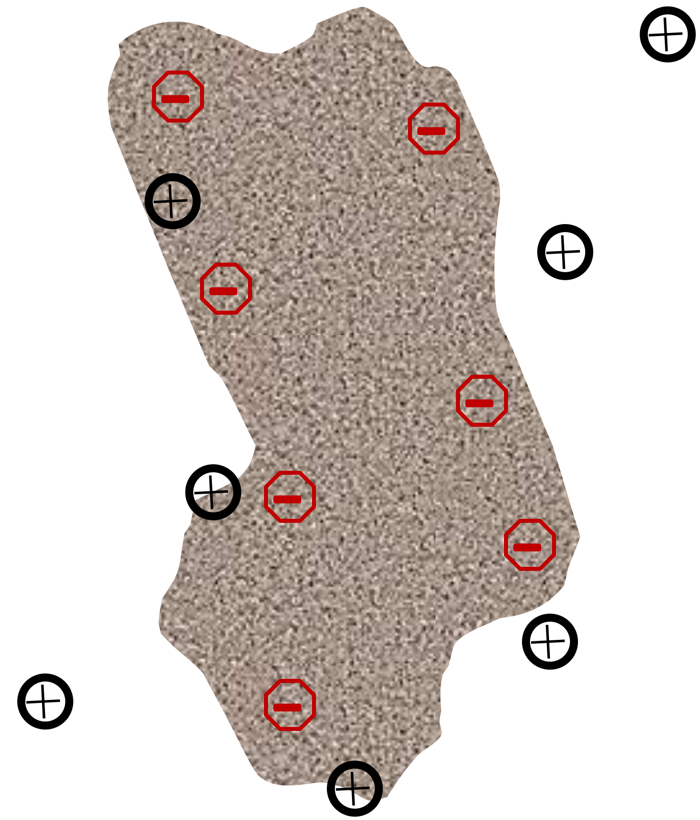


Response Counter

CEC is generally >> AEC

Cation Exchange Capacity

- Many essential plant nutrients carry positive charges. Example: Potassium (K^+) and Zinc (Zn^{+2})
- A fertile soil has the capacity to attract and hold these nutrients.
- Soils with large surface areas, such as clay and O.M., have more CEC and surface area and therefore are generally more fertile.



CEC ranges for different soil types

Soil texture	CEC range (meq/100 g soil)
Sand	2-4
Sandy loam	2-17
Loam	8-16
Silt loam	9-26
Clay	5-58
From Brady 1984	

A CEC >15 meq/100 g soil has high capacity to hold cations such as K^+, NH_4^+

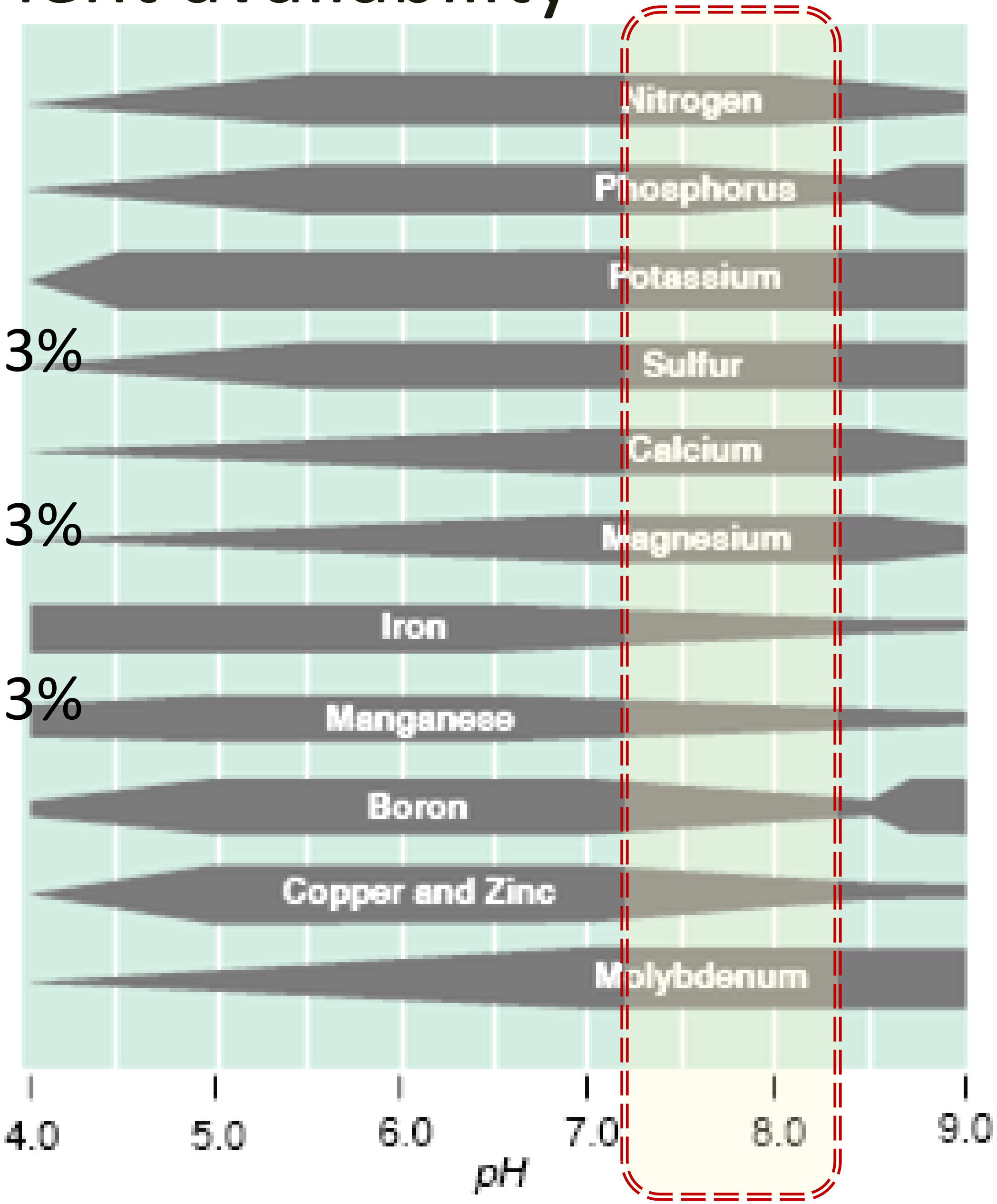
pH

- Generally high in MT soils
- Can decrease with elemental sulfur, but likely not economical
- Fertilizing with ammonia-based fertilizer can lower pH over time
- If low then consider liming but seldom necessary here
- Crops have different optimum pH ranges, e.g. alfalfa 6.2-7.5, barley 5.5-7.0, sugarbeet 6.5-8.0

pH affects soil nutrient availability

Most Montana soils are:

