Phosphorus cycle

Introduction

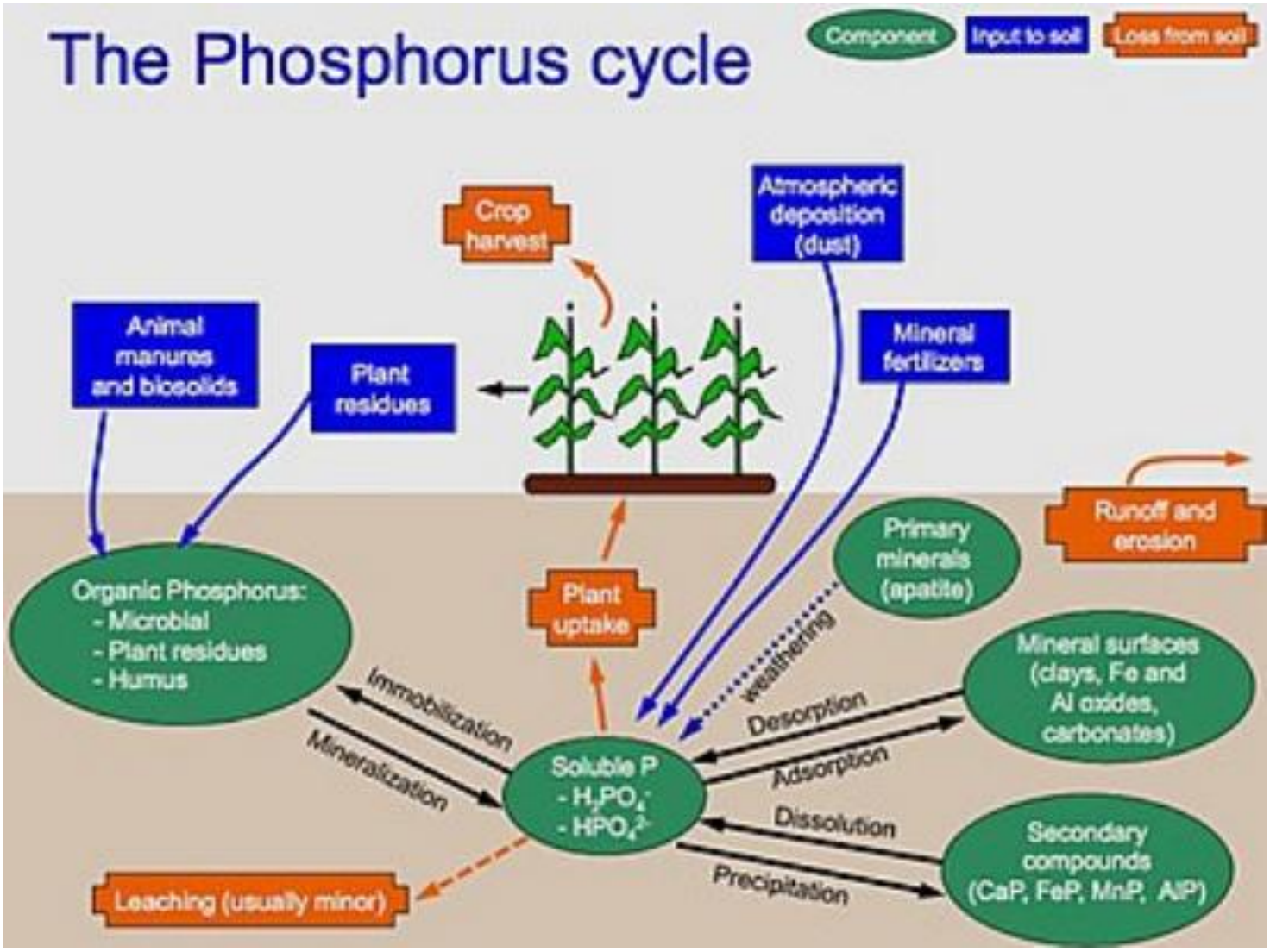
- The Phosphorus Cycle is the biogeochemical cycle that describes the transformation and translocation of phosphorus in soil, water, and living and dead organic material.
- The **phosphorus cycle** is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere.
- Of all the elements recycled in the biosphere, phosphorus is the scarcest and therefore the one most limiting in any given ecological system.
- It is indispensable to life, being intimately involved in energy transfer and in the passage of genetic information in the deoxyribonucleic acid (DNA) of all cells.
- The phosphorus cycle encompasses numerous living and nonliving environmental reservoirs and various transport pathways.
- In tracing the movement of phosphorus in the environment, the interplay between physical and biological processes becomes apparent.
- In addition to acting as reservoirs of phosphorus in the environment, microbes contribute to the transformation of phosphorus within other reservoirs such as in soil or aquatic environments.

