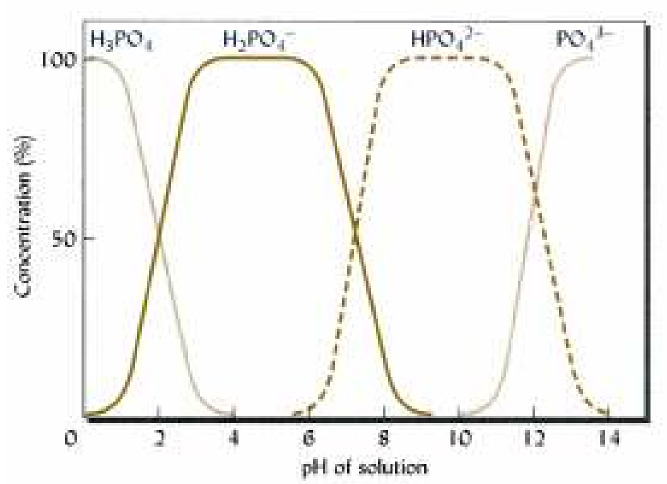
Phosphorus in Soils

Phosphorus is a very stable element in soils. It does not form a gas (like ammonia) and does not readily leach (like N compounds & K ions). The reason for the stability of phosphate compounds in soils is that they are very reactive with other compounds, which become increasingly insoluble in the soil.

Phosphates are taken up by plants in various forms, depending on pH of soil and to some extent organic matter. As the chart indicates when the pH range is from pH 4.0 to 5.5 phosphorus is taken up as $H_2PO_4^-$. At a higher pH range, the element is taken up as HPO_4^{2-}. In most soils were the pH ranges from 5.5 to 7.5, the P is taken up as a combination of the above. Phosphorus is also taken up in organic forms. Organic P can be directly taken up, or converted at the root interface.

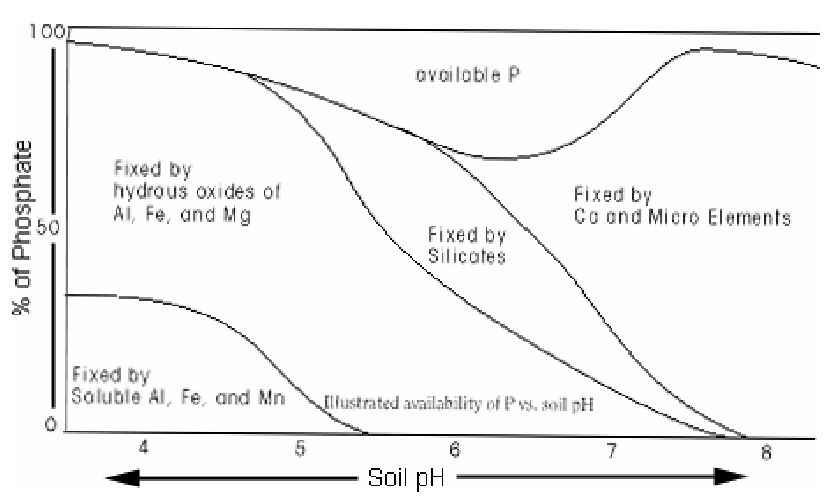


Phosphate Compounds in Soils	
Low pH, acid soils (<7.0)	*High pH, alkaline soils(>7.0)*
Iron & Aluminum Compounds	Calcium Compounds
Organic P Compounds	Organic P Compounds

Phosphates are most available in soils at a pH range of 6.0 to 7.0 as the chart indicates.

As the pH moves from acid or alkaline to neutral the Ca – P and Al or Fe – P compounds become more soluble.

