# Basic Soil Fertility

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## Urban Nutrient Management Handbook: Chapter 4.

http://pubs.ext.vt.edu/430/430-350/430-350.html

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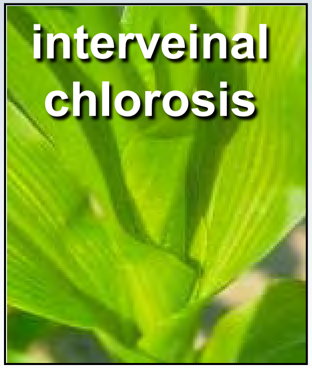
Department of Crop and Soil Environmental Sciences

# The eighteen essential elements for plant growth

| Element | Symbol | Form Absorbed by Plants |
|---|---|---|
| Carbon | C | $CO_2$ |
| Hydrogen | H | $H^+$, $OH^-$, $H_2O$ |
| Oxygen | O | $O_2$ |
| Nitrogen | N | $NH_4^+$, $NO_3^-$ |
| Phosphorus | P | $HPO_4^{2-}$, $H_2PO_4^-$ |
| Potassium | K | $K^+$ |
| Calcium | Ca | $Ca^{2+}$ |
| Magnesium | Mg | $Mg^{2+}$ |
| Sulfur | S | $SO_4^{2-}$ |
| Iron | Fe | $Fe^{2+}$, $Fe^{3+}$ |
| Manganese | Mn | $Mn^{2+}$, $Mn^{4+}$ |
| Boron | B | $H_3BO_3$, $BO_3^-$ , $B_40_7{}^{2-}$ |
| Zinc | Zn | $Zn^{2+}$ |
| Copper | Cu | $Cu^{2+}$ |
| Molybdenum | Mo | $MoO_4^{2-}$ |
| Chlorine | Cl | $Cl^-$ |
| Cobalt | Co | $Co^{2+}$ |
| Nickel | Ni | $Ni^{2+}$ |

# Terminology used to describe deficiency symptoms

| Term | Definition |
|---|---|
| *Chlorosis* | Yellowing or lighter shade of green |
| *Necrosis* | Browning or dying of plant tissue |
| *Interveinal* | Between the leaf veins |
| *Meristem* | The growing point of a plant |
| *Internode* | Distance of the stem between the leaves |
| *Mobile* | A mobile element is one that is able to *translocate*, or move, from one part of the plant to another depending on its need. Mobile elements generally move from older (lower) plant parts to the plant's site of most active growth (*meristem*). |




Michigan State University Extension


Delaware Coop. Extension

# Translocation of Nutrients in the Plant

## Mobile Nutrients:

- Nitrogen
- Phosphorus
- Potassium
- Magnesium
- Chlorine

## Immobile Nutrients:

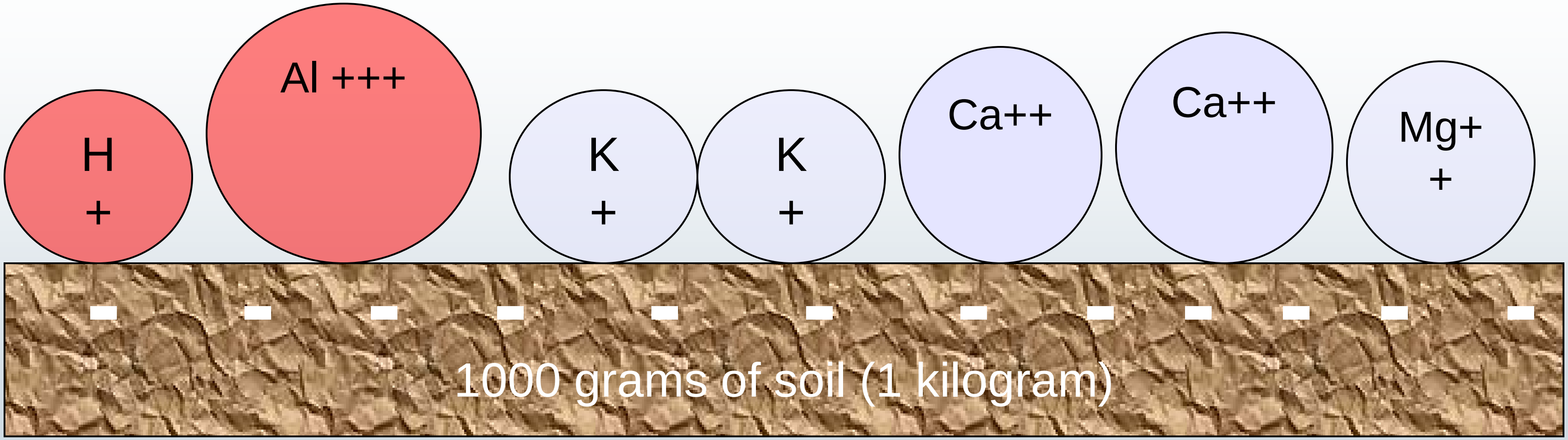
| | |
|---|---|
| Sulfur | Calcium |
| Iron | Manganese |
| Boron | Zinc |
| Copper | Molybdenum |

K deficiency

Fe or Mn deficiency

# Soil Properties: Cation Exchange

- CEC: $cmol_c\ kg^{-1}$
  - Sum of all cations (H, Na, K, Ca, Mg, Al, etc.) held by soil charges on an equivalent basis (per 1000 g)
  - 1H + 3 Al +2 K + 4 Ca +2 Mg = 12 $cmol_c\ kg^{-1}$



# Soil properties: CEC and base saturation

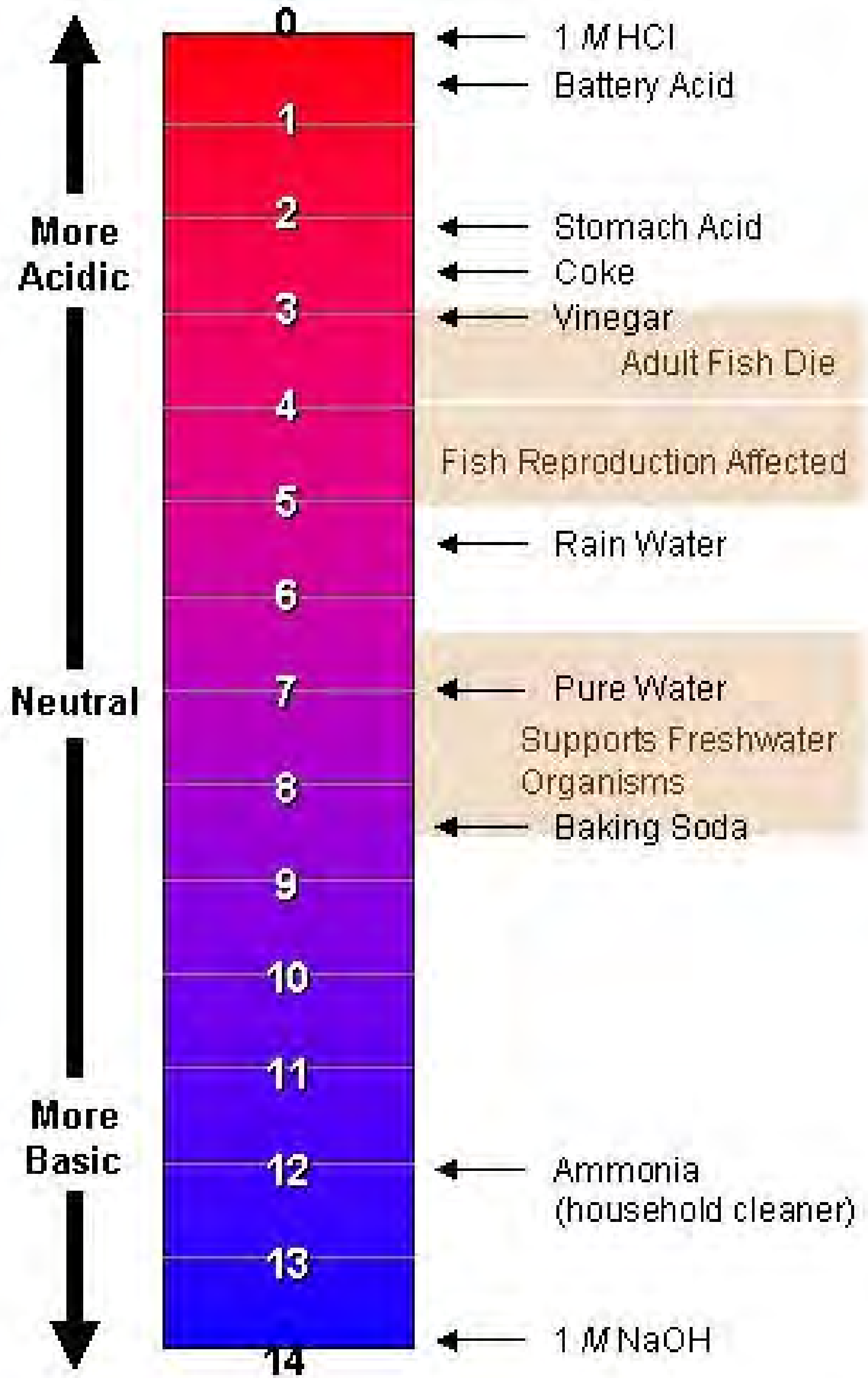
- **CEC:**
  - Smaller amounts of fertilizer (e.g., K), applied more often, reduce leaching losses low CEC soils.
- **Base saturation:**
  - Most crops grow best at a base saturation of >80%.
  - Relative amounts of soil Ca, Mg and K can vary widely with no detrimental effects.

