

# Phosphorus Cycling in the Agricultural Landscape

## Introduction and Purpose

Crops often receive beneficial nutrients such as phosphorus (P) from manure and/or commercial fertilizer applications. However, the Delaware Nutrient Management Law limits the amount of P that can be applied to many agricultural soils in Delaware. These restrictions were instituted in response to elevated soil test P concentrations following historical poultry litter application at rates that exceeded crop P removal. Elevated soil test P levels, as well as improper use of manures/fertilizer containing P, can increase the risk of P transport from the field by rain or irrigation water to nearby water bodies, which can potentially lead to pollution of the water body. Understanding how P behaves in agricultural soils can help maximize crop productivity and minimize harmful losses of P to local waterbodies. This document helps agricultural producers understand how P interacts in the environment through the P cycle to guide maintenance and sustainability of agricultural crop production. Each agricultural crop differs in crop P removal rate. Therefore, fertilizer and manure applicators should consider the balance between P levels in the soil and removal rates per harvest and hydrologic conditions affecting the loss potential of P.

## The Phosphorus Cycle

### Sources of Phosphorus

We begin our discussion of the P cycle in a typical grain crop rotation (corn, wheat, double-crop beans) by considering the plant residue left on the field surface after harvest. Crop residues that are left on the soil surface or incorporated into the topsoil during tillage provide a source of organic matter to the soil. These crop residues contain forms of P that are not available for uptake by growing plants. However, soil microorganisms, including bacteria and fungi, change the complex, unavailable forms of P into an inorganic form that is plant-available. Inorganic P can then be dissolved in the water held in the soil (soil solution) and can be taken up by the roots of the next growing crop in the rotation. The cycle repeats when this crop is harvested (Figure 1). This description is a very simplified example of the P cycle; we will now go into more detail.