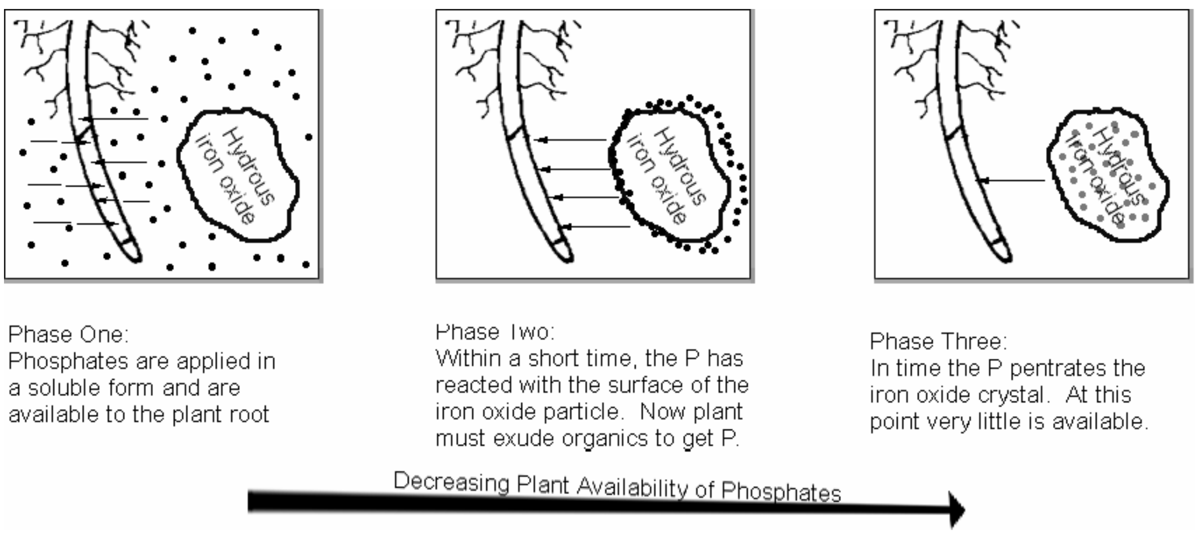
Solubility of these compounds is also time dependent.



Solubility of Phosphate Fertilizers

The solubility of phosphate fertilizer applications is also very time dependent. Immediately after applications (especially in pH of <5.5 or >7.5) the phosphate begins to tie up with either iron (Fe) or aluminum (Al) compounds in acid soils, or calcium (Ca) compounds in basic (high pH or alkaline) soils. However, if the mineral/phosphate particle is in the vicinity of the plant root, the P can still be utilized, until enough time passes that the P is more tightly bound and less available.

For example, an application of soluble phosphate fertilizers on an acid soil will be available for only a short time. (The more acidic the soil, the shorter the time.) The phosphates are first available for plant uptake. However, with a spring application of P, there is very little root growth. Soon the phosphate have reacted and absorbed to the iron (or aluminum) particle. At this time the phosphate is not tied up, but is available to plants roots, especially under conditions where the plant excretes organic acids and help solubilize the P. As time passes, the phosphate penetrates the iron crystal further and becomes very unavailable.



Phase One:
Phosphates are applied in a soluble form and are available to the plant root

Phase Two:
Within a short time, the P has reacted with the surface of the iron oxide particle. Now plant must exude organics to get P.

Phase Three:
In time the P pentrates the iron oxide crystal. At this point very little is available.

In high pH soils, free phosphorus compounds quickly bind with calcium carbonate ($CaCO_3$) to form mono-, di- and tri- calcium phosphates with become increasingly insoluble as more calcium reacts. These insoluble compounds also can form is other cations such as iron, zinc, manganese, magnesium, etc. Although tri-calcium phosphate is quite insoluble, with time, even more insoluble compounds form such as; Oxy apatite (tri-calcium phosphate + CaO), hydroxy apatite, carbonate apatite and fluorapatite.

Some of this chemistry is important to understand to better manage phosphates in acid or alkaline soils. Phosphate fertilization is one area that in most cases simply management applications and types of P can result in up to 40% to 75% reductions in actual P needed.

Phosphates & Clay Types

As with potassium and other cations, the type of clay present in the soil also plays an important role in regulating phosphorus availability. Some clay has strong positive sites that are a result of their chemical structure. This is anion exchange capacity (AEC). Allophane (associated with volcanic ash) is such a type of clay. Generally, the order in which clay types effect the fixing of phosphates is as follows (from strongest to weakest):

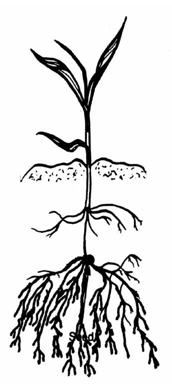
Amorphous Al, Fe, Mn oxides & Allophane >> Crystalline Al, Fe & Mn Oxides >> Carbonate crystals >> 1:1 Clay >> 2:1 Clay.