# Soil properties: Anion leaching

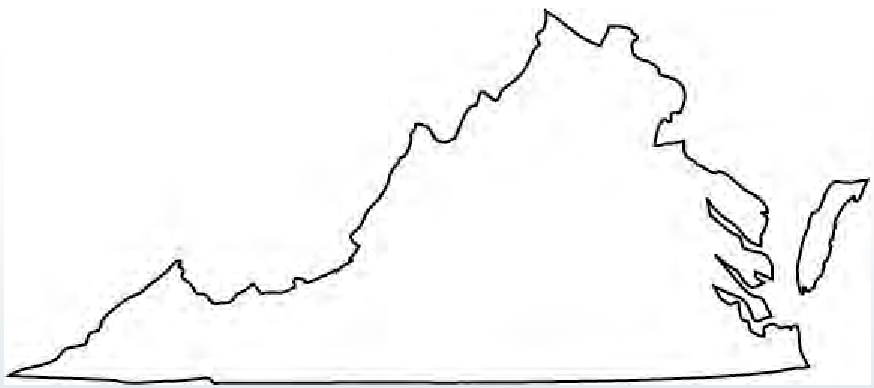
## ❖Anion leaching:

- Anions (negatively charged ions such as $NO_3^-$) usually leach more readily than cations because they are not attracted to the predominantly negative charge of soil colloids.

- **Exception:** P anions ($HPO_4^{2-}$, $H_2PO_4^-$):
  - These anionic forms do not easily leach through the soil profile due to specific complexing reactions with soil components.
  - Surface applications of P fertilizer without incorporation will result in the accumulation of P near the soil surface.

