**BIOL 695**

**PHOSPHORUS**

Chapter 9

MENGEL et al, 5th Ed

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**PHOSPHORUS SOIL FRACTIONS**

- **Labile P = sol Ca-PO₄ + sorbed PO₄**
- **P-sol'n vs P-sorbed follows Langmuir Equation**
- **Effect of pH:**
  - stronger sorption at low pH
  - less strong at mod. to neutral
  - strong sorption at v. high pH
- **Most sorption to Fe, Al oxides**

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**PHOSPHATE SORPTION PROCESSES**

- **P in soils mostly as orthophosphates X-PO₄⁻³, X may be Ca, Na, H, combo**
- **Total P in soils ~ 0.02-0.15%**
- **Organic P ~ 20-80% total P**
- **Important soil phosphate minerals:**
  - Hydroxyapatite - Ca₅(PO₄)₃OH
  - Fluorapatite - Ca₅(PO₄)₃F
  - Dicalciumphosphate - CaHPO₄
  - Tricalciumphosphate - Ca₃(PO₄)₂

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**PHOSPHORUS SOIL FRACTIONS**

- P-soil interaction:
  - both sorption and precipitation
  - sorption mostly to Fe-oxides
  - slow conversion to insol. Forms
  - formation of Ca-, Fe-, Al-phosphates
- OM decomposition releases PO₄
  - most P inform of inositol-P compds (synthesized by microbes)
  - phosphatase Rx'n liberates PO₄
  - phosphatase conc high in root cell walls & in rhizosphere

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**PHOSPHORUS SOIL FRACTIONS**

- Over time, much of the labile P is converted to non labile P

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**PHOSPHORUS CYCLE**

- Phosphorus in soils mostly as orthophosphates X-PO₄⁻³, X may be Ca, Na, H, combo
- Total P in soils ~ 0.02-0.15%
- Organic P ~ 20-80% total P
- Important soil phosphate minerals:
  - Hydroxyapatite - Ca₅(PO₄)₃OH
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**PHOSPHORUS SOIL FRACTIONS**

- Root uptake
- Solution P
- Labile P
- Non Labile P

Fig. 9.1 Schematic representation of the 3 important P soil fractions for plant nutrition.

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### PO₄ IN SOIL SOLUTION

- Low levels (0.3 - 3 ppm)
- Low pH: predominately H₃PO₄⁻
- High pH: predominately HPO₄²⁻
- Beans absorb PO₄ at pH 4 (10x) > pH 8.7
- Roots push thru soil & contact PO₄
- PO₄ gradient near root caused by absorption of PO₄ so more PO₄ moves in.

### P DEPLETION ZONES

- 20% photosynthesate of wheat
  - released into soil
- Rape roots had P depletion zones
- Microbial activity at 30 - 45°C
  - Favors organic P from tropical soil

### PO₄ IN SOIL SOLUTION

- In addition there is some mass flow.
- Mycorrhizal fungi can take up PO₄ more rapidly than root.
- Microorganisms that produce acids and chelating agents aiding PO₄ abs:
  - Aspergillus niger
  - Escherichia freundi
  - Penicillium sp. Pseudomonas sp.

### ABSORPTION & TRANSLOCATION

- PO₄ conc in root 100-1000 > conc soil
  - Metabolism drives active uptake
- 1st trans in xylem to young leaves 2nd in phloem as phosphoryl-choline and organic PO₄ to older leaves.
- Most P in plant in inorganic P (Pᵢ) form.

### MYCORRHIZAL FUNGI & P UPTAKE

![Mycorrhizal Fungi & P Uptake](image)

**FIGURE 15.7** Roles of diffusion and mycorrhizal hyphae in the movement of phosphate into plant roots. In soils with low solution phosphate concentration and high phosphate fixation, slow diffusion may seriously limit the amount of phosphate available to the plant. Mycorrhizal fungi are particularly beneficial to the plant where phosphate diffusion is slow, because mycorrhizal fungi secrete the phosphate for their own consumption, making the plant much less dependent on the diffusion of phosphate ions through the soil.