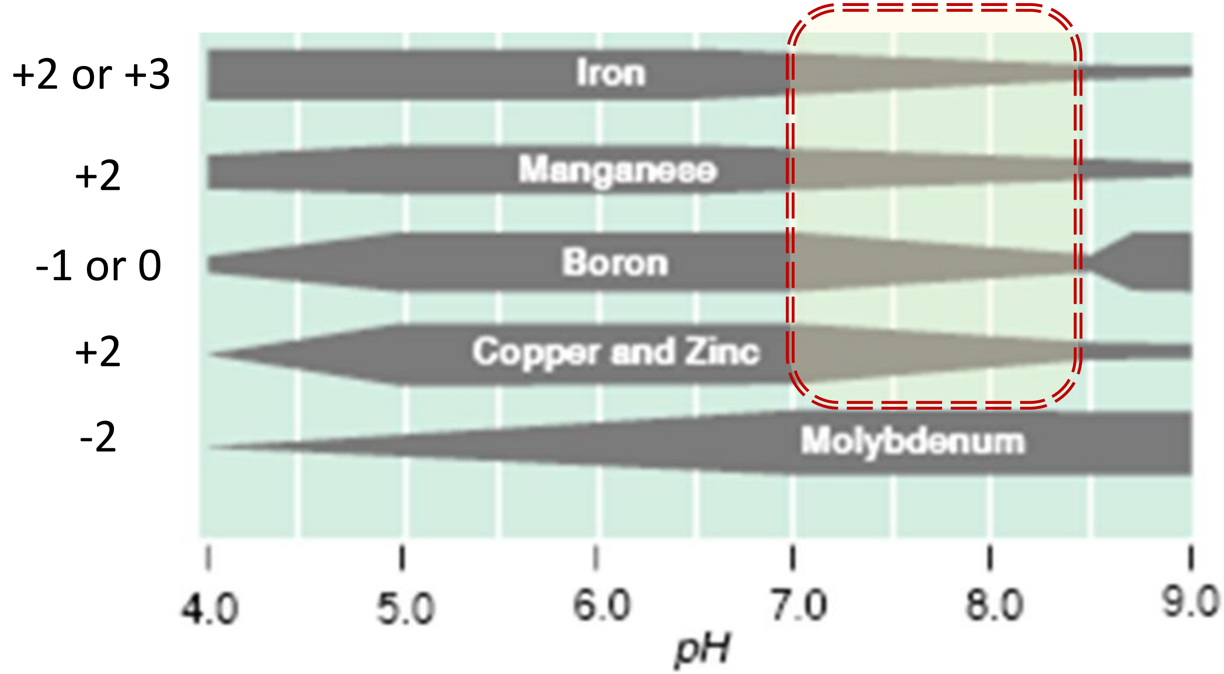
1. Generally alkaline (pH > 7.0) — 33%
2. Generally acidic (pH < 7.0) — 33%
3. “Gumbo” = too difficult to sample — 33%



Response Counter

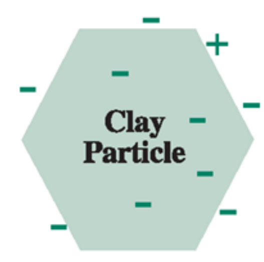
pH affects soil nutrient availability

These are relatively small ions when in soluble form – strong charge density (small balloon sticks to wall easier)



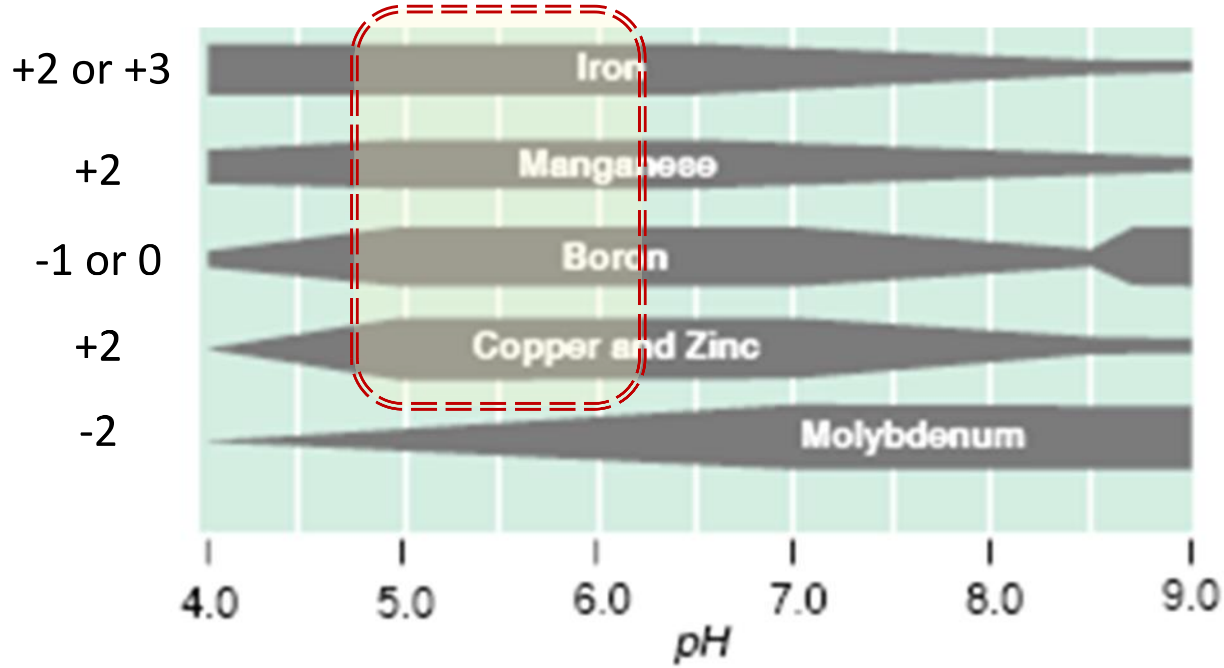
How tightly are they bound to soil in high pH?

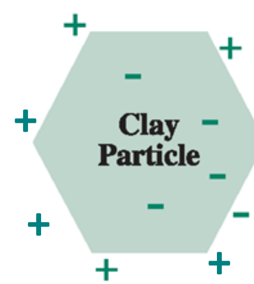
So strong they are not very plant available.



pH affects soil nutrient availability

What happens when they are in a lower pH?