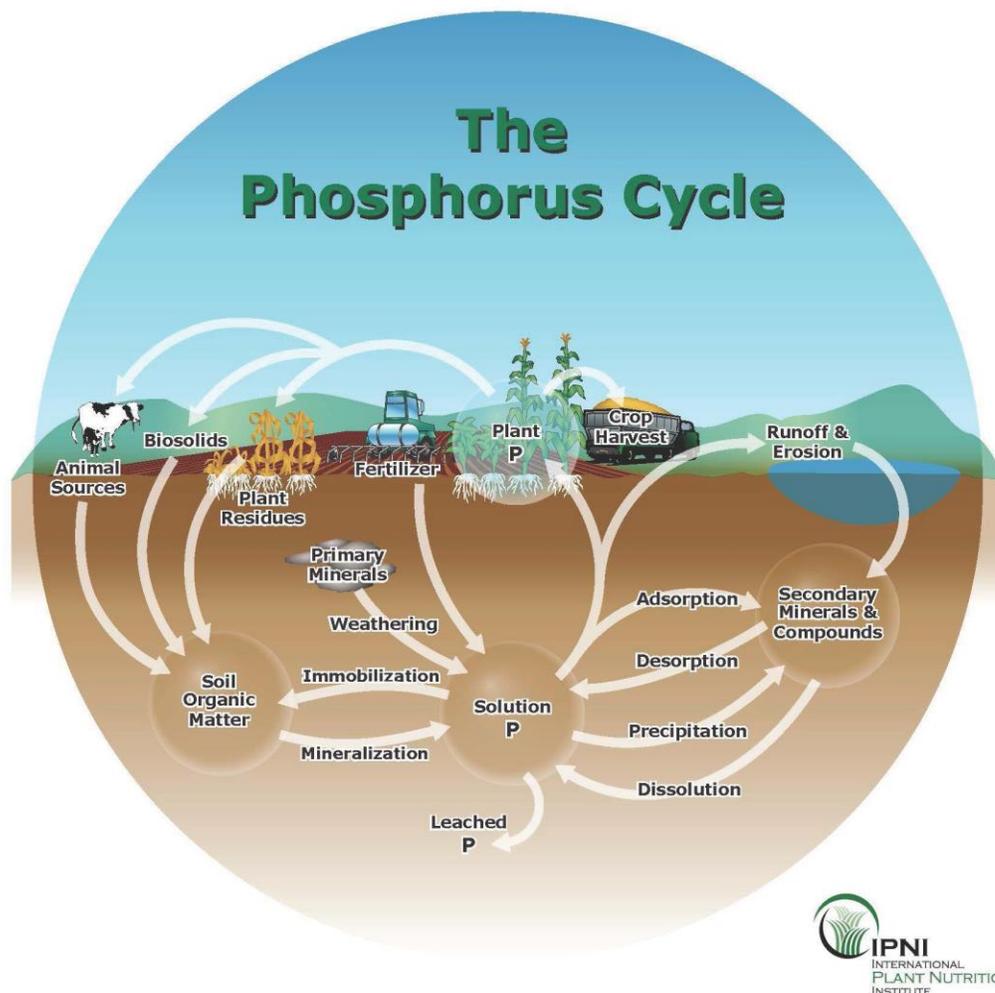


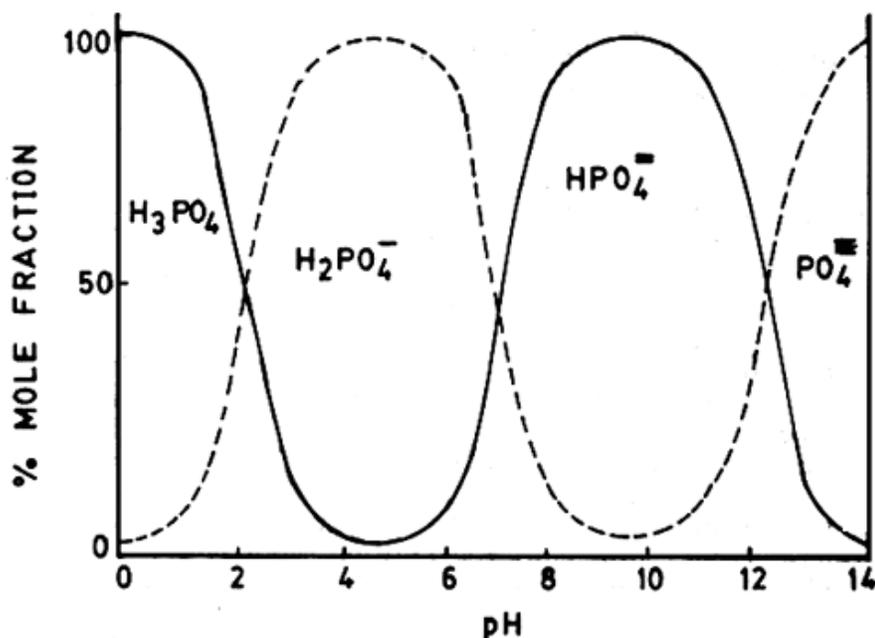
Figure 1. The phosphorus cycle. (Credits: IPNI)

Decaying plant residues are not the only source of P in the soil. Manure and other organic residues (e.g., biosolids, composted manures, food waste residuals) contain phosphorus in plant available (soluble P), slowly available (phosphorus minerals and P attached to mineral surfaces), and plant unavailable forms. These materials are typically derived from plant residues or animal wastes. Like the crop residue in our earlier example, the forms of P in these materials that are not available to the plant must be converted to soluble P by soil microbes. Commercial P fertilizers are also available for use in crop production. Most of these materials are derived from P rich rocks that were deposited in ancient sea beds many years ago. This P rich material is mined from the earth and processed into more soluble P forms that plants can use. The ability of these P fertilizers to dissolve in soil water depends on the chemical form.

### How Does Phosphorus Behave in the Soil?

Phosphorus must be dissolved in the soil solution to be taken up by plant roots. The dissolved forms of plant-available P in the soil solution are called orthophosphates ( $\text{H}_2\text{PO}_4^-$  or  $\text{HPO}_4^{2-}$ , depending on the soil pH; Figure 2). The amount of P dissolved in the soil solution at any particular time is usually very small.

