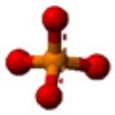
Phosphorus Behavior in Soil

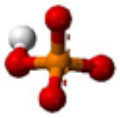
- Phosphorus is essential for plant growth and is second only to nitrogen in the frequency which it limits yield in crop production.
- Phosphorus plays a critical role in energy storage and transfer in plants and is a component of DNA and RNA.

Molecular Forms

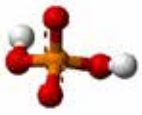
- Phosphorus is highly reactive and does not exist in elemental form in nature.
- Phosphorus is present as phosphate in natural systems, which results when phosphorus exposed to air binds with oxygen.
- The simplest form of phosphate is PO_4^{-3} (orthophosphate), which is the predominant form of phosphorus taken up by plants.
- Phosphate exists in different ionic forms depending on the pH of the soil:
  - HPO_4^{-2} (hydrogen phosphate) in basic soils
  - $H_2PO_4^-$ (dihydrogen phosphate) in acid soils



orthophosphate



hydrogen phosphate



dihydrogen phosphate

- Analyses of phosphorus fertilizers are typically reported as percent P_2O_5, a phosphate form that is produced during fertilizer analysis but does not exist in either fertilizer or soils.

Phosphorus Reactions in Soil

- Adsorption – Binding of phosphates to soil particles; also referred to as fixation.
- Desorption – Release of phosphates from soil particles.
- Precipitation – Reaction of phosphate with another substance to form a solid mineral.
- Dissolution – Release of phosphorus that occurs when soil minerals dissolve. Occurs slowly over long periods of time.
- Mineralization – Conversion of organic phosphorus to inorganic phosphate by microorganisms breaking down organic compounds.
- Immobilization – Conversion of inorganic phosphate to organic phosphate and incorporation into the living cells of soil microorganisms.

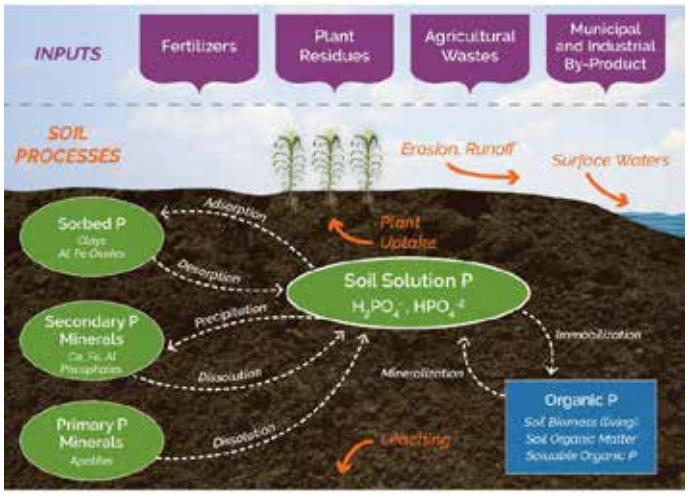


Figure 1. Soil phosphorus cycle.

Phosphorus States in Soil

Fixed Phosphorus

- Largest pool of phosphorus in the soil; unavailable for plant uptake; also referred to as non-labile phosphorus.
- Dissolution of fixed phosphorus into the active pool occurs very slowly over time; phosphorus can remain in the fixed pool for years and have little effect on the fertility of the soil.
- Composed of insoluble inorganic phosphate compounds (primary minerals) and organic phosphorus compounds.

Active Phosphorus

- Phosphorus in solid phase that is relatively easily released into the soil solution; also referred to as labile phosphorus.
- Consists of inorganic phosphate adsorbed to soil particles, secondary phosphate minerals (phosphate bound to cations such as calcium and aluminum), and organic phosphorus that is readily mineralized.
- Replenishes phosphorus in the soil solution as it is removed by plants and is the main source of phosphorus for crop uptake.

Solution Phosphorus

- By far the smallest of the three pools, usually less than a pound/acre.
- Phosphorus in the soil solution with limited mobility that is available for uptake by plants.
- Composed mostly of inorganic phosphate, small amount of organic phosphorus.
- Rapidly depleted by plant uptake and continuously replenished by the active phosphorus pool.

Mobility in Soil Solution

- Forces of attraction between nutrient ions and soil and water molecule determines their behavior and mobility in soil.
- Cations such as K^+ bond to negatively charged soil particles, thus are not as abundant in soil water and tend to have low mobility.
- Anions such as NO_3^- do not as readily bond to soil, therefore are more abundant and more mobile in soil water.
- Phosphorus is an exception, as it exists as an anion but has low water solubility, making it relatively immobile in the soil.

