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PHOSPHORUS IN KENTUCKY SOILS

Sources/Fixation/Release

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Sources, Fixation, Release

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Phosphorus is 1 of the 16 or more plant food elements that are essential for crop growth. When plants do not get enough phosphorus, root and top growth are stunted; blossoms, fruits, and seeds do not develop properly; yields are low and often maturity is delayed.

Knowing how chemical reactions affect the availability of phosphorus to plants will help farmers develop better soil fertility programs, thus resulting in more economical crop production.

The phosphorus contained in the plow layer of Kentucky soils will range from a few hundred to several thousand pounds per acre. Table 1 shows the total phosphorus content from experiment fields located throughout Kentucky.

Table 1. Total Phosphorus Content of Some Major Soil Types in Kentucky[a]

Soil Class	Location of Experiment Field	Total Phosphorous Content per Acre Plow Layer
		Pounds
Maury silt loam	Lexington	12,400
Crider silt loam	Princeton	780
Tilsit silt loam	Princeton	900
Monongahela silt loam	Berea	880
Wellston silt loam	Fariston	820
Bedford and Dickson silt loam	Campbellsville	1,100
Tilsit catena silt loam	Greenville	660
Grenada silt loam	Mayfield	960

[a] Kentucky Agricultural Experiment Station Bulletin 397, *Soil Management Experiments* (out of print—copies available only at libraries)

The total phosphorus content of most of the other soil types in Kentucky falls somewhere between the lowest and the highest recorded in Table 1. Relatively few, however, approach the Maury silt loam.

A 100-bushel corn crop (stover included) contains at maturity about 25 pounds of elemental phosphorus. Four tons of alfalfa hay requires about 20 pounds of this element. Other crops grown in Kentucky likewise require relatively small amounts of phosphorus. Even though the total phosphorus content of Kentucky soils is well above the amounts found in crops, additional phosphorus is required on most of them for good crop production.

The reason for this is the wide difference between the amounts of "total" and "available" phosphorus in the soil. The "available" phosphorus is that part of the "total" phosphorus that is potentially usable by a crop during a growing season. The "total" phosphorus, on the other hand, includes that part that is available plus the much larger amount that is not immediately available to the crop. Terms that are commonly used by soil scientists to describe this phosphorus are "insoluble," "fixed" or "unavailable." However, a small part of this phosphorus is slowly soluble and can convert itself to an available form. This process is called "phosphorus release." Likewise, available phosphorus can revert to the unavailable forms. This process is commonly called "phosphorus fixation." These two processes will be discussed more fully later.

SOURCES OF SOIL PHOSPHORUS

The wide variations of the phosphorus content of Kentucky soils can be attributed to two sources:

1. *Native Phosphorus* This is the phosphorus that was in the parent rock from which the soil was formed. Originally it was mostly a constituent of the phosphorus-bearing minerals generally referred to as apatites. Chemical and biological reactions in the soil slowly released it from the apatites as the parent rock weathered and decomposed to form the soil. Thus, a soil may be low or high in phosphorus depending on the parent rocks from which the soil originated. The Maury silt loam (Table 1) is a good example of a soil derived from parent rocks with a high content of phosphorus-bearing minerals. Likewise, the Tilsit catena silt loam (Table 1) is a good example of the opposite.

Alluvial (deposited by water) soil materials may have been transported some distance from their area of origin. However, they too may be low or high in native phosphorus content depending on the composition of the parent material.

2. *Applied Phosphorus* Phosphorus in commercial fertilizers has been applied, sometimes in large amounts, to many Kentucky soils. Thus, the original phosphorus content, particularly that in the plow layer, may have been increased by these phosphorus applications. Much of the tobacco land is a good example. On the other hand, the phosphorus content may have decreased where plant removal has been greater than phosphorus applications.

PHOSPHORUS FIXATION AND RELEASE

The sand and silt fractions of a soil are made up largely of quartz and other minerals which are resistant to weathering or decomposition. They may contain phosphorus and other nutrient elements; however, since they are generally insoluble, their ability to release phosphorus is very low. Also, because of their physical and chemical nature, their ability to attract or fix phosphorus is very low. Hence, in very sandy soils, there may be little phosphorus fixation or release.

On the other hand, the clay minerals of a soil, often called colloidal material, are relatively active chemically. They are capable of adsorbing phosphorus that is in the soil solution (soil moisture) because of the electrical charges that surround them. The clay minerals also are capable of releasing the adsorbed phosphorus back to the soil solution (phosphorus release). This reaction of phosphorus and the soil colloids is often called "anion exchange."

In the process of soil formation, iron, aluminum, and calcium are released from the parent rock. Phosphorus will, under certain soil conditions, combine with these elements to form insoluble compounds (phosphorus fixation). If soil conditions change (for example, due to liming acid, soils), these compounds can release phosphorus to the soil solution (phosphorus release).

Growing plants obtain phosphorus from the soil for their food supply. When these plants die and return to the soil as organic matter, this phosphorus will be returned to the soil solution through the processes of decay (phosphorus release). However, because of the electrical charges surrounding the humus particles (also called collodial material), these particles may adsorb phosphorus just as the clay minerals do (phosphorus fixation).

The soil conditions under which phosphorus fixation and release occur will be discussed more fully later.