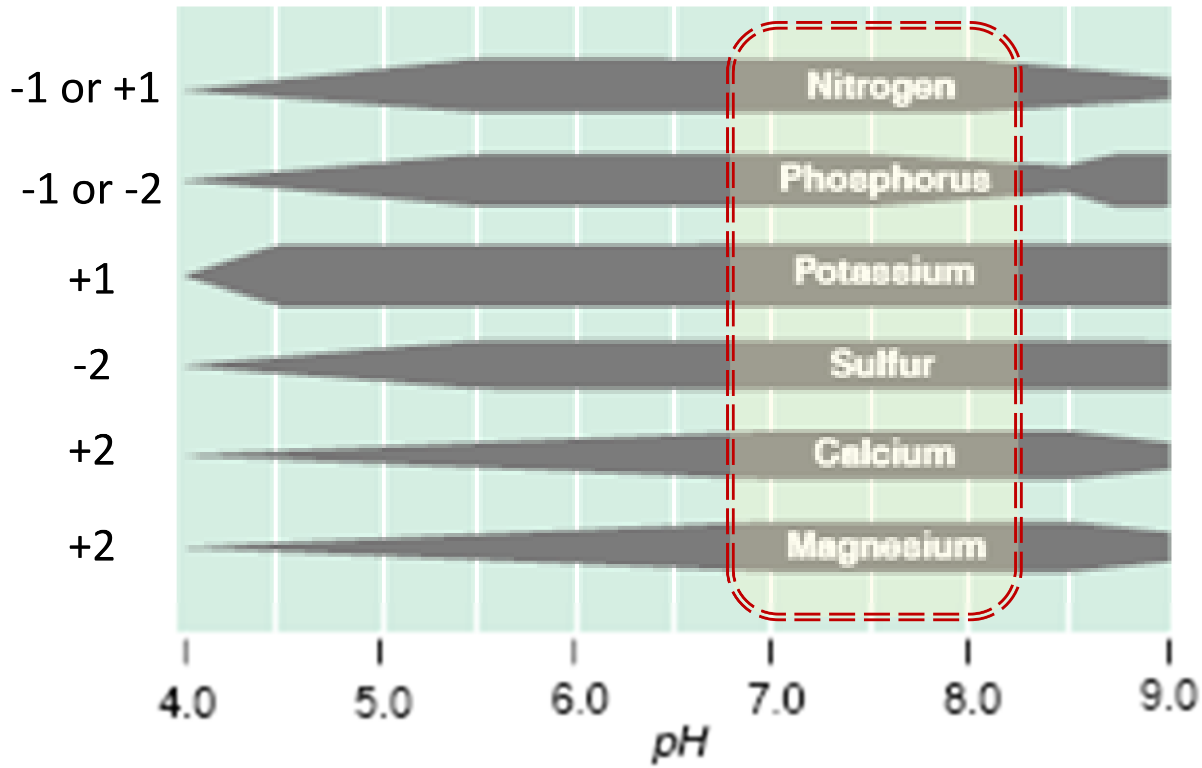




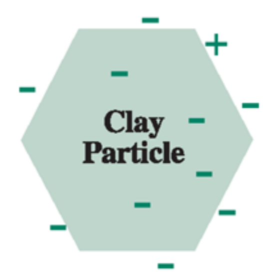
The bonds weaken, they become more available

pH affects soil nutrient availability

These are relatively large ions when in soluble form – even if +, the charge density is weak



Compare to metals, are they tightly or loosely bound to soil in high pH?



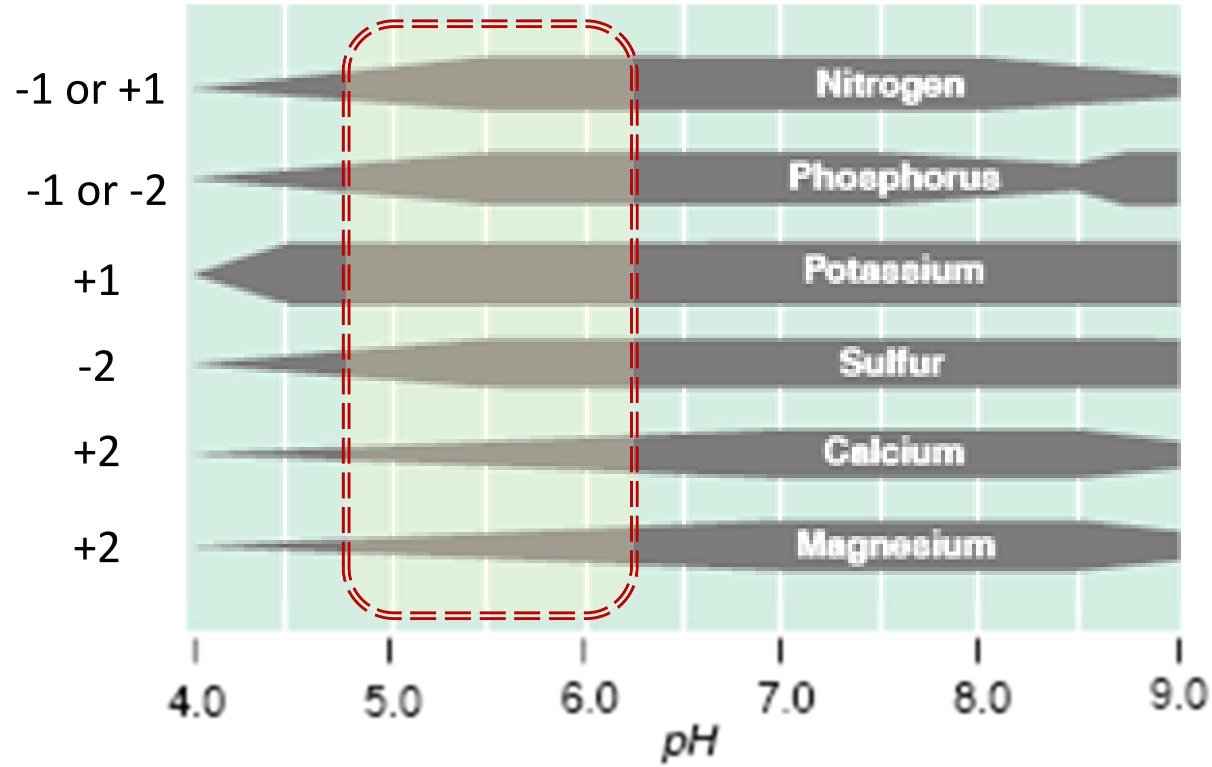
pH affects soil nutrient availability

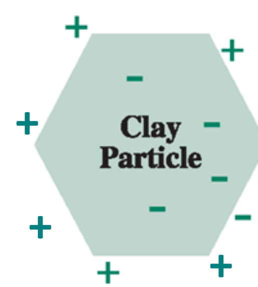
What happens when they are in a lower pH?

They let go!

Then what?

They can be leached from the soil and therefore no longer available!





SOM = Soil organic matter

- Is <6% of soil by weight but controls >90% of the function
- High surface area and CEC (215 meq/100 g vs. 58 for clay)

