**Phosphorus**

In the tropics, phosphorus is often the most limiting plant nutrient.

* This is primarily due to the challenges in the management of phosphorus.
* In plants, the concentration of phosphorus ranges from 0.1-0.5%.

**Phosphorus Forms and Functions**

**Forms of Phosphorus available for Plant Uptake**

* The orthophosphates, H2PO4- and HPO42-, are the primary forms of phosphorus taken up by plants.
* When the soil pH is less than 7.0, H2PO4- is the predominate form in the soil.
* Although less common, certain organic phosphorus forms can also be directly taken up by plants.

**Functions of Phosphorus in Plants**

Phosphorus is involved in many plant processes, including:

* Energy transfer reactions
* Development of reproductive structures
* Crop maturity
* Root growth
* Protein synthesis

**The Phosphorus Cycle**

In contrast to nitrogen, the atmosphere does not provide phosphorus. Instead, orthophosphates originate largely from primary and secondary minerals and/or from organic sources. However, the phosphorus cycle is by no means less complex than the nitrogen cycle, and there are many factors that affect the availability of phosphorus in the soil. The diagram below is an illustration of the phosphorus cycle.

**Figure 11**. A representation of the phosphorus cycle. 

**PHOSPHORUS UPTAKE BY PLANT ROOTS**

Plant roots absorb phosphorus from the soil solution. In comparison to other macronutrients, the phosphorus concentration in the soil solution is much lower and ranges from 0.001 mg/L to 1 mg/L (Brady and Weil, 2002). In general, roots absorb phosphorus in the form of orthophosphate, but can also absorb certain forms of organic phosphorus. Phosphorus moves to the root surface through diffusion. However, the presence of mycorrhizal fungi, which develop a symbiotic relationship with plant roots and extend threadlike hyphae into the soil, can enhance the uptake of phosphorus, as well especially in acidic soils that are low in phosphorus.

For further information on mycorrhizal fungi and its use in Hawaii, click on the link below:
<http://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm14.pdf>

**PHOSPHORUS SORPTION AND DESORPTION**

**P-sorption** occurs when the orthophosphates, H2PO4- and HPO42-, bind tightly to soil particles.

Since phosphate is an anion, particles that generate an **anion exchange capacity** will form strong bonds with phosphate.

**Particles with anion exchange capacity:**

* Aluminum and iron oxides
* Highly weathered kaolin clays (under acidic conditions)
* Amorphous materials.

These particles are commonly found in many of the most highly weathered soils and high weathered volcanic soils of Hawaii. Since P-sorption results in a decrease of plant available phosphorus, P-sorption can become a major issue in many Hawaii soils.

Additionally, in **calcareous soils** P-sorption may occur as phosphates sorb to impurities such as aluminum and iron hydroxides or displace carbonates in calcium carbonate minerals.

**Factors that affect P-sorption**

* **Soil Mineral Type**: Mineralogy of the soil has a great effect on P-sorption.
	+ Volcanic soils tend to have the greatest P-sorption of all soils since volcanic soils contain large amounts of amorphous material.
	+ Following volcanic soils, highly weathered soils (such as Oxisols and Ultisols) have the next greatest P-sorption capacities. This is due to the presence of large amounts of aluminum and iron oxides and highly weathered kaolin clays.
	+ On the other end of the spectrum, less weathered soils and organic soils have low P-sorption capacities.
* **Amount of clay**: As the amount of clay increases in the soil, the P-sorption capacity increases as well. This is because clay particles have a tremendous amount of surface area for which phosphate sorption can take place.
* **pH**: At low pH, soils have greater amounts of aluminum in the soil solution, which forms very strong bonds with phosphate. In fact, a soil binds twice the amount of phosphorus under acidic conditions, and these bonds are five times stronger.
* **Temperature**: Generally, P-sorption increases as temperature increases.

Factors that decrease P-sorption:

* **Other anions**, such as **silicates, carbonates, sulfates, arsenate, and molybdate**, compete with phosphate for a position on the anion exchange site. As a result, these anions can cause the displacement, or desorption, of phosphate from the soil exchange site. Desorption causes phosphate availability in the soil solution to increase.
* **Organic matter** increases P availability in four ways.
	+ First, organic matter forms complexes with organic phosphate which increases phosphate uptake by plants.
	+ Second, organic anions can also displace sorbed phosphate.
	+ Third, humus coats aluminum and iron oxides, which reduces P sorption.
	+ Finally, organic matter is also a source of phosphorus through mineralization reactions.
* **Flooding** the soil reduces P-sorption by increasing the solubility of phosphates that are bound to aluminum and iron oxides and amorphous minerals.