AVAILABLE PHOSPHORUS

As already stated, "available phosphorus" is that part of the total phosphorus in a soil that is potentially usable by a crop during a growing season. It includes the phosphorus in the soil solution plus part of the phosphorus that is adsorbed by the soil colloids. Some of the adsorbed phosphorus is so loosely attached that it can be picked off by plant roots if these roots grow in close proximity to the phosphorus. Also an electrical imbalance may develop between the plant root and the soil colloid which is strong enough to pull the phosphorus away from the colloid.

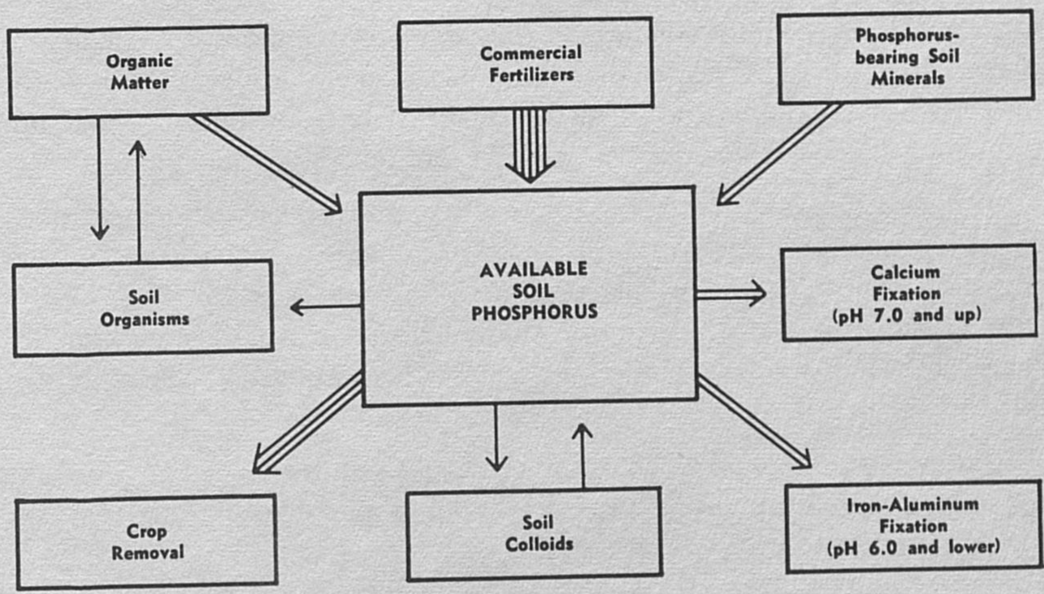
Phosphorus in commercial fertilizers is guaranteed to be in an "available" form, meaning that it is soluble in a standardized extracting solution (water or citric acid) that supposedly simulates a normal soil solution. This phosphorus is "available" until it is placed in the soil complex. It does enter the soil solution as it is guaranteed to do, but in the presence of the soil colloids and other elements, it may become fixed as described above. This chemical reaction is sometimes called "phosphorus reversion." This phosphorus "fixation" or "reversion" explains why soils may test low in available phosphorus even though phosphate fertilizers have been recently applied.

Chemical reactions in a soil are such that somewhat of a balance is maintained between the levels of available phosphorus and fixed phosphorus. As growing crops remove the available phosphorus from the soil solution, fixed phosphorus will move into the soil solution to maintain the soil balance. A standard soil test will show the amount of phosphorus available at the time the sample was collected. It does not show all the fixed phosphorus that can move into the soil solution over a long period as the available phosphorus is removed. This explains why a soil that has had recent applications of phosphorus may test low but yet have enough to produce good crops. It also shows the need for knowledge of the soil itself, recent phosphorus applications, past crop growth, along with the results of a soil test, before phosphate fertilizer programs are planned.

The preceding discussion and Fig. 1 point out that phosphorus in the soil may be a part of several complex compounds. The amounts of phosphorus "fixed" in a soil depend on the amount and kinds of clay minerals and organic matter present and the reaction (pH) of the soil. Hence, a heavy clay soil or one high in organic matter will "fix" more phosphorus than a sandy soil or one that is low in organic matter. Likewise, more phosphorus will be "fixed" in an acid or alkaline soil than one that is neutral in reaction.

PHOSPHORUS COMPOUNDS IN THE SOIL

Iron, Aluminum, and Manganese Phosphates In acid soils, large amounts of iron, aluminum, and manganese are present in the soil solution. Phosphorus from the native supply or from fertilizer materials will combine with these minerals to form iron, aluminum, and manganese phosphates. This phosphorus is "tied up" and relatively unavailable for plant use. The process may be represented as follows using aluminum in the example:



Size of the arrow indicates value of phosphorus movement.

Fig. 1.—This schematic drawing shows the sources of available phosphorus, phosphorus fixation, and how the levels of available phosphorus are depleted and replenished.

$$\underset{\text{aluminum}}{Al^{+++}} + \underset{\text{soluble phosphorus}}{H_2PO_4^-} + \underset{\text{water}}{2\,H_2O} \rightleftarrows \underset{\text{hydrogen}}{2\,H^+} + \underset{\text{insoluble phosphorus compound (aluminum phosphate)}}{Al