Welcome to the Phosphorus Fixation Training Module.
Click to next slide.
Phosphorus (P) is an essential element and classified as a macronutrient because of the relatively large amounts of P required by plants.

Phosphorus is intimately involved in the transfer of energy from one reaction to drive another reaction in cells.

Phosphorus is a necessary element for plant growth, metabolism and reproduction and is a limiting factor to plant productivity on an estimated 40% of the world’s arable soil.

1. Phosphorus is often referred to as the “Master Key Element,” involved in a broad array of functions that impact plant growth and metabolism.
2. Cell division, growth, photosynthesis, energy transfer and nutrient transfer are a few examples of functions that are influenced by phosphorus.
3. Click to next slide.
The main inorganic forms of phosphorus in dry fertilizers (as well as a few liquids) are HPO$_4^{2-}$ and H$_2$PO$_4^-$ (orthophosphate anions).

These anions are highly reactive and quickly engage in adsorption reactions on the surface of mineral particles and organic matter in the soil. These “fixation” reactions decrease the availability of soluble phosphates for plant uptake.

1. In soil, P exists chiefly as orthophosphate ions.
2. The type of orthophosphate ions that exist in the soil are primarily dependent on pH and soil type.
3. Click to next slide.
The Phosphorus Cycle
In Turfgrass

Phosphate fixation reactions in soil profiles typically allow only a small fraction (10-20%) of phosphorus in fertilizers to be taken up by plants.

These reactions also contribute to the pollution of water sources.

1. Read slide.
2. Let’s review the Phosphorus Cycle and review where these reactions occur and how they can be problematic to effective management of this important and certainly essential element.
3. Click to next slide.
1. As you can tell by the direction of all the arrows, the phosphorus cycle is quite complex – as are the adsorption reactions involved in the cycle.
2. The types of reactions and complexes that phosphate ions form may be better understood if we break this into smaller components.
3. Click to next slide.
1. Although the phosphate ion can occur in three states, at pH values normally found in soils (4.5 - 6.2), $\text{H}_2\text{PO}_4^-$ and $\text{HPO}_4^{2-}$ are the dominant ion species that form following phosphate fertilizer application.

2. Click to next slide.
The Phosphorus Cycle

H$_2$PO$_4^-$ and HPO$_4^{2-}$ can be found in many forms, but in general, they are found most often in 3 “phases, or pools”

1. Read Text
2. Click to next slide.
1. The **Soil Solution** pool is extremely small and may contain on a fraction of a pound of P per acre.
2. It is the **only** pool from which plants take up P and is the only pool with any measurable mobility.
3. Must be constantly replenished.
4. Click to next slide.
1. Turfgrasses uptake phosphate only from the soil solution pool.
2. Click to next slide.
1. The **Active P** pool is in a solid phase, formed through: 1.) loosely held inorganic complexes and are usually held on the soil surface, 2.) phosphates that react with elements such as iron, aluminum or calcium to form somewhat soluble soilids and 3.) organic P that is easily mineralized.

2. As the phosphate concentration of the soil water decreases, some phosphate from the Active pool is released.

3. This may seem like what happens during cation exchange, but in actuality, it is quite different.

4. Click to next slide.
1. The active P pool is the main source of available P for crops.
2. Click to next slide.
1. Illustration of phosphorus fixation reactions involving iron oxide and aluminum oxide. While the adsorbed phosphate is labile and considered to be in a reversible (desorbable) condition, it may be months or years before biological or chemical conditions exist to release the phosphate.

2. The phosphate anion is not strongly adsorbed and may return to the soluble phase over time. However, labile P is only a very small fraction of total soil P.

3. Adsorption reactions can also occur between phosphates and organic matter.

4. Organic solubilization is accomplished through microbial mineralization.

5. Click to next slide.
1. The Active pool is supplemented / refreshed via microbial mineralization of turfgrass residue containing P.
2. While a “cycle” appears to have been constructed here, the fate of applied phosphates that become unavailable or “fixed” requires further explanation.
3. Click to next slide.
1. The **Fixed** pool of inorganic and organic phosphate compounds are very insoluble and may remain in soils for years without being made available to the soil.
2. Some very slow conversion between the Fixed pool and the Active P pool does occur in soils.
3. Have very little impact on soil fertility.

**The Phosphorus Cycle**

A **Fixed** pool – comprised of inorganic phosphate compounds that are very insoluble and organic compounds that are resistant to mineralization.
1. Phosphate fixation refers to the processes that retrain P availability and efficiency.
2. It involves a series of reactions that remove P from the soil solution and render it unavailable for plants.
3. Click to next slide.
1. Phosphate fixation reduces P efficiency to 10-20% -- either temporarily or permanently depending on the stage of the fixation reactions.
2. Click to next slide.
Under low pH conditions, significant amounts of exchangeable iron (Fe3+), aluminum (Al3+) and manganese (Mn3+) are released which build rapidly on mineral surfaces and in the soil solution.
1. Different types of adsorption reactions can occur and may proceed in a series of reactions that interlocks the phosphates.
2. Some of the reactions may be reversible and allow phosphate availability and others render P unavailable.
3. Click to next slide.
1. Illustration depicting phosphate **fixation reactions** between iron / aluminum and phosphate through the creation of coordinate (chelation) bidentate linkages. This results in **very strong bonds that take a much longer time to desorb**.

2. These bond configurations are much stronger than single atom bonds (monodentate bonds). Processes that form these types of adsorption complexes are **often referred to as chemisorption, specific adsorption, or ligand exchange**.

3. Click to next slide.
1. Here we see the worst case scenario.
2. Phosphates trapped by a metal mantle coating are usually deemed as permanently fixed and cannot be desorbed (released) under normal soil conditions.
3. This usually occurs under very acidic conditions.
4. Click to next slide.
1. In alkaline soils, soluble phosphate ions quickly react with calcium to form a sequence of products of decreasing solubility.
2. Click to next slide.
1. Example of initial fixation reaction of calcium carbonate with phosphoric acid resulting in the formation of Dicalcium Phosphate.
2. Continued reactions between calcium carbonate and phosphate ions result in formation of even more insoluble phosphate compounds.
3. Click to next slide.
Clearly, Phosphorus fixation is highly problematic. Conversion of phosphates into unavailable forms in the soil depletes the amount of P available for plant uptake. The efficiency of plant uptake of Phosphorus from applied fertilizers is usually around 30% or less.
Adequate Phosphorus nutrition depends on the ability to replenish the soil solution with dissolved phosphate anions to meet plant demand. For over 100 years in the United States, applications of fertilizers containing phosphates have been used to compensate for phosphate fixation.
1. Active and fixed phosphate compounds on the soil surface can be washed away and find themselves polluting water resources.
2. Fertilizer restrictions are being implemented in many areas of the United States in an attempt to protect surface waters from phosphorus nutrient pollution causing water quality degradation, harmful algal blooms and negative effects on drinking water.
3. We expect that regulatory use limitations assigned to fertilizers containing phosphates will continue to expand.
1. While the need to prevent nutrient pollution from P needs to be addressed, regulatory prohibition or limitation of P in fertilizers needs to be balanced with efforts to develop more efficient tactics to recover soluble phosphates “fixed” in the soil.
2. Continued on Phosphorus Module 4b.