...Introduction

- Phosphorus occurs in soil as inorganic and organic P compounds.
- Most soils contain a relatively low amount of total P, and only a small fraction of the total P is available to plants.
- Most P compounds in soils have low water solubility. Once in the soil solution, soluble P moves mainly by diffusion.
- Phosphorus in soils generally occurs as the anions H_2PO^{4-}or HPO_4^{2-}. Phosphorus reacts with calcium (Ca^{2+}), magnesium (Mg^{2+}), iron (Fe^{3+}), and aluminum (Al^{3+}).
- Phosphorus reactions in soil are pH dependent. In acid soils, soluble phosphorus in the soil solution reacts with Fe and Al to form low solubility Fe and Al phosphates. In calcareous soils, soluble phosphorus in the soil solution reacts with Ca to form low solubility Ca phosphates.

Key Steps of Phosphorus Cycle

- Over time, rain and weathering cause rocks to release phosphate ions and other minerals. This inorganic phosphate is then distributed in soils and water.
- Plants take up inorganic phosphate from the soil. The plants may then be consumed by animals. Once in the plant or animal, the phosphate is incorporated into organic molecules such as DNA. When the plant or animal dies, it decays, and the organic phosphate is returned to the soil.
- Within the soil, organic forms of phosphate can be made available to plants by bacteria that break down organic matter to inorganic forms of phosphorus. This process is known as mineralisation.
- Phosphorus in soil can end up in waterways and eventually oceans. Once there, it can be incorporated into sediments over time.


The Phosphorus cycle
Component
Input to soil
Loss from soil
Crop harvest
Atmospheric deposition (dust)
Animal manures and biosolids
Plant residues
Mineral fertilizers
Runoff and erosion
Primary minerals (apatite)
Organic Phosphorus:
- Microbial
- Plant residues
- Humus
Plant uptake
weathering
Mineral surfaces (clays, Fe and Al oxides, carbonates)
Immobilization
Mineralization
Desorption
Adsorption
Soluble P
- $H_2PO_4^-$
- HPO_4^{2-}
Dissolution
Precipitation
Secondary compounds (CaP, FeP, MnP, AlP)
Leaching (usually minor)

Weathering

- Phosphorus can be found in the rocks in very high concentrations.
- The crust of the earth is where the phosphorus cycle gets its start for this reason.
- Physical erosion and chemical weathering of rocks producing soils and providing dissolved and particulate phosphorus to rivers
- Phosphate salts are extracted from the rocks by breaking them down.
- These salts are carried away by the water and deposited into the earth, where they combine with the dirt.

Absorption by Plants

- The plants are able to take up the phosphate salts that have been dissolved in the water. On the other hand, the amount of phosphorus that is found in the soil is extremely low. Phosphate fertilisers are spread throughout agricultural area for this very reason by the farmers.
- The inorganic phosphorus is taken up by the aquatic plants from the deeper layers of the bodies of water. Phosphate salts, which do not dissolve completely in water, have a negative impact on the growth of plant life in aquatic ecosystems.

… Absorption by Plants

- The availability of phosphorus in soil to plants depends of several reversible pathways:
- **Bacteria**: Bacteria convert plant-available phosphate into organic forms that are then not available to plants. Although other bacteria make phosphate available by mineralisation, the contribution of this is small.
- **Adsorption**: Inorganic (and available) phosphorus can be chemically bound (adsorbed) to soil particles, making it unavailable to plants. Desorption is the release of adsorbed phosphorus from its bound state into soil solution.
- **pH**: Inorganic phosphorus compounds need to be soluble to be taken up by plants. This depends on the acidity (pH) of the soil. If soils are less than pH 4 or greater than pH 8, the phosphorus starts to become tied up with other compounds, making it less available to plants.