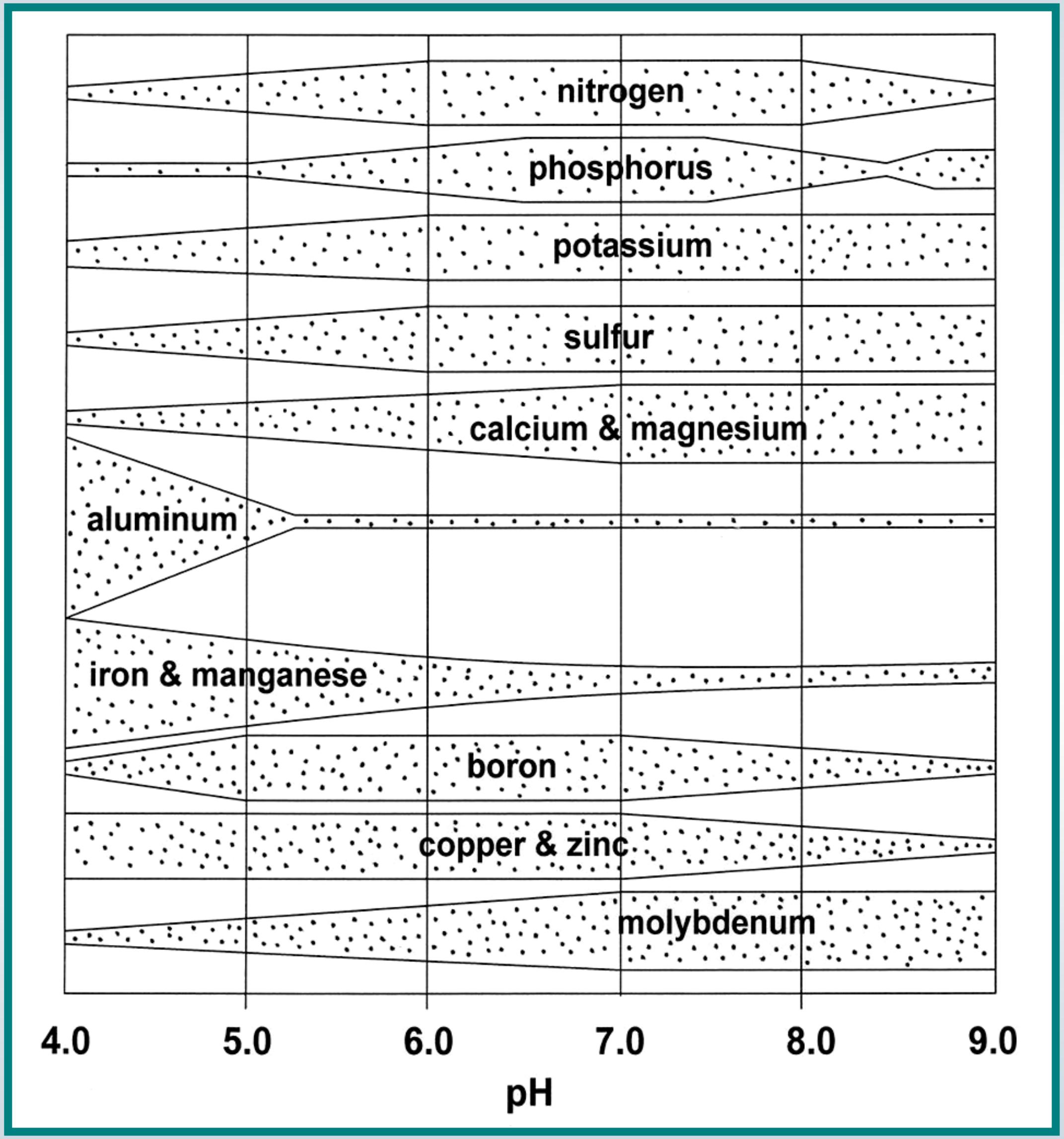



# For Virginia Most Mineral Soils have a pH from 4.0 to 8.0



5.1 -5.3 most common for <u>un</u>limed soils

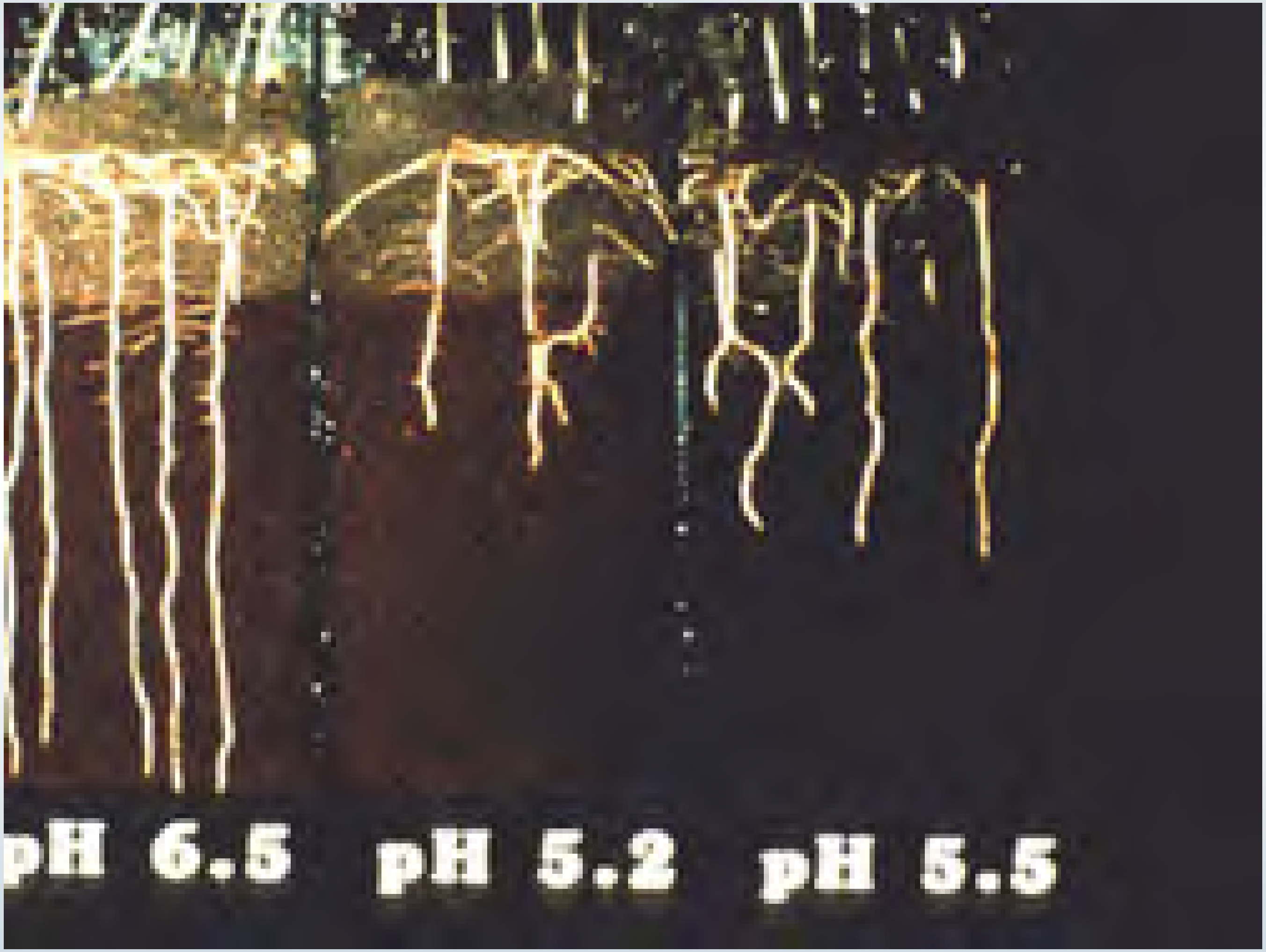
# Soil properties: pH




❖Soil pH influences nutrient solubility

- K, Ca, and Mg most available at pH > 6.0.
- P availability is usually greatest in the pH range of 5.5 to 6.8.
- At pH values less than 5.0, soluble Al, Fe, and Mn may be toxic to the growth of some plants.
- Most micronutrients (except Mo and B) are more available in acid than alkaline soils.

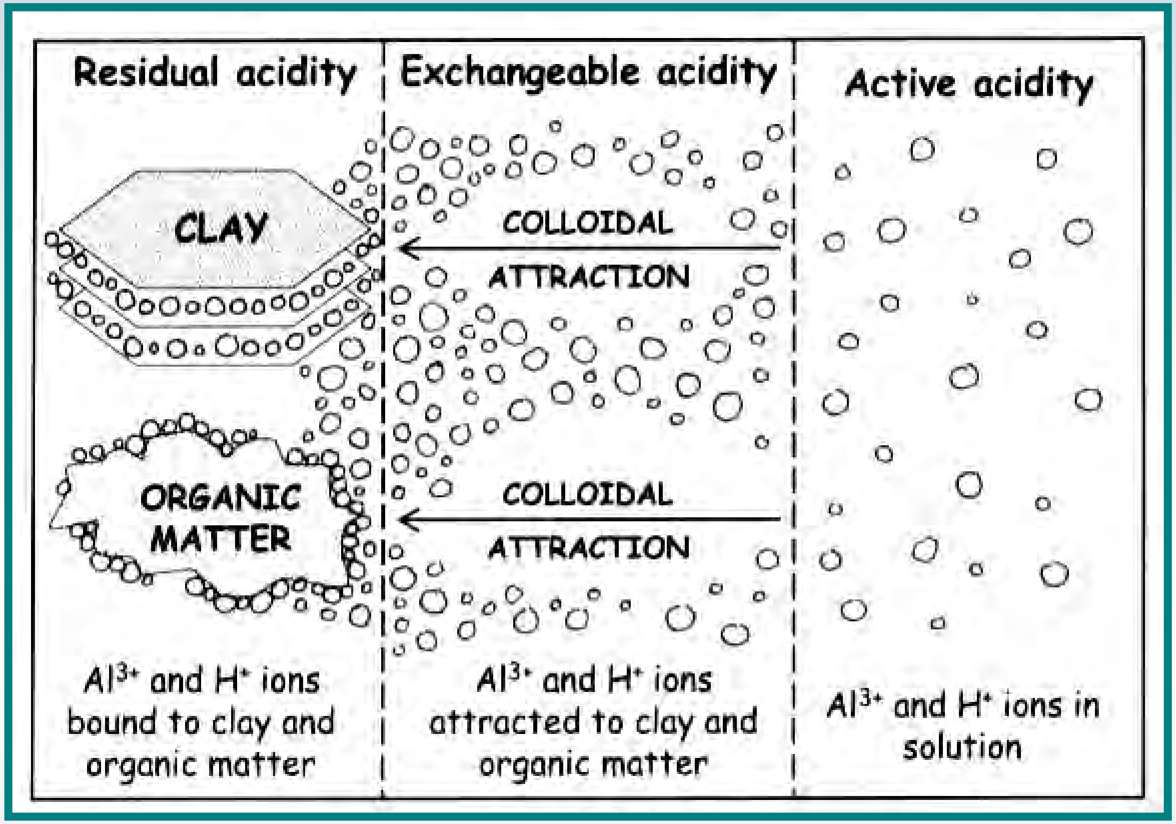
# Root Growth Restricted by Al



# Lime requirement vs. pH

❖The *lime requirement* for a soil is the amount of limestone needed to achieve a desired pH range.

❖ Soil pH determines only *active acidity* (the amount of $H^+$ in the soil solution at that particular time),




❖Lime requirement determines the amount of *exchangeable, or reserve, acidity* held by soil clay and organic matter.