This once again points out the importance of understanding clay types and structure to be able to better plan and apply fertilizers.

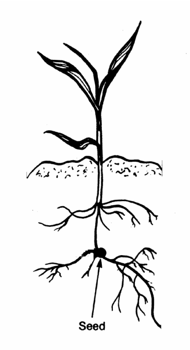
Practical Controls of Phosphate Availability

Placement – In row and banding are the best available methods of phosphate applications in soils that tend to tie up soluble sources of P. This is especially important as a starter, for many plants utilize up to 50% of their total P requirements in the first 2 to 3 weeks of development. Phosphate is very immobile in soils and therefore when young root growth is slow, or poor, phosphate uptake is severely limited. Placement in the immediate vicinity of newly developing root hairs is important.

Combination with Ammonium – Using ammonium in the same band as the phosphates greatly enhances the uptake of P, especially in alkaline soils. Plant roots tend to manufacture and excrete organic acids when they take up ammonium forms of N. This leads to the production of chelating agents that compete with the cations to help prevent phosphate tie up. Remember that ammonium can also burn and damage plant roots.



Early Root Growth – One of the most overlooked tools in phosphate utilization is the in row placement of a small amount of nutrients with a biological material that stimulates root development. Materials such as mono-ammonium phosphate (MAP) are important to increase the early root development of plants. Phosphate uptake is very dependent on root surface area to soil surface area contact. Doubling the size of the root system in the first 2 – 3 weeks of growth can double the P uptake efficiency. *Best advice - row place ortho-phosphate & rooting agents.*



Control of Soil pH – Maintaining a pH from 6.0 to 7.0 is a valuable tool is practical. This is especially important to consider when growing high value crops such as vegetable, which are generally weak in phosphate uptake in phosphate poor soils. However, the value of the crop verses the inputs of liming or acidifying materials can often be justified. Fortunately, many low value crops such as wheat or barley, have root systems and root microbiology that is very efficient at take up phosphates under poor conditions, especially when the root system is started properly.

Increasing Organic Matter & Organic P Forms – Creating conditions whereby phosphate compounds can be incorporated into organic forms is the best long-term practice available. This includes applications of manure, compost and organic wastes whenever possible. In many instances, the value of high dollar crops can also justify utilizing a green manure crop in the rotation. Green manure crops that have strong and deep growing root systems will do much more than increase phosphate uptake.

Utilizing organic compounds with soluble phosphate fertilizers is another useful tool. Especially when the two can be placed in a concentrated band. Humic acids and other organic acids are often used with success.

Organic forms of P in soils occur in four major forms. Although the first three are found in plants, it is not plants that supply these forms to soils, but soil microorganisms, which produce the compounds in the soil.

1) Inositol phosphates or phosphate esters of a sugar like compounds. These are the most commonly occurring compounds.
2) Nucleic acids are a source of organic P, but only a small amount is found in most soils (1 – 2%).
3) Phospholipids, the "filter" or membrane of cells. Again, only a very small amount of organic P is found in this form (1 – 2%).
4) Bound with certain humic acid compounds.

Many other organic compounds of phosphate are known. However, little is understood about the organic structures that complex phosphates like fulvic acids and other low molecular weight organic compounds. This does not detract from the fact that they are important.

Plants can also utilize organic compounds of phosphorus directly. The amount of organic P that plants can use is thought to be small in comparison to inorganic forms of phosphate like $H_2PO_4^-$ and HPO_4^{2-}. However, roots are not "bare" tissues growing through the soil, they are surrounded by microorganisms which act as powerful chemical manufacturing plants which can process and make available many types of phosphate forms.