### P NOT REDUCED

- Remains in oxidized form (Pᵢ) after uptake as H₃PO₄
- May be esterified thru hydroxyl group to carbon chain C-O-P as PO₄ ester
- Attached to another pyrophosphate by energy-rich bond P ~ P e.g., ATP

**P** - Organic P
### Exchange Rate

- Frequent exchange between $P_i$ & $P$ :
  - $P_i$ taken up by roots in $P$ in few min
  - Then released in few min as $P_i$ into xylem

- Another type of bond is diester state $C \cdot P \cdot C$ which is relatively stable.

### Phospholipid Biomembrane

- $P$ diesters form bridge between:
  - diglyceride and
  - another molecule e.g.
    - amino acids
    - amine
    - alcohol
  - phosphatidylcholine (lethicin)

### P as Structural Element

- Nucleic acids
  - DNA carrier of genetic information
  - RNA - translation of genetic inform
  - $P$ forms bridge between ribonucleoside units to form macromolecules
    - (Section of RNA molecule, Fig 9.7)

### Role in Energy Transfer

- Metabolic mechanisms of cells
  - Phosphate esters ($C \cdot P$)
  - Energy rich phosphates ($P \cdot P$)
- 2 of most important esters:
  - glucose-6-phosphate
  - Phosphoglyceraldehyde
- Energy for metabolic functions (ATP)

### P Responsible for Acidic Nature of Nucleic Acids

- Exceptionally high cation conc in DNA and RNA
- $P$ high in meristems
- $P$ low in storage tissue

### P Supply

- P required for optimum growth
  - 0.3 - 0.5% of plant DM during vegetative growth
- P toxicity if > 1% plant DM
  - But Pigeon Peas P toxicity at 0.3 to 0.4% plant dry matter
**P DEFICIENCY**

- Autotrophic growth (req C & N) requires PO$_4$ export from chloroplasts.
  - Influences
    - Protein synthesis
    - Nucleic acid synthesis

**PHOSPHOTASE ACTIVITY**

- Higher in low P plant
  - High rates P can lower Zn, Fe, Cu
  - Very high PO$_4$ retards uptake & translocation of Zn, Fe, Cu

**P DEFICIENT PLANTS**

- P$_i$ depressed but P is unchanged
  - Thus plant growth retarded. Why?
  - Low shoot/root ratio
    - Fruit trees show
      - Reduced shoot growth
      - Retarded bud opening
      - Fruit & seed form depressed

**P CROP REQUIREMENTS**

- $10^{-4}$ M PO$_4$ in soil solution adequate
- If P buffer cap is high, then the P content of sol’n may be opt at lower conc’n
- Crops with high growth rates need more P
  - Potatoes
  - Tomatoes
  - Cabbage

**DEFICIENCY SYMPTOMS**

- First in older leaves
  - Is P$_i$ and/or P ion mobile or not?
- Leaves - Dark green ⇒ Necrotic mar ⇒ Abscise prematurely
- Stems - Reddish from anthocyanin

**P FERTILIZERS**

See Text, Table 9.4 for PO$_4$ fertilizers

Raw material is rock phosphate

$$3[Ca_3(PO_4)_2] \cdot CaF_2 + 7H_2SO_4 \Rightarrow$$

$$3Ca(H_2PO_4)_2 + 7CaSO_4 + HF_{(g)} \uparrow$$

monocalcium phosphate
### P FERTILIZERS

**IN SOIL:**

\[
\text{Ca(H}_2\text{PO}_4\text{)}_2 + \text{Ca}^{2+} \rightarrow 2\text{CaHPO}_4 + 2\text{H}^+
\]

Mono-Ca-phosphate \hspace{1cm} Di-Ca-phosphate

\[
3\text{CaHPO}_4 + \text{Ca}^{2+} \rightarrow \text{Ca}_4\text{H(PO}_4\text{)}_3\text{OH} + 2\text{H}^+
\]

Octo-Ca-phosphate

\[
\text{Ca}_4\text{H(PO}_4\text{)}_3\text{OH} + \text{Ca}^{2+} + \text{H}_2\text{O} \rightarrow \text{Ca}_5(\text{PO}_4\text{)}_3\text{OH} + 2\text{H}^+
\]

Hydroxy apatite

### PHOSPHATE APPLICATION

- \(\text{PO}_4\) mobility comparatively low
- Need to apply to root zone of crop
  - lettuce: 0-18 cm depth
  - carrots: 30-40 cm depth
- Placed (banded) application may be better than broadcast
- Apply at any time of year, except in soils of high \(\text{P}\)-fixing capacity