# How do liming materials affect pH?

$$CaCO_3 + 2H_2O = Ca^{2+} + 2OH^- + H_2CO_3$$

$H^+$

$H^+$

$+ 2\ OH^- + Ca^{2+} = 2\ H_2O +$ $Ca^{++}$

$Al^{3+}$

$Al^{3+}$

$+ 6\ OH^- + 3\ Ca^{2+} = Al(OH)_{3(s)} + H_2O +$

$Ca^{++}$

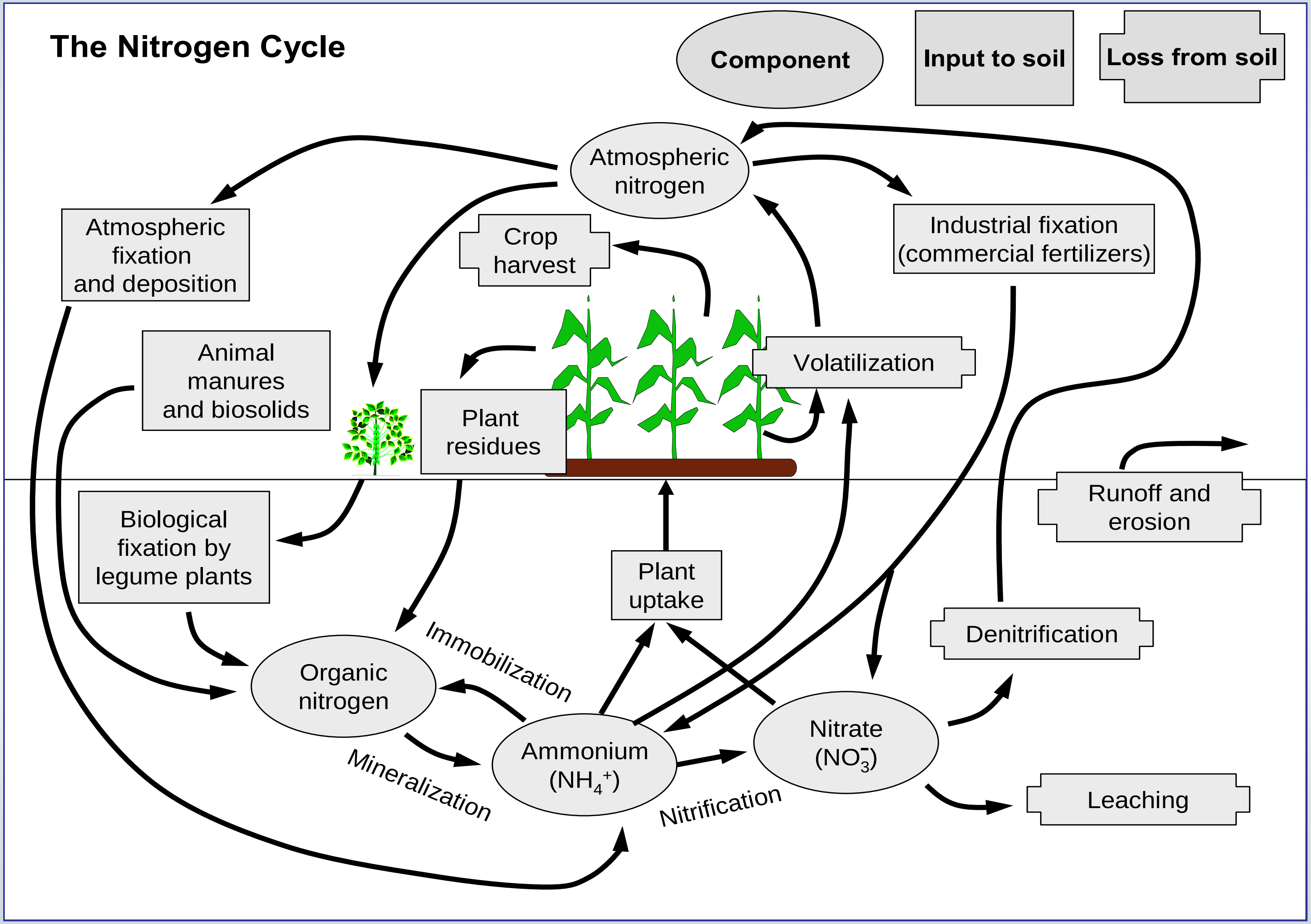
$Ca^{++}$

$Ca^{++}$

# To consider when selecting a liming material

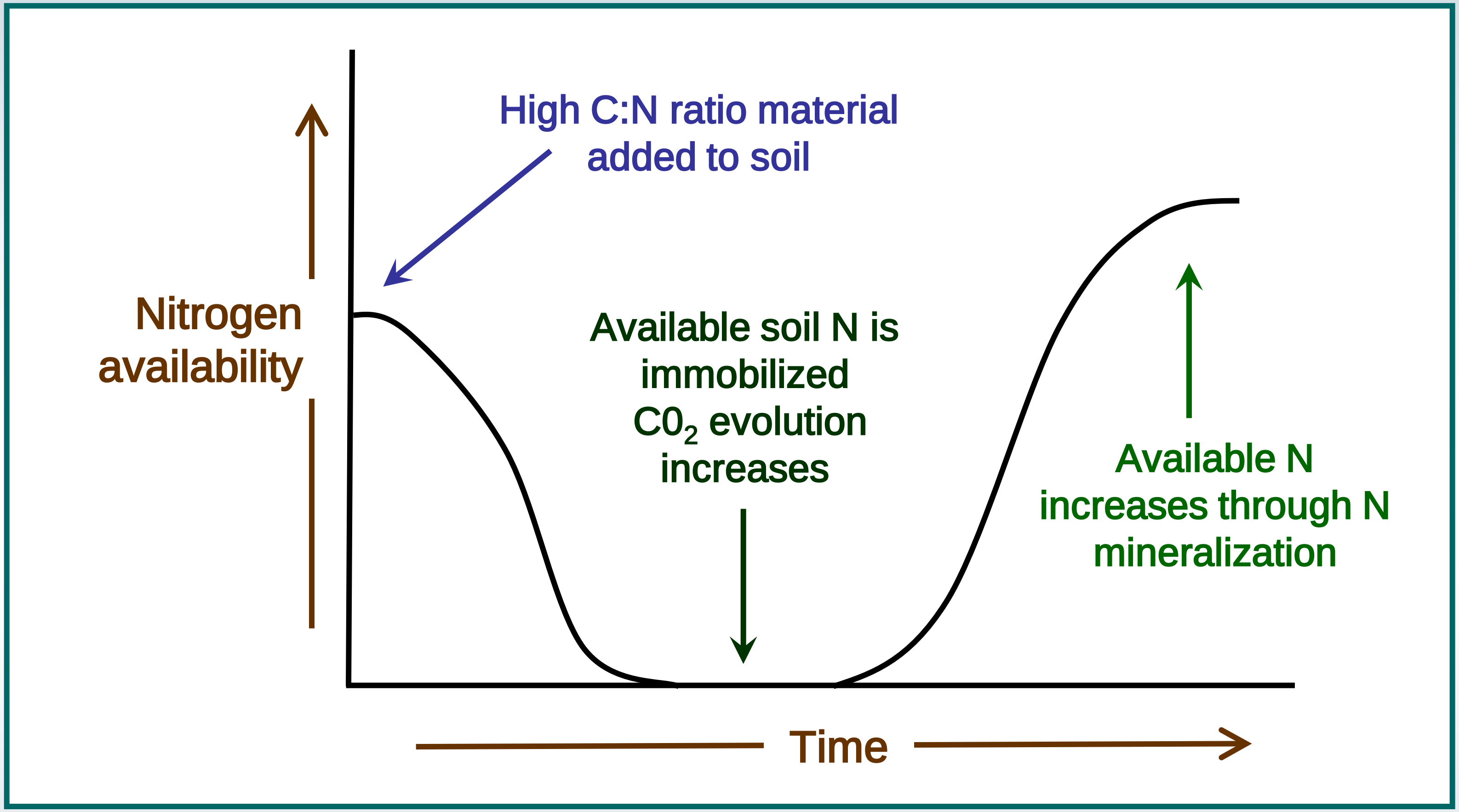
- **Calcium carbonate equivalence (CCE):**
  - CCE measures the liming capability of a material relative to pure calcium carbonate and is expressed as a percentage.
- **Time required for reaction:**
  - Slower acting versus quick-acting liming material.
- **Need for magnesium:**
  - Calcitic lime can be used in soils with high magnesium levels
  - Dolomitic limes should be used on soils low in magnesium.