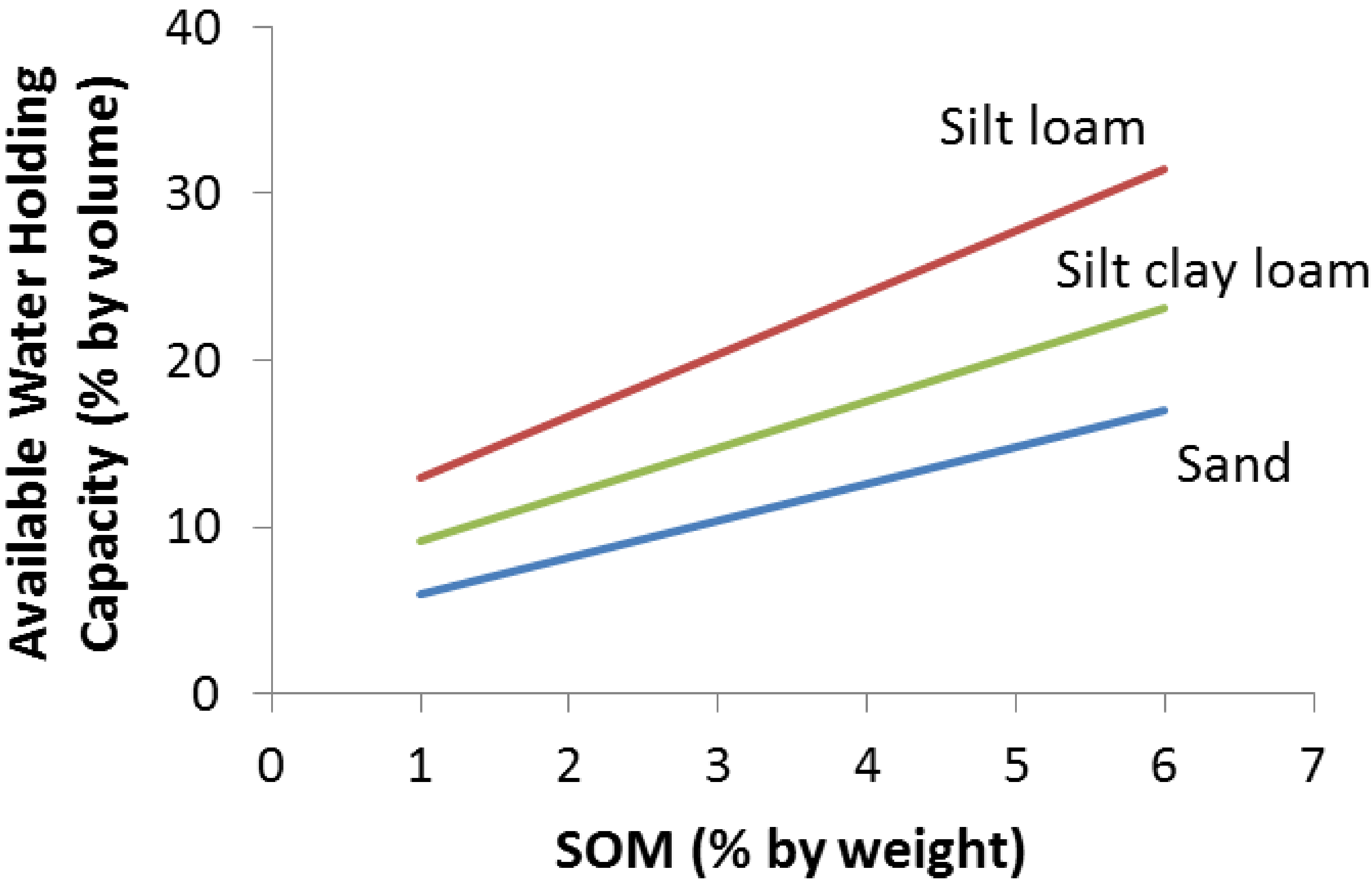
What does SOM do for soil?

- Increase CEC
- Can't change CEC of mineral soil or soil pH very well, but can increase SOM to influence soil CEC

What else does SOM do for soil?

- As decomposes it releases nutrients bound in OM structure
- Holds water which helps nutrients move from soil to plant roots

SOM increases available water holding capacity



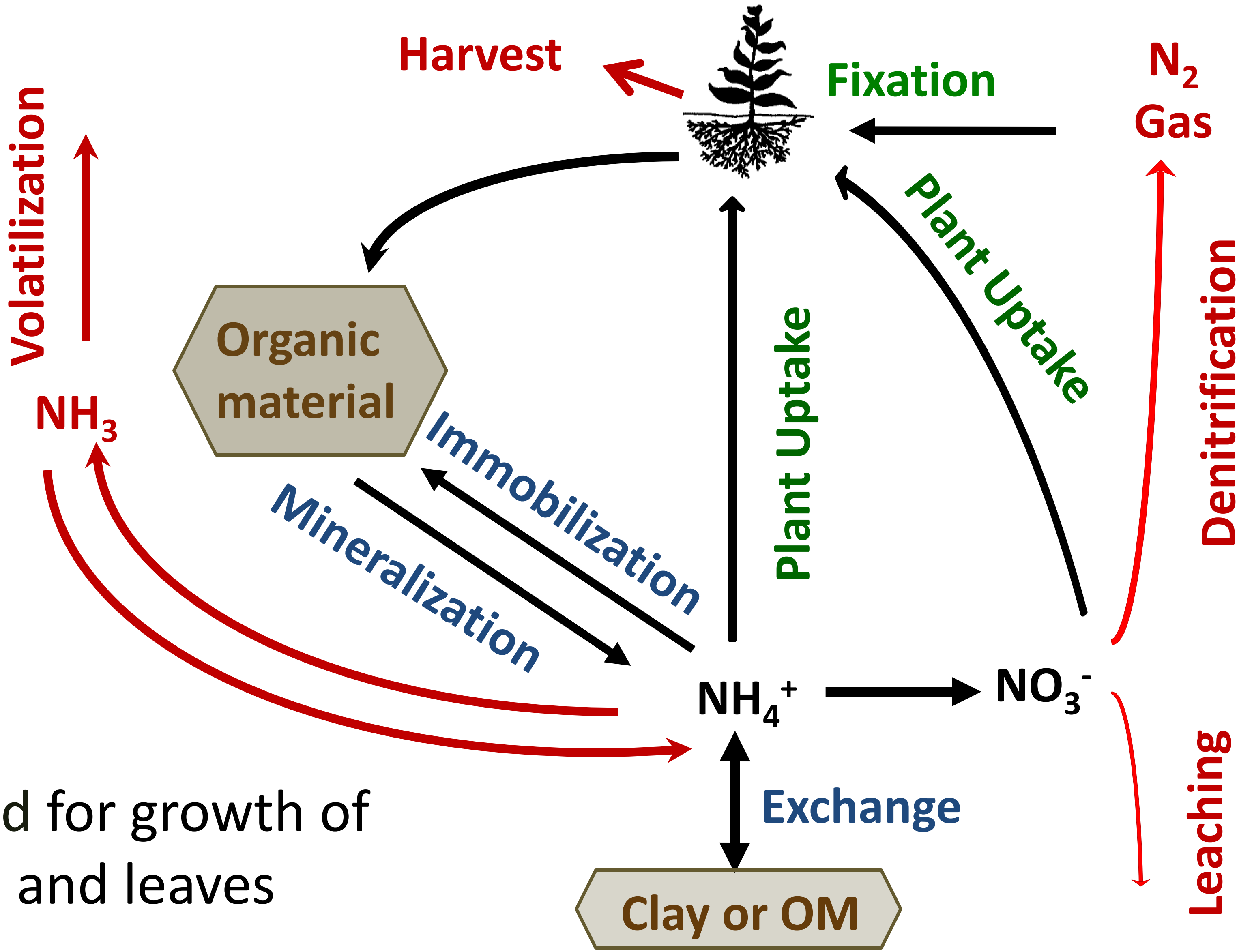
Hudson 1994

Questions?

Nutrient cycling

Some knowledge helps understand the whys of source, rate, timing and placement. Even my research associate still refers to nutrient cycling diagrams for clarity ☺

Most common lacking nutrient is nitrogen (N)



Needed for growth of shoots and leaves

Mineralization

Decomposition of SOM by microbes, releasing available N

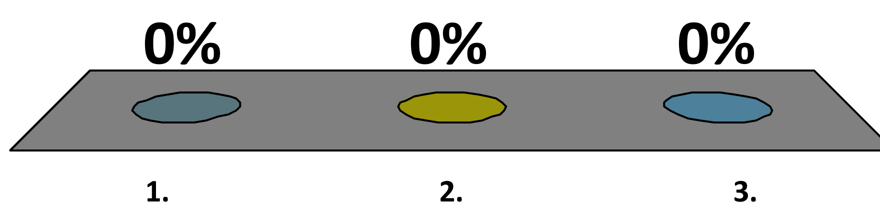
Organic-N → Plant-Available N

How does high SOM affect recommended fertilizer N rate assuming yield goal is same?