**PHOSPHATE PRECIPITATION AND DISSOLUTION**

Phosphate precipitation is a process in which phosphorus reacts with another substance to form a solid mineral.

In contrast, dissolution of phosphate minerals occurs when the mineral dissolves and releases phosphorus.

Precipitation and dissolution reactions greatly influence the availability of phosphate in the soil.

* Phosphate minerals can dissolve over time to replenish the phosphate in the soil solution. This reaction increases the availability of phosphorus.
* On the other hand, phosphate minerals form by removing phosphate from soil solution. This reaction decreases the availability of phosphorus.
* However, both precipitation and dissolution are very slow processes.

**Solubility of Phosphate Minerals**

The solubility of phosphate minerals is very dependent upon soil pH.

* The soil pH for optimum phosphorus availability is 6.5
* At high or neutral pH, phosphate reacts with calcium to form minerals, such as apatite.
* Under acidic conditions, phosphorus may react with aluminum and iron to form minerals, such as strengite and varescite.

**MINERALIZATION AND IMMOBILIZATION OF PHOSPHATE**

In an average soil, approximately 50% of total phosphorus is organic. Thus, soil organic phosphorus is a very important aspect of the P cycle.

**The various sources of organic phosphorus include**

* Phytin
* Nucleic acids
* Phospholipids

Like nitrogen, organic phosphorus is converted to inorganic phosphate through the process of mineralization.

The immobilization of inorganic phosphate, in contrast, is the reverse reaction of mineralization. During immobilization, microorganisms convert inorganic forms to organic phosphate, which are then incorporated into their living cells.

Mineralization and immobilization of phosphorus occur simultaneously in the soil. Ultimately, the C:P ratio determines whether there is net mineralization or net immobilization.

* When the C:P ratio is less than 200:1, net mineralization prevails. Net mineralization indicates that there is enough phosphorus in the soil to sustain both plants and microorganisms.
* When the C:P ration is between 200:1 and 300:1, immobilization and mineralization rates are fairly equal.
* When the C:P ratio is greater than 300:1, net immobilization occurs. During immobilization there is not enough P to sustain both plants and microorganisms; and so, microorganisms scavenge the soil for P.

**Factors affecting mineralization and immobilization**

The factors that affect P mineralization and immobilization are the same that affect nitrogen mineralization and immobilization:

* Temperature
* Moisture
* Aeration

**Management of phosphorus—P-fixation**

P-fixation is a term that is used to describe both P-sorption and P precipitation. Since both P-sorption and P precipitation reduce phosphorus availability, a soil with a great P-fixation capacity has less available phosphorus after fertilization than a soil with a low P-fixation capacity.

In other words, when the same amount of fertilizer is applied to a volcanic soil and a moderately weathered grassland soil, the volcanic soil has less P available due to its greater P-fixation capacity.

**How do we determine how much phosphorus to add?**

The answer is that we must account for the P-fixation capacity of the specific soil. For some Hawaii soils, researchers have determined the P-fixation capacity as various levels of phosphorus is added to the soil. This information allows us to predict how much phosphorus must be added to the soil to achieve a target phosphorus level. To view the P-sorption curves for selected soils, click on the link below:
<http://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm9.pdf>

**PHOSPHORUS LEACHING AND RUNOFF**

In Maui County and other tropical regions, highly weathered soils often provide little available phosphorus for plant growth. To further compound this issue, agricultural systems can experience phosphorus losses as the result of erosion by wind and runoff water. Erosion by wind can carry particles that contain sorbed-P to water systems, where phosphorus may later desorb. Sediments containing phosphorus can also contaminate ground and/or surface waters. Additionally, phosphorus availability is reduced by the removal of plant material (which can serve as a source of organic phosphorus) during harvest.

Although phosphorus leaching is normally limited in most Hawaii soils due to their high P-fixing characteristics, phosphorus leaching can occur if the soil reaches maximum phosphorus holding capacity, especially when P fertilizers are overapplied. Sandy soils are most susceptible to phosphorus leaching. The consequence of phosphorus leaching is the contamination of ground water reserves.