# The nitrogen cycle




Modified from the Potash & Phosphate Institute web site at www.ppi-ppic.org

# Mineralization, immobilization, and C:N ratio




**Nitrogen immobilization and mineralization after material with a high C:N ratio is added to soil.**

# Nitrification

## ❖Nitrification:

- Biological oxidation of ammonium ($NH_4^+$ ) to nitrate ($NO_3^-$) in the soil.
- Two-step process:

*Nitrosomonas*

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$$

*Nitrobacter*

$$2NO_2^- + O_2 \rightarrow NO_3^-$$

# Significance of nitrification

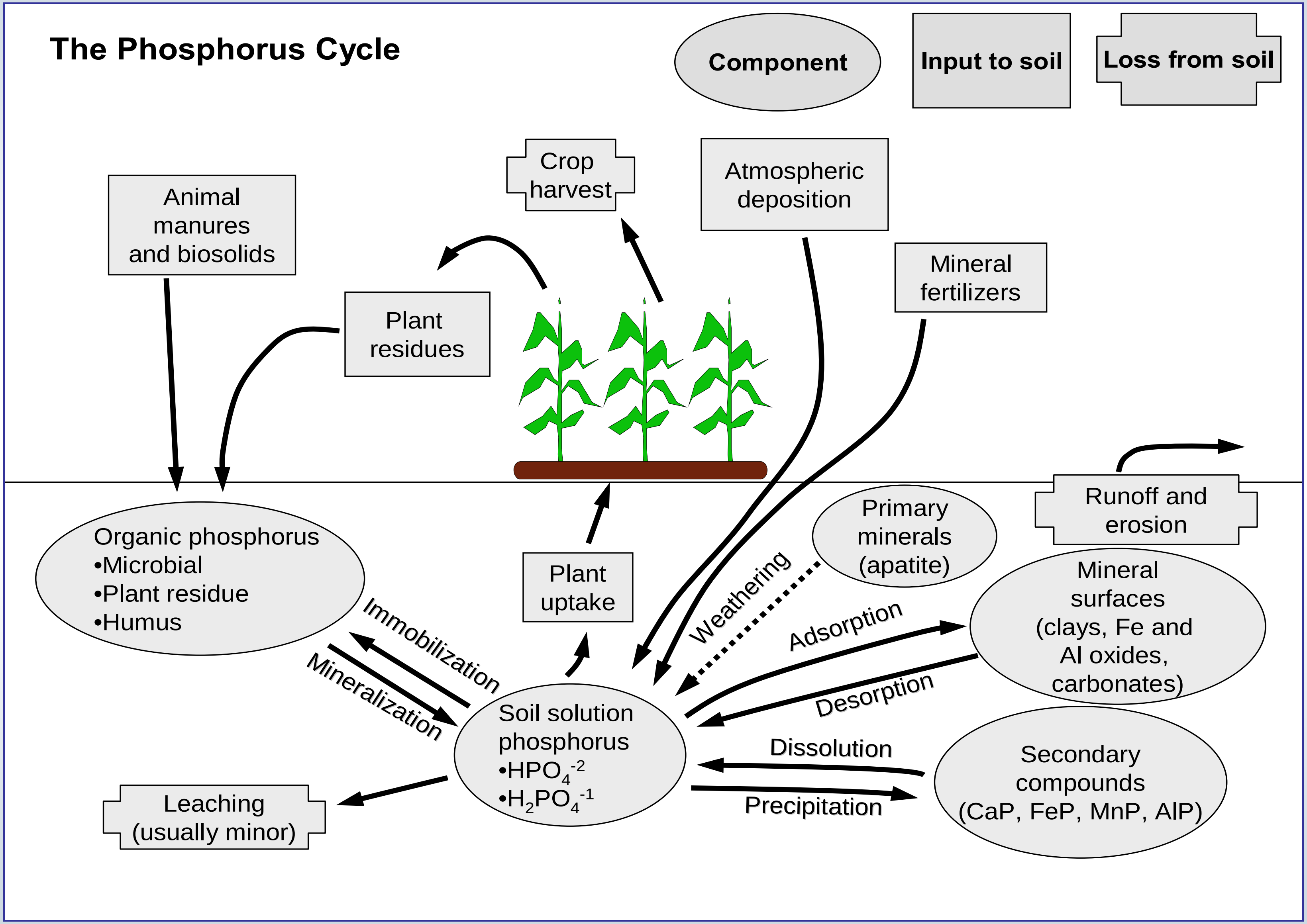
- ❖ Nitrate ($NO_3^-$) is readily available for uptake and use by plants and microbes.

- ❖ $NO_3^-$ leaching is a major N loss mechanism from soil in humid climates and under irrigation. N losses can be minimized through N management, including the application rate and timing of N fertilizer.

- ❖ $NO_3^-$-N can be lost through *denitrification*, the process where $NO_3^-$ is reduced to gaseous nitrous oxide ($N_2O$) or elemental N ($N_2$).

- ❖ During nitrification, 2 $H^+$ ions are produced for every $NH_4^+$ ion that is oxidized. These $H^+$ cations will reduce soil pH; thus, ammonium-containing fertilizers will decrease soil pH due to nitrification.