1. Increases N rate
2. SOM becomes PAN becomes IUO
3. Decreases N rate

SOM supplies N

Response Counter



Immobilization

Incorporation of available N into microbial cells or plant tissue

Plant-Available N → Organic-N

Why need to know about it?

- Crop residue gives microbes energy source
- Microbes use plant available N
- We need to provide more N for crop

Is immobilized N lost from the system? Yes/No?

No – just temporarily unavailable to plants

Questions on N cycle?

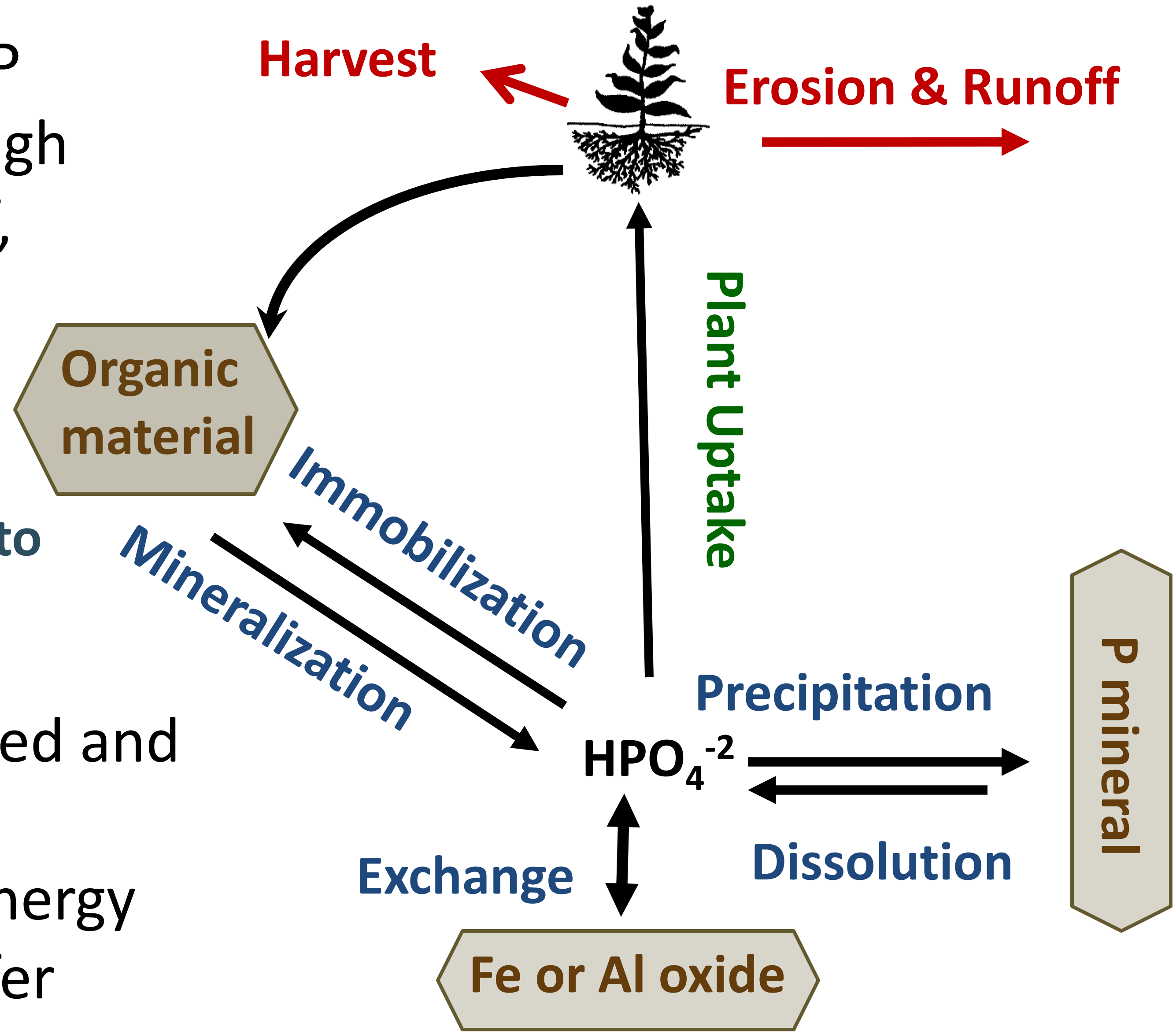
References for more information are provided at end of this ppt.

Phosphorus (P)

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

P binds strongly to soil

Needed for seed and fruit ripening, maturation, energy storage/transfer



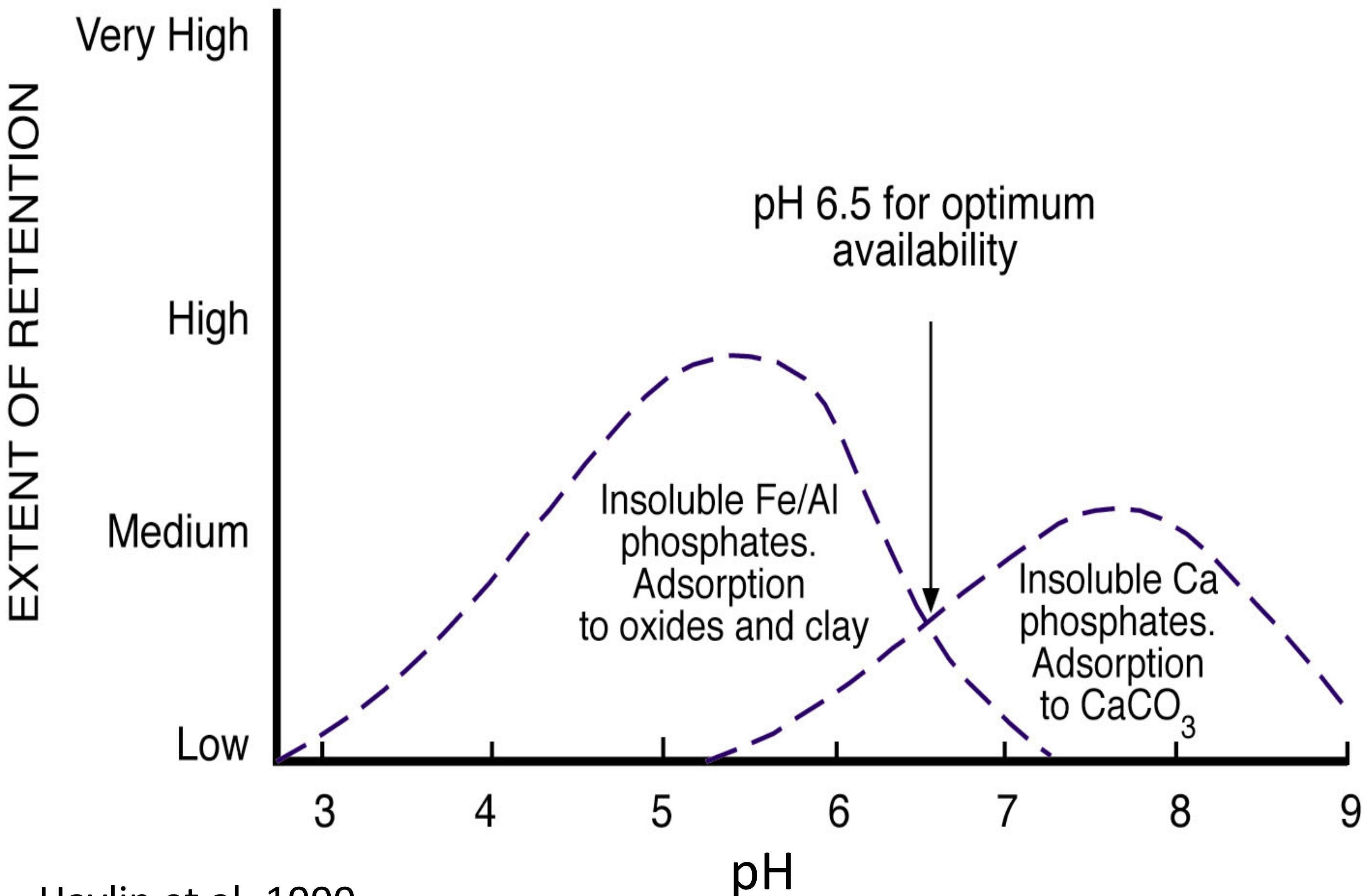
Soluble P concentrations in soil are generally very low (0.01 – 1 mg/L) due to:

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

- 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?

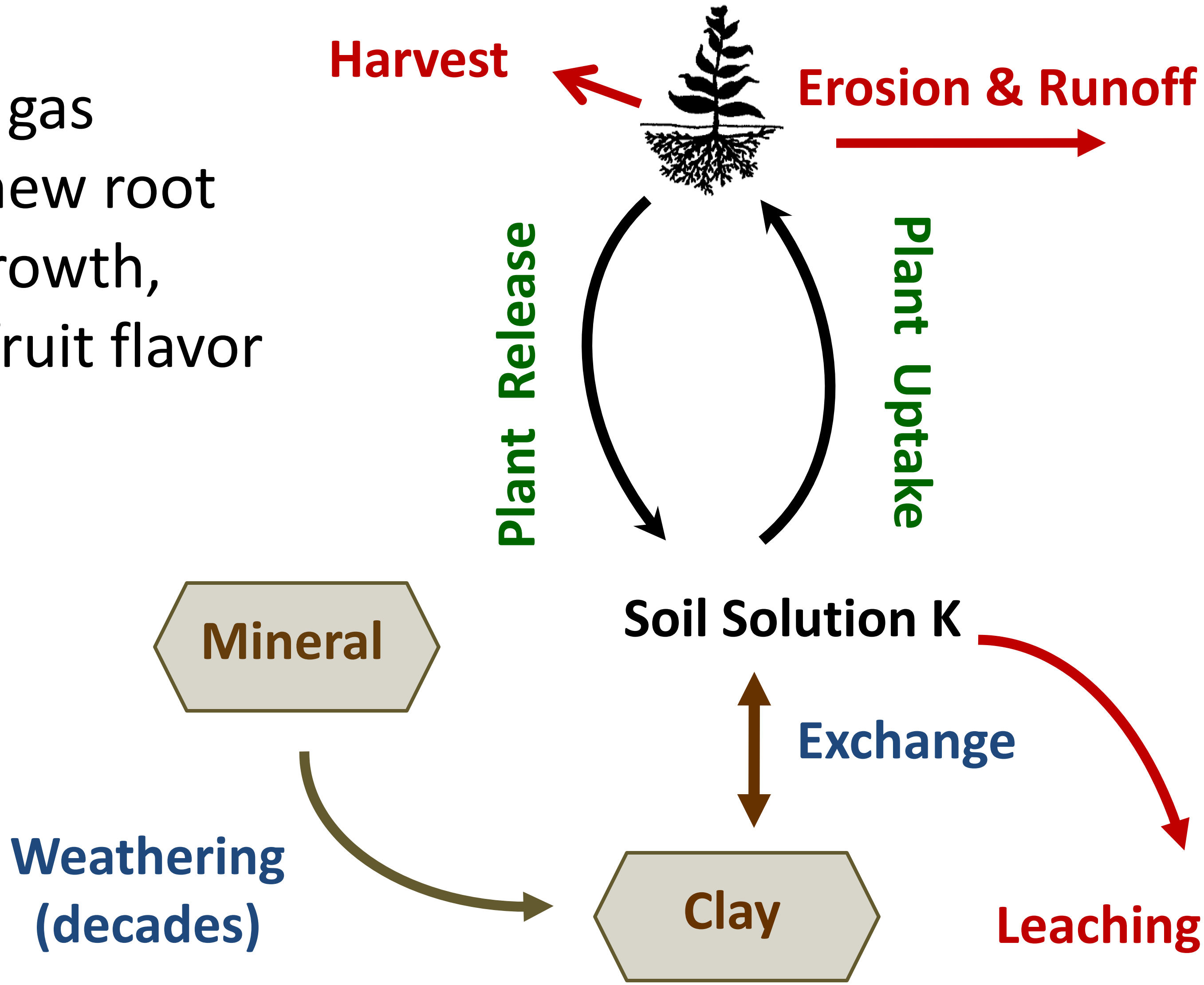
Effect of soil pH on soil P retention and plant availability



Havlin et al.,1999

Potassium (K)

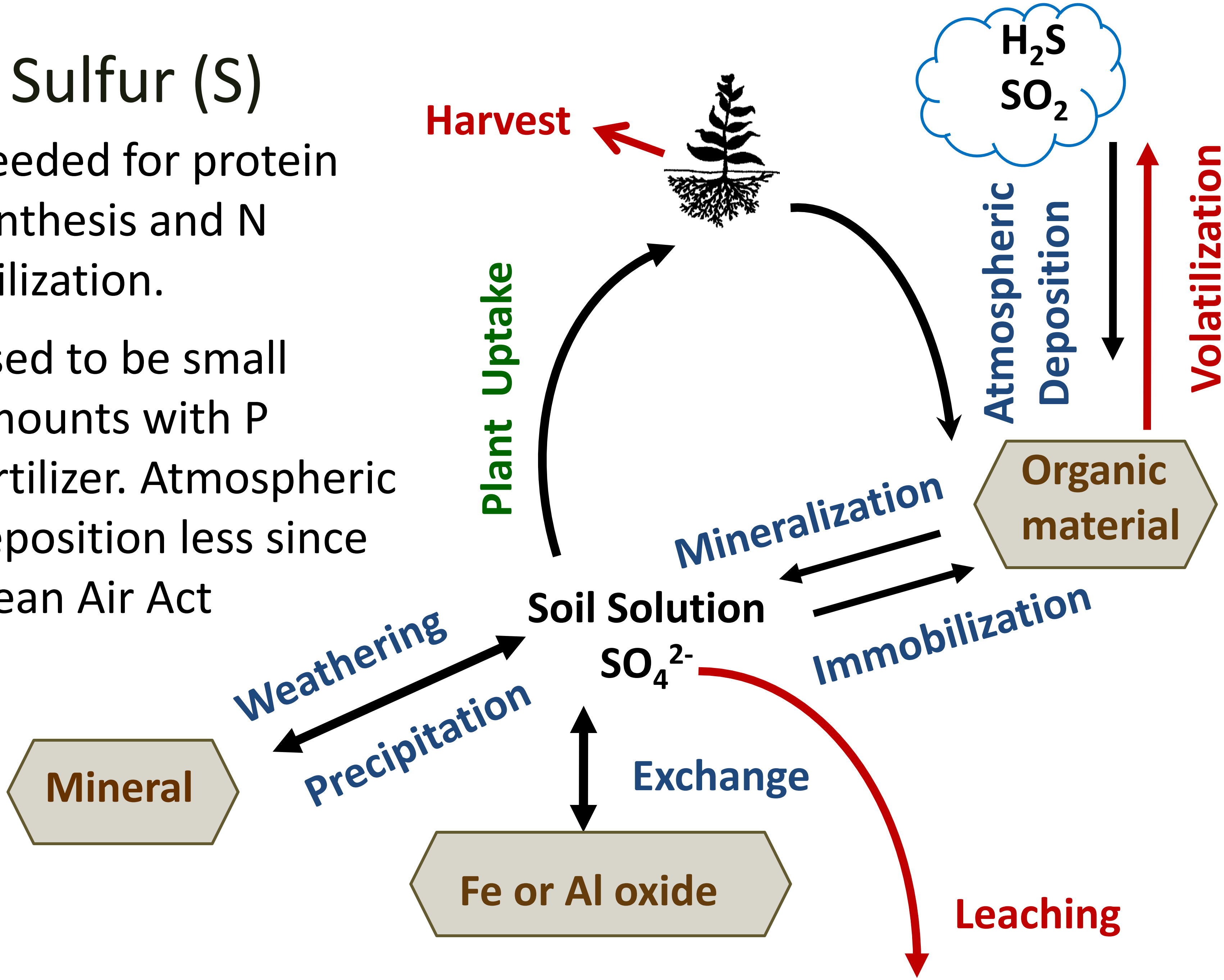
Needed for gas exchange, new root and stem growth, hardiness, fruit flavor and color