Table 1. Essential nutrients for plant growth, forms available for plant uptake, and relative mobility in soil water.

Nutrient	Plant-Available Form(s)	Soil Mobility
Nitrogen	NO_3^- NH_4^+	Mobile Immobile
Phosphorus	HPO_4^{2-}, $H_2PO_4^-$	Immobile
Potassium	K^+	Somewhat mobile
Sulfur	SO_4^-	Mobile
Calcium	Ca^{2+}	Somewhat mobile
Magnesium	Mg^{2+}	Immobile
Boron	H_3BO_3, BO_3^-	Very Mobile
Chlorine	Cl^-	Mobile
Copper	Cu^{2+}	Immobile
Iron	Fe^{2+}, Fe^{3+}	Immobile
Manganese	Mn^{2+}	Mobile
Molybdenum	MoO_4^-	Somewhat Mobile
Zinc	Zn^{2+}	Immobile

Factors Affecting Phosphorus Availability

Soil pH

- The optimum soil pH range for phosphorus availability is 6.0 to 7.0.
- At lower pH levels, phosphate tends to bind with aluminum or iron compounds in the soil, making less available for plant uptake.
- At higher pH levels, phosphate tends to precipitate with calcium.

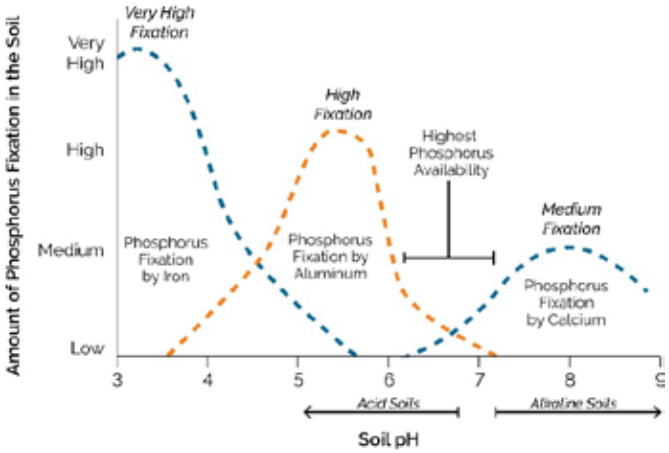


Table 1. The effect of soil pH on phosphorus availability.

Soil Mineral Type

- Volcanic soils and highly weathered soils (such as Ultisols and Oxisols) have high phosphorus sorption capacity and thus lower phosphorus availability.
- Less-weathered and organic soils have lower sorption capacity.

Clay Content

- As the amount of clay in the soil increases, sorption capacity increases as well. Clay particles have a large amount of surface area where phosphate sorption can take place.

Organic Matter

- Mineralization of organic matter provides a significant portion of phosphorus for crops, so higher organic matter levels will tend to result in greater phosphorus availability.

Other Anions

- Phosphate availability is higher when other anions, such as bicarbonate, carbonate, silicate, sulfate, or molybdate are abundant in the soil solution.
- These anions compete for sorption sites on soil particles, which reduces the amount of phosphate that can be adsorbed.

Climatic and Soil Conditions

- Conditions such as temperature, moisture, soil aeration (oxygen levels), and salinity (salt content/electrical conductivity) can affect the rate of phosphorus mineralization from organic matter decomposition.
- Organic matter decomposes releasing phosphorus more quickly in warm humid climates and slower in cool dry climates.
- Phosphorus is released faster when soil is well aerated (higher oxygen levels) than when it is saturated.

Plant Uptake

- Despite the relatively small amount of phosphate in the soil solution at any given time, plants can take up substantial amounts due to replenishment of the solution phosphorus pool through desorption from soil particles and dissolution from soil minerals.
- Uptake of phosphate by plants creates a strong diffusion gradient that moves phosphate toward plant roots at a higher rate relative to water uptake driven by transpiration.

Phosphorus Loss from Soils

- Given the immobility of phosphorus in soil, it does not readily leach out of the root zone; however, leaching can occur when soil phosphorus levels are very high, particularly in fields with tile drainage.
- Phosphorus loss is more commonly associated with erosion and runoff. Phosphate bound to soil particles is carried away with eroded sediment.

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