# The phosphorus cycle

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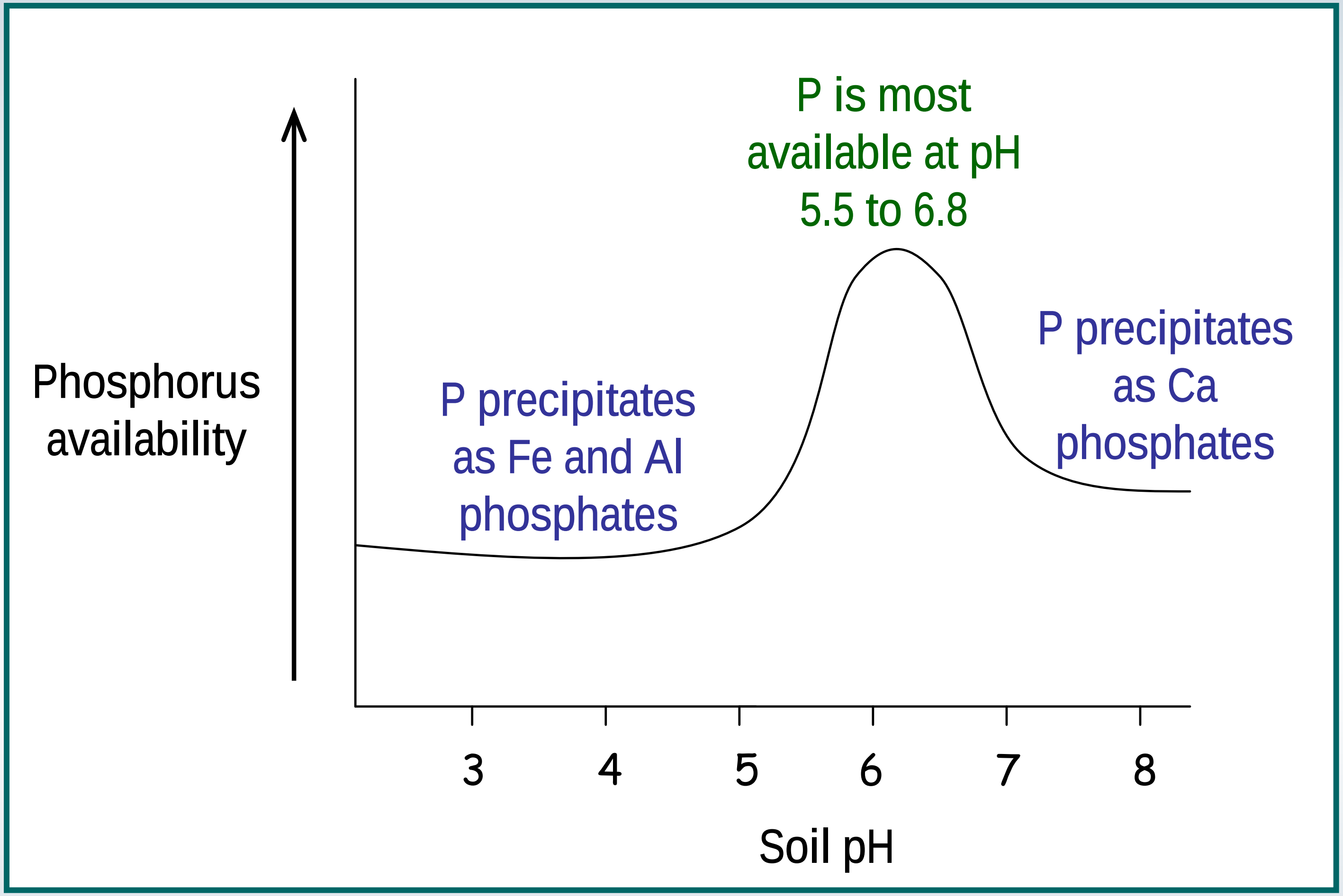
# Effect of pH on P availability



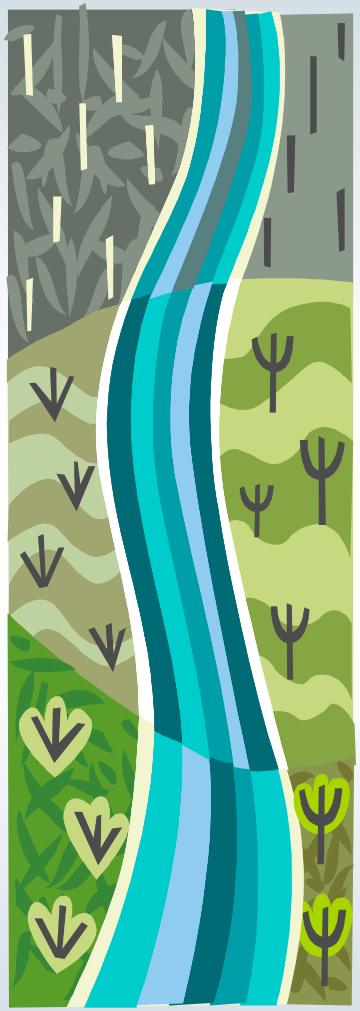

**Note: Plant roots take up P in the forms of $HPO_4^{-2}$ and $H_2PO_4^{-}$. In soils with pH values greater than 7.2, the $HPO_4^{-2}$ form is predominant. In soils with a pH between 5.0 and 7.2, the $H_2PO_4^{-}$ form predominates.**

# P transport to surface waters

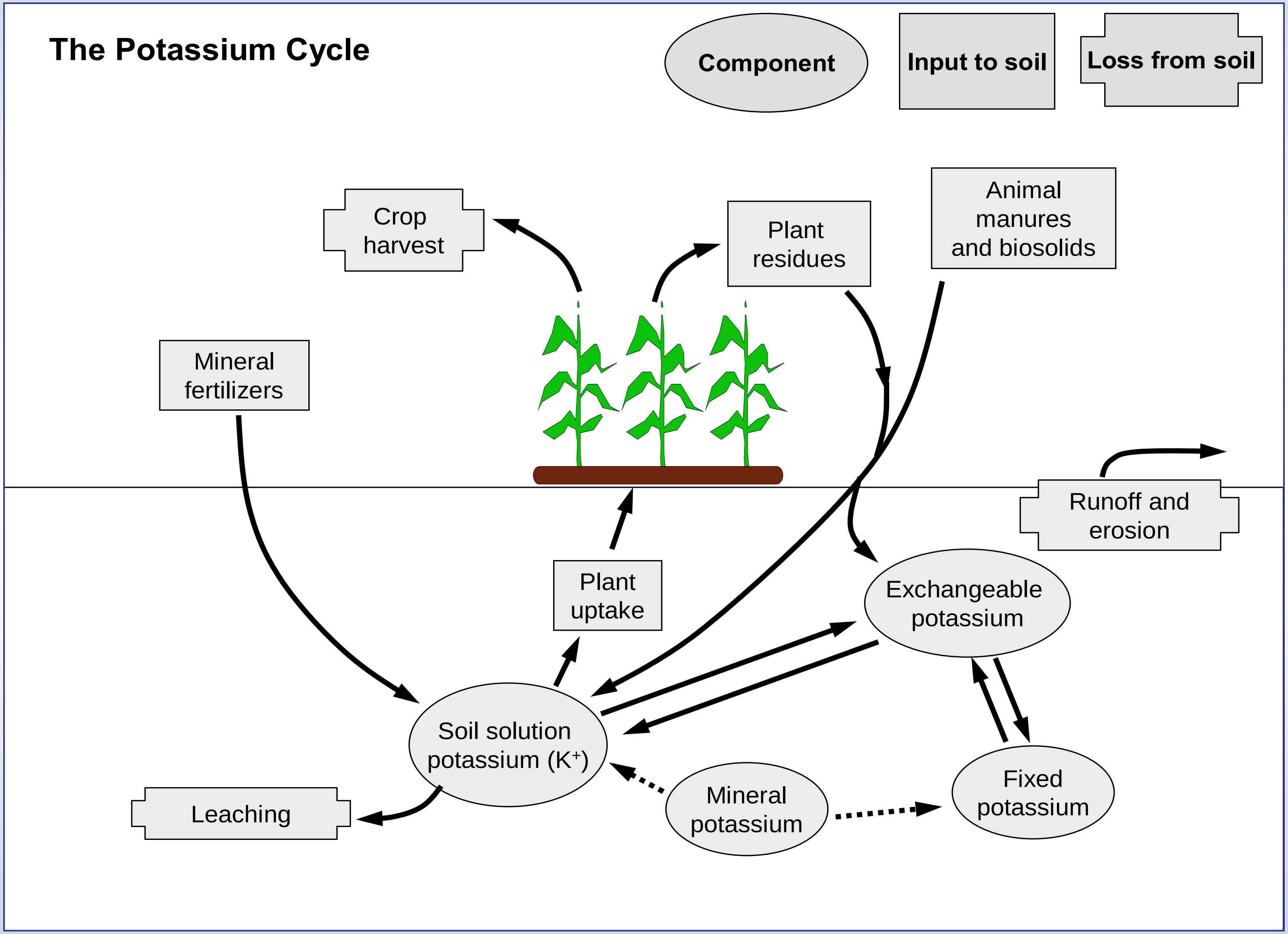
❖ Soils have a finite capacity to bind P. When a soil becomes saturated with P, desorption of soluble P can be accelerated, with a consequent increase in dissolved inorganic P in runoff.