Mycorrhizal Fungi & Phosphorus

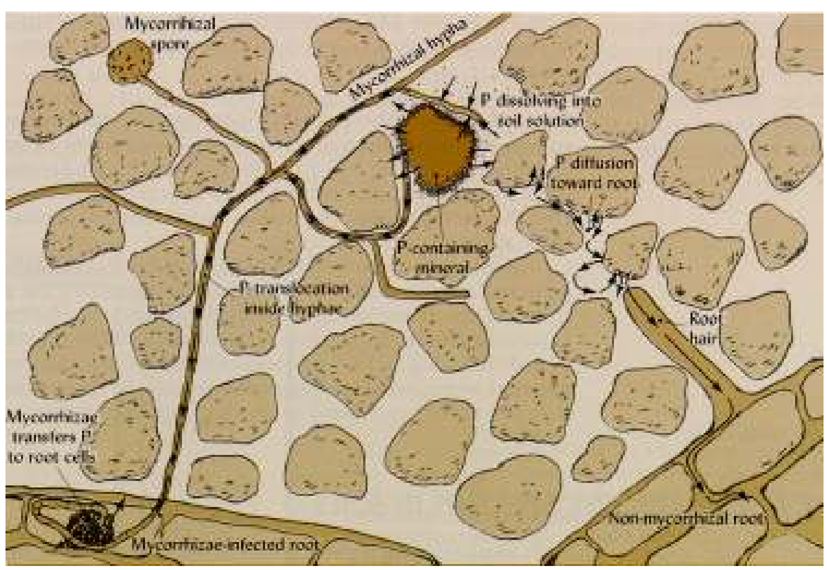
One of the most important mechanisms of phosphate uptake is the effect of beneficial fungi on the roots of most plants. The word mycorrhiza means "fungus root". This growth is a symbiotic (mutually beneficial) relationship between the plant root and the fungus. Mycorrhizal fungi gets its energy from the photosynthetic capabilities of the plant, therefore it does not have to compete with other organisms in the soil for food energy. A plant can lose as much as 5% to 10% of its photosynthate production to the root fungi. However, the benefit is definitely mutual for the plant as demonstrated by the improved nutrient uptake of corn in the table below.

Effect of Inoculation with Mycorrhiza and of Added Phosphorus on the Content of Different Elements in the Shoots of Corn

Nutrient Levels are expressed as micrograms per plant (from; Lambert et al, 1979, Soil Sci Amer. J, v43)

	No Phosphorus Added		25 mg/kg Phosphorus Added	
Element in Plant	No mycorrhiza	Mycorrhiza	No mycorrhiza	Mycorrhiza
P	750	1340	2970	5910
K	6000	9700	17500	19900
Ca	1200	1600	2700	3500
Mg	430	630	990	1750
Zn	28	95	48	169
Cu	7	14	12	30
Mn	72	101	159	238
Fe	80	147	161	277

In soils low in phosphates, some plants can barely survive without the support of mycorrhiza on the root. Mycorrhiza works by acting as an extension of the root system. With phosphates this is important because they are easily immobilized in soils. As the diagram below illustrates, the fungi act as a pipeline for P uptake.



Phosphate Interactions with other Elements

Nitrogen

- ✓ For most crops a N:P ratio of 10:1 is consider optimum.
- ✓ In alkaline soils ammonium base P fertilizers are the best for application of P

Calcium

- ✓ Increased soluble Ca in solution tends to increase P uptake because Ca stimulates the transport of P at the micochondrial membranes.
- ✓ Calcium in high pH soils ties up P.
- ✓ High bicarbonate irrigation water can also affect P uptake.
- ✓ Humic & other organic acids can also complex Ca to protect P availability.

Magnesium

- ✓ Magnesium is an activator of kinase enzymes and activates many reactions involving phosphate transfers.

Minerals & pH

- ✓ Aluminum (Al) will restrict P uptake in low pH soils. It can bind with P and be taken up by the root, but availability to the plant is unclear.
- ✓ Iron (Fe) can also interfere wit the absorption, translocation and assimilation of P by forming iron phosphates (mostly in low pH soils).
- ✓ High levels of P (fertilizer application included) induce Zn deficiency. A ratio of P:Zn of 100:1 should be maintained.

Soil Type

Highly Weathered Soils (Ultisols & Oxisols) - Low organic matter:

- ✓ Inorganic P - too soluble, ties up rapidly (VAM essential)
- ✓ Organic P - readily decomposable & most effective form.

Less Weathered Soils (Mollisols & Vertisols) - Even in higher organic matter:

- ✓ Inorganic P - Best form (Chemical Fertilizers)
- ✓ Organic P - Less available - High amounts of organics actually "tie up" applied P.