P solubilization and mineralization

- A large number of microbial organisms including bacteria, fungi, actinomycetes, and algae exhibit P solubilization and mineralization ability.
- Soil bacteria that have been reported to mobilize poorly available phosphorus via solubilization and mineralization include *Pseudomonas spp., Agrobacterium spp., and Bacillus circulans.*
- The microbial fungi that function similarly include strains of *Achrothcium, Alternaria, Arthrobotrys, Aspergillus, Cephalosporium, Cladosporium, Curvularia, Cunninghamella, Chaetomium, Fusarium etc.*

Mechanisms of Inorganic Phosphate Solubilization by PSM

- A number of theories explain the mechanism of inorganic phosphate solubilization.
- As observed in many experiments, the principal mechanism is the production of mineral dissolving compounds such as organic acids, siderophores, protons, hydroxyl ions and CO2.
- Organic acids produced as described in together with their carboxyl and hydroxyl ions chelate cations or reduce the pH to release P.
- The organic acids are produced in the periplasmic space by the direct oxidation pathway . The excretion of these organic acids is accompanied by a drop in pH that results in the acidification of the microbial cells and the surroundings, hence, P ions are released by substitution of H^+ for Ca^{2+}
- An alternative mechanism to organic acid production for solubilization of mineral phosphates is the release of H^+ to the outer surface in exchange for cation uptake or with the help of H^+ translocation ATPase.
- Of all the organic acids, gluconic acid is the most frequent agent of mineral phosphate solubilization; it chelates the cations bound to phosphate, thus making the phosphate available to plants.
- Gram-negative bacteria solubilize mineral phosphate by direct oxidation of glucose to gluconic acid

... Inorganic Phosphate Solubilization

- Other mechanisms of mineral phosphate solubilization by microorganisms are the production of inorganic acids (such as sulphuric, nitric, and carbonic acids) and the production of chelating substances.
- It has, however, been reported that the effectiveness of the inorganic acids and the chelating substances in the release of phosphorus in soil is less than that of the organic acids.
- Another mechanism of microbial phosphate solubilization reported in the literature is the liberation of enzymes or enzymolysis, the mechanism of P solubilization by PSM in a medium containing lecithin where the increase in acidity is caused by enzymes that act on lecithin and produce choline

Mechanisms of Organic Phosphorus Mineralization

- The major source of organic phosphorus in soil is the organic matter.
- The values of organic phosphorus in soil can be as high as 30–50% of the total P and soil organic P is largely in the form of inositol phosphate (soil phytate).
- Other organic P compounds that have been reported are: phosphomonoesters, phosphodiesters, phospholipids, nucleic acids, and phosphotriesters.
- In addition, large quantities of xenobiotic phosphonates (pesticides, detergent additives, antibiotics, and flame retardants) that are regularly released into the environment also conta
- Phosphorus mineralization refers to the solubilization of organic phosphorus and the degradation of the remaining portion of the molecule.

... Mechanisms of Organic Phosphorus Mineralization

- The first groups of enzymes are those that dephosphorylate the phosphor-ester or phosphoanhydride bond of organic compounds.
- They are non-specific acid phosphatases (NSAPs).
- The most studied among these NSAPs enzymes released by PSM, are the phosphomonoesterases also referred to as phosphatases.
- These enzymes can either be acid or alkaline phosphomonoesterases. The pH of most soils where phosphate activities were reported ranges from acidic to neutral values.
- Another enzyme produced by PSM in the process of organic P mineralization is phytase.
- This enzyme is responsible for the release of phosphorus from organic materials in soil (plant seeds and pollen) that are stored in the form of phytate.

Absorption by Animals

- Phosphorus can be obtained by the animals either directly from the plants or indirectly through the consumption of animals that feed on plants.
- In comparison to rocks, the rate of the phosphorus cycle is quicker in living organisms such as plants and animals.

Return to the Environment Through Decomposition

- Microorganisms are responsible for the breakdown of dead plants and animals once they have passed away.
- Phosphorus in its organic form is converted into its inorganic form during this process.
- The resulting inorganic phosphorus is then returned to the ground and the water supply.
- Both the soil and the water will eventually become sediments and rocks, both of which will then weather and release phosphorus. Therefore, the phosphorus cycle begins all over again.