❖ This potential loss of soluble P increases with increasing levels of soil test P.

❖ Very high levels of soil test P can result from over-application of organic or inorganic P fertilizers.



# The potassium cycle

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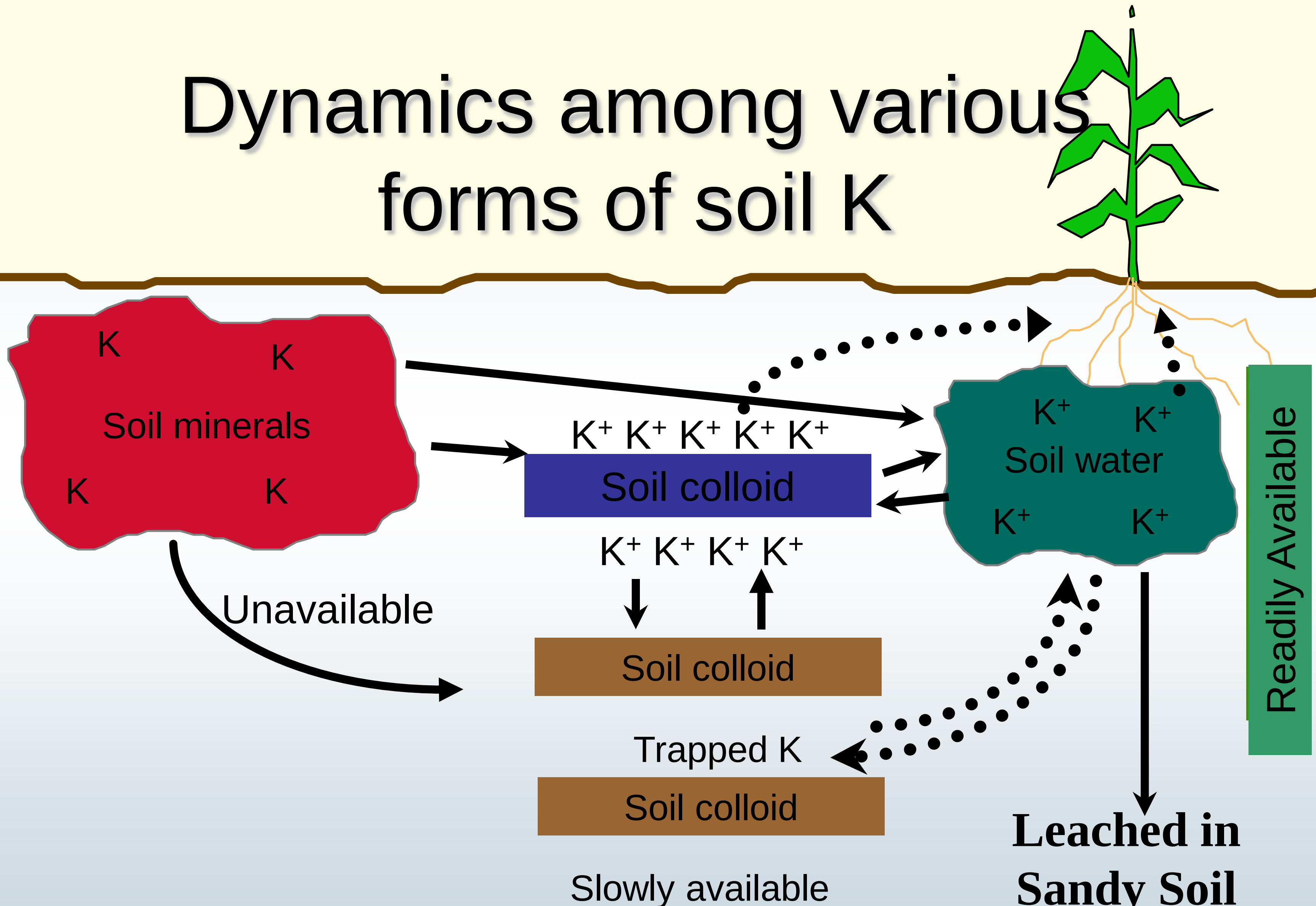
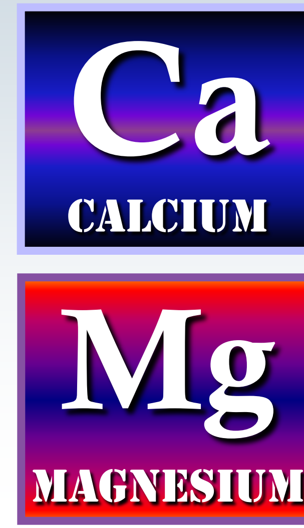
# Dynamics among various forms of soil K