Figure 2. Various forms of orthophosphate in soil solution at different pH levels. (Figure credit: FAO adapted from Boyd, 1982)



Once plant roots remove P from the soil solution, it is replenished by the residual P in the soil. We previously discussed how soil microbes transform organic forms of P in plant residues or organic soil amendments into plant-available P. This process is called mineralization, and the end products are soluble the plant-available orthophosphates. Once in the soil solution, the orthophosphate form of P can be taken up by plant roots. The soil solution can also be replenished from several pools of inorganic (mineral) P in the soil. Solid P minerals in the soil can dissolve in the soil solution when concentrations of soluble P diminish. This process can be compared with adding sugar to a glass of iced tea. When solid sugar is added to tea, it will dissolve in the liquid. Phosphorus can be attached to soil particles such as clay or specific minerals that contain iron (Fe) or aluminum (Al). Phosphorus can detach from these soil particles, thereby supplying P to the soil solution via a process called desorption. Finally, solid rocks can be a source of P as they break down into soil over a long period of time by a process called weathering.

Just as soil solution P can be replenished when the concentration of P becomes low, P can be removed from the soil solution if the amount of P in the soil solution gets too high. Consider the iced tea example again. If too much sugar is added to the tea, some of it will not dissolve and will remain in solid form at the bottom of the glass. Similarly, when concentrations of P in the soil solution are too high, some of the dissolved P will form solid P minerals by a process called precipitation. Depending on soil pH, precipitation can result in the formation of solid calcium phosphate minerals (high soil pH) or aluminum and iron phosphate minerals (low soil pH). Alternatively, P can be removed from the soil solution and attach to soil particles like clays or iron (Fe) and aluminum (Al)-bearing minerals via a process called adsorption.

## Phosphorus and Water Quality

Phosphorus can move from the soil to surface or groundwater as the field drains following heavy rain or excessive irrigation. When the rainfall or irrigation rate is higher than the soil's ability to absorb water, the result is runoff. Runoff can transport soluble P, P attached to eroding soil particles, plant residues, and/or any recently applied commercial fertilizers into lakes, ponds, streams, rivers and bays. The risk for soluble P losses is increased when the concentration of P in the soil exceeds the natural soil P holding capacity. The sandy soils of Delaware have naturally have low P-holding capacity. In some cases, P can be carried downward, or leached, through the soil and may eventually reach groundwater.

Once transported into water bodies or groundwater, inorganic P can become a water pollutant. For example, P lost in runoff or leachate may contribute to eutrophication of Delaware's surface water bodies. Eutrophication is the enrichment of water with nutrients that results in excessive aquatic plant (mostly algae) growth. With time, oxygen depletion of eutrophic waters can lead to fish kills and the accompanying foul smell. Eutrophic water bodies can often no longer be used for fishing, swimming, boating, or other recreational activities.

### Can I Test My Soil for Phosphorus?

Phosphorus is one of the elements for which soil testing is useful. When testing is performed by a reputable agricultural laboratory, the results indicate the relative availability of soil P. Soil test results help producers and consultants properly manage application of manure. The soil test report from the University of Delaware Soil Testing Program (<http://ag.udel.edu/dstp/index.html>), or other reputable regional laboratory, will include recommendations for P fertilizer rates for crops if results indicate that P fertilization is necessary.

Contact your county Extension office for more information about soil testing and taking a soil sample.

### How Can You Help Protect Water Quality

As a grower in Delaware, you can help protect water quality by following best management practices (BMPs) when using fertilizers and manure. Fertilizer and manure applications are restricted to a three year crop-removal rate on "high P" soils (>150 FIV) to protect water quality. Alternatively, growers may opt to conduct a P Site Index to determine if other P management strategies (i.e., N-based management during one or more years of a crop rotation) are permitted.

### References

Boyd, C.E. 1982. Liming fish ponds. *Journal of Soil and Water Conservation* 37:86-88.

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