Sulfur (S)

Needed for protein synthesis and N utilization.

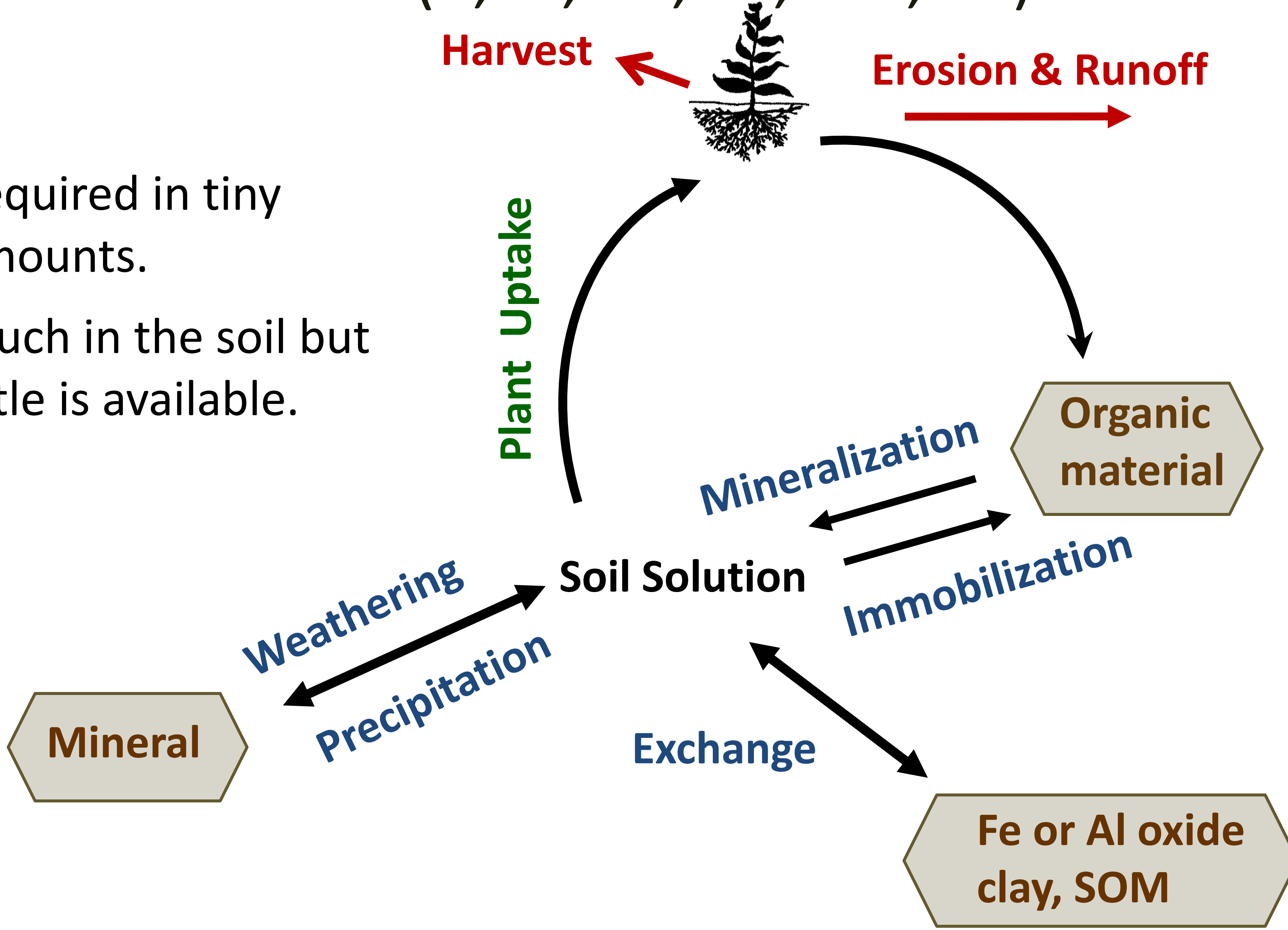
Used to be small amounts with P fertilizer. Atmospheric deposition less since Clean Air Act



Micronutrients (B, Cl, Cu, Fe, Mn, Zn)

Required in tiny amounts.

Much in the soil but little is available.