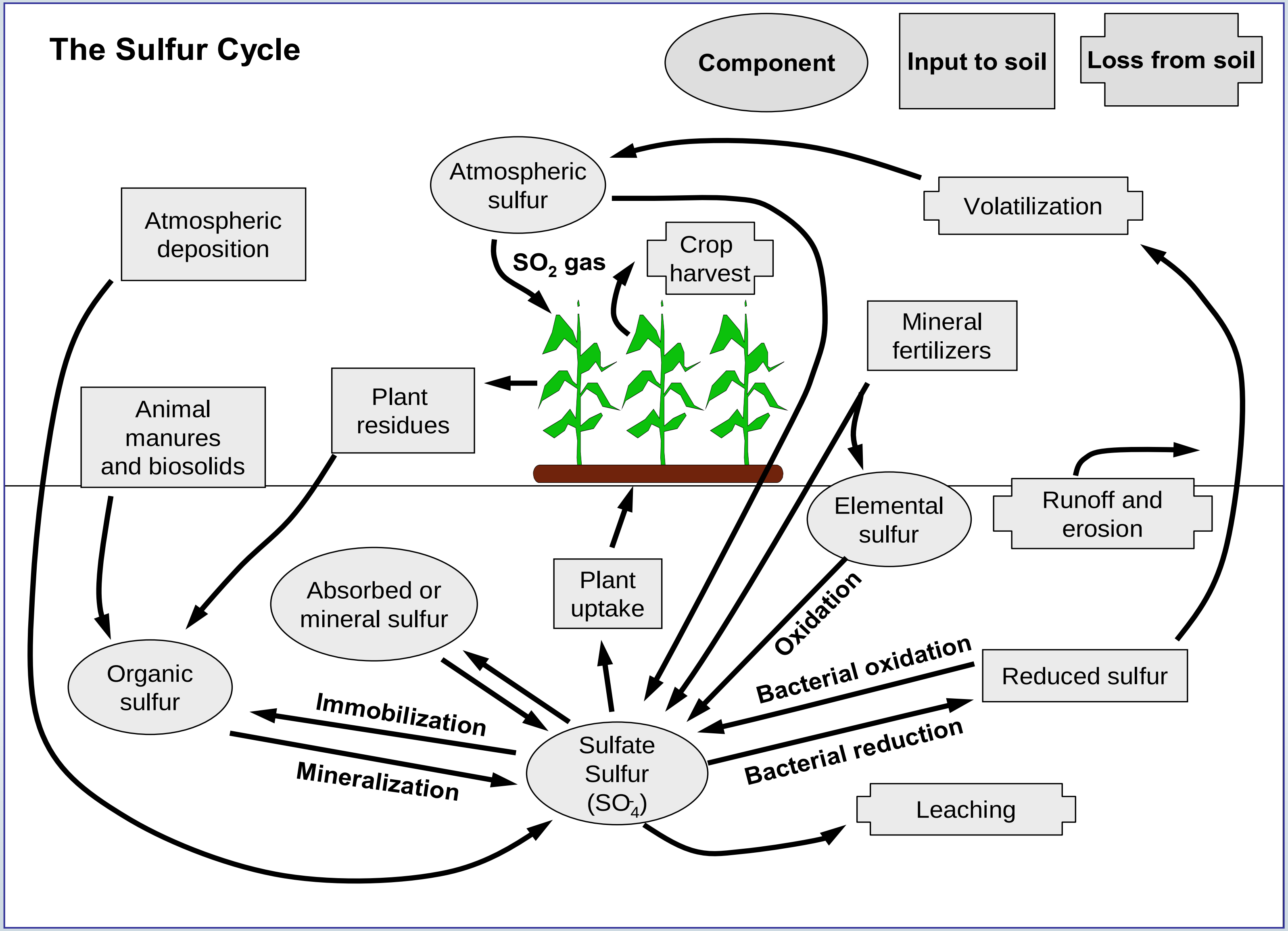

**Dissolved K in soil water = $\leq$ 10 lb/A**

# Calcium and magnesium




- **Ca and Mg behave very similarly in the soil:**
  - **Both are cations that have same charge ($Ca^{2+}$, $Mg^{2+}$)**
  - **Both are held by cation exchange sites; thus, they have low mobility and low leaching.**
- **Soil Ca:**
  - **Calcium is the dominant (70-90%) cation on the cation exchange complex in soils with moderate pH levels.**
- **Soil Mg:**
  - **Held less tightly than Ca by cation exchange sites, so it is more easily leached. In the Mid-Atlantic region, Mg deficiencies occur most often on acid and coarse-textured soils.**

# The sulfur cycle

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# Sulfur fertilizers and soil acidity

❖ **Sulfur-containing fertilizers and soil acidity:**

- **Little to no effect on soil pH (neutral salts):**
  - gypsum ($CaSO_4$)
  - potassium sulfate ($K_2SO_4$)
  - magnesium sulfate ($MgSO_4$)
  - potassium magnesium sulfate (K-Mag, or Sul-Po-Mag)
- **Contribute to soil acidity:**
  - ammonium sulfate ($(NH_4)2SO_4$)
  - aluminum sulfate ($(Al_2SO_4)_3$)
  - iron sulfate ($FeSO_4$)

**Note:** Ammonium sulfate has a strong acidic reaction primarily because of the nitrification of $NH_4^+$, and Al and Fe sulfates are very acidic due to the hydrolysis of $Al^{3+}$ and $Fe^{3+}$.

# Micronutrients

- Micronutrients:
  - B, Cl, Cu, Fe, Mn, Mo, Ni, and Zn.
  - Cobalt (Co) is needed by nodulating bacteria for fixing atmospheric N in legumes.
  - Micronutrient availability decreases as pH increases for all micronutrients except Mo and Cl.
- Increased emphasis on micronutrient fertility because:
  - Modern fertilizer production processes remove impurities so micronutrients are not commonly provided as incidental ingredients in fertilizers.

# Micronutrients: Boron

- **Soil boron (B):**
  - **Found in soil organic matter (most important source). Also in minerals, adsorbed on the surfaces of clay and oxides, and in the soil solution.**
- **Factors affecting plant-available B:**
  - **Soil moisture and weather: Dry or cold weather slows organic matter decomposition, resulting in B deficiency.**
  - **Soil pH: Plant availability of B is maximum between pH 5.0 and 7.0. Boron availability decreases with increasing soil pH.**
  - **Soil texture: Coarse-textured (sandy) soils are typically low in minerals that contain B. Boron is mobile in the soil and is subject to leaching on sandy soils.**

# Micronutrients: Copper

❖**Soil copper (Cu):**

- **Most soluble $Cu^{2+}$ in surface soils is complexed with organic matter.**
- **Cu concentrations in mineral soils are controlled primarily by soil pH and the amount of Cu adsorbed on clay and soil organic matter.**
- **Cu is more strongly bound to soil organic matter than any of the other micronutrients.**

❖**Copper deficiencies:**

- **Organic soils are most likely to be deficient in Cu, since Cu is held so tightly that only small amounts are available to the crop.**
- **Sandy soils with low organic matter content may also become deficient in Cu because of leaching losses.**
- **Concentrations of Fe, Mn, and Al in soil affect the availability of Cu for plant growth, regardless of soil type.**

# Micronutrients: Iron

- ❖ **Soil iron (Fe):**
  - ▪Solubility of Fe is very low and decreases with increasing soil pH. Fe can react with organic compounds to form chelates or Fe-organic complexes.
- ❖ **Causes of Fe deficiencies:**
  - ▪An imbalance with other metals such as Mo, Cu, or Mn.
  - ▪Excessive P in the soil.
  - ▪A combination of high pH, high lime, wet, cold soils, and high bicarbonate levels.
  - ▪Plant genetic differences. Plant species can differ significantly in their ability to take up Fe.
  - ▪Low soil organic matter levels.

# Benefits of Applying Iron to Turf

**Almost immediate color response from foliar application**

**No rapid increase in shoot growth rates that occur with N**

**Normal application rate 3 to 6 lbs Fe/acre**

# Micronutrients: Manganese

❖ **Soil manganese (Mn):**

- Plant-availability of Mn determined by the equilibrium among solution, exchangeable, organic and mineral forms of soil Mn.
- Chemical reactions affecting Mn solubility include oxidation-reduction and complexation with soil organic matter.

❖ **Mn deficiencies:**

- Occur most often on:
  - high organic matter soils.
  - soils with neutral-to-alkaline pH that are naturally low in Mn.
- May result from an antagonism with other nutrients such as Ca, Mg and Fe.
- Excess moisture in organic soils favors Mn availability because reducing conditions convert $Mn^{4+}$ to $Mn^{2+}$, which is plant available, so deficiencies often observed in dry conditions in formerly wet sandy Coastal Plain soils.

# Micronutrients: Molybdenum

- **Soil molybdenum (Mo):**
  - **Adsorbed and soluble Mo is an anion ($MoO_4^-$).**
  - **Mo is found in soil minerals, as exchangeable Mo on the surfaces of Fe/Al oxides, and bound soil organic matter.**
- **Mo deficiencies:**
  - **Mo becomes less available as soil pH decreases, so deficiencies are more likely to occur on acid soils.**
  - **Sandy soils are deficient more often than finer-textured soils.**
  - **Soils high in Fe/Al oxides tend to be low in available Mo because Mo is strongly adsorbed to the surfaces of Fe/Al oxides.**
  - **Heavy P applications increase Mo uptake by plants.**
  - **Heavy S applications decrease Mo uptake.**

# Micronutrients: Zinc

❖ **Soil zinc (Zn):**

- Zn is found in soil minerals, as adsorbed Zn on the surfaces of organic matter and clay, and as dissolved Zn in the soil solution.

❖ **Zn deficiencies:**

- Zn becomes less available as soil pH increases.
- Much of a mineral soil's available Zn is associated with organic matter. Low organic matter levels in mineral soils are frequently indicative of low Zn availability.
- Zn deficiencies tend to occur early in the growing season when soils are cold and wet due to slow root growth.
- Susceptibility to Zn deficiency is species and variety dependent.

# Micronutrients: Chlorine

❖ **Soil chlorine (Cl)**:

- **In soils, found in the form of chloride ($Cl^-$).**
- **Chloride has a high mobility in soils, which makes it susceptible to leaching.**

❖ **Chloride fertilization:**

- **Most practical source is potassium chloride (KCl), or muriate of potash, which contains about 47% Cl.**