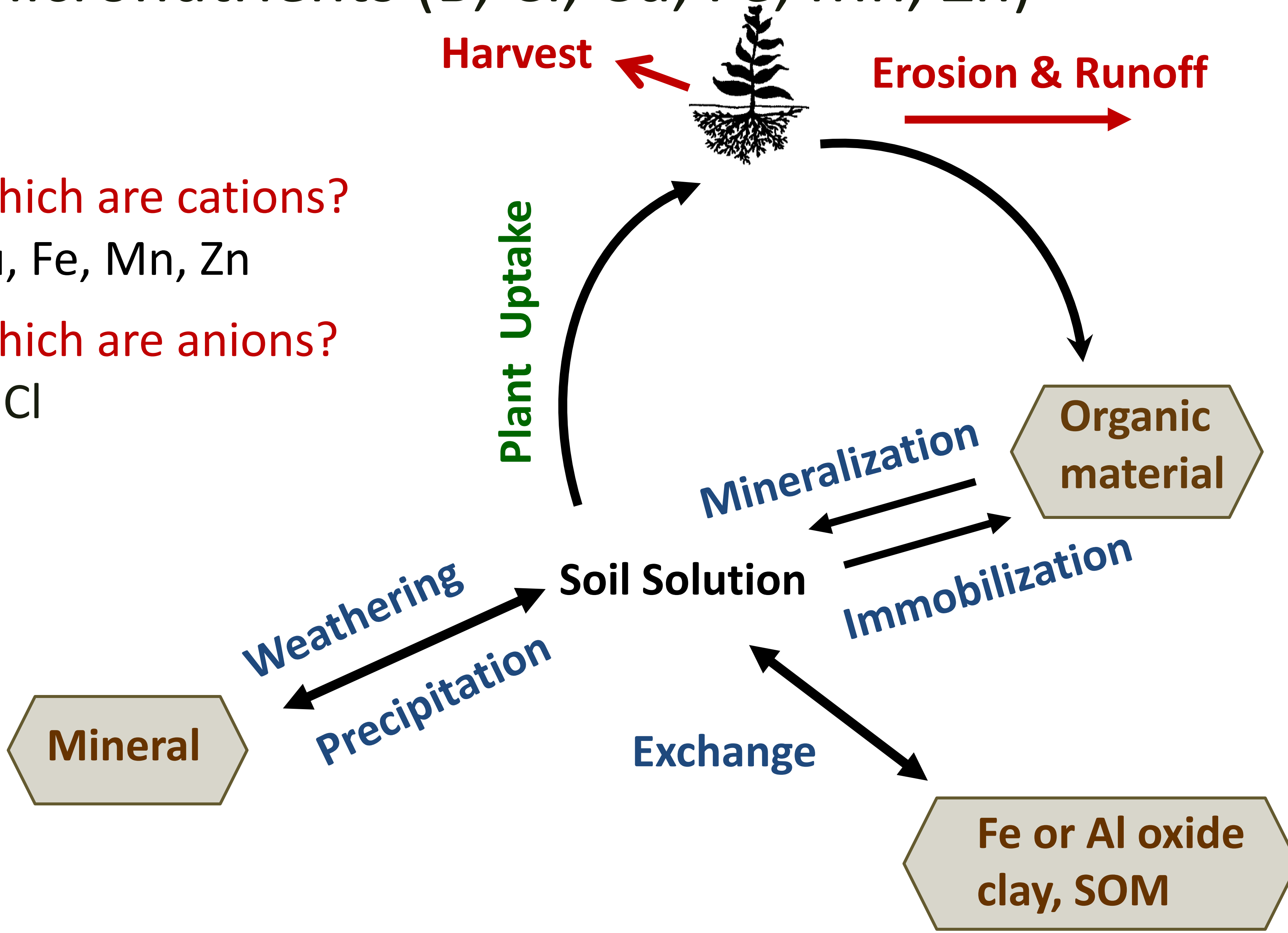
Micronutrients (B, Cl, Cu, Fe, Mn, Zn)

Which are cations?

Cu, Fe, Mn, Zn

Which are anions?

B, Cl

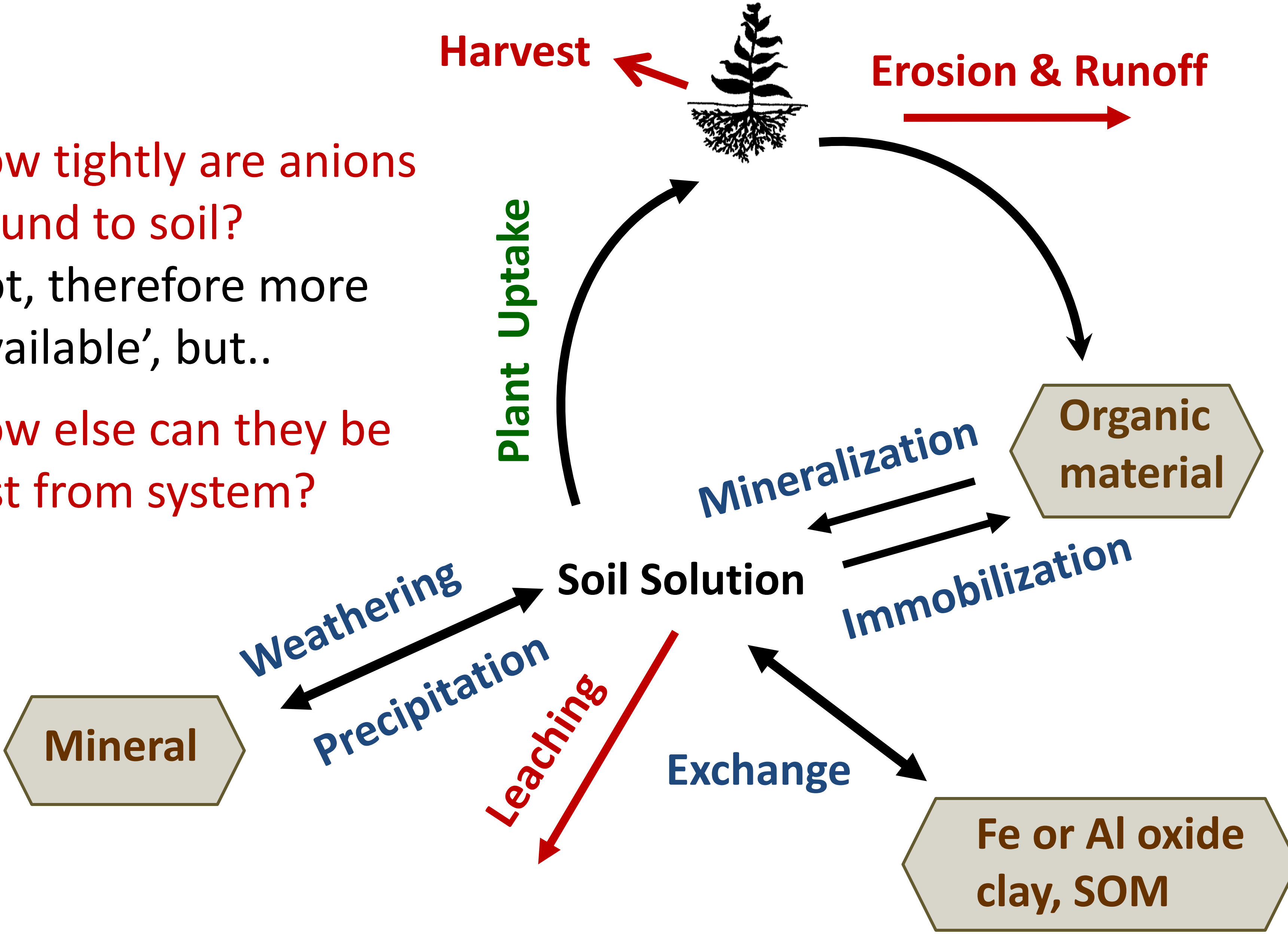


Micronutrients – anions B and Cl

How tightly are anions bound to soil?

Not, therefore more ‘available’, but..

How else can they be lost from system?



Summary

- Nutrients need to be in the right form to be plant available
- Nutrients cycle among different forms in the soil
- Soil characteristics influence nutrient availability
- Many soil properties cannot readily be changed by management
- Soil organic matter is one that can be changed and has large impact on soil nutrient availability

Questions?

For more information see MSU Extension's

Nutrient Management Modules: http://landresources.montana.edu/nm/

- NM2 Plant nutrition & soil fertility
- NM3 Nitrogen
- NM4 Phosphorus
- NM5 Potassium
- NM6 Sulfur (and Ca, Mg)
- NM7 Micronutrients
- NM8 Soil pH and SOM

Soil & Water Management Modules: http://landresources.montana.edu/SWM/

- SWM1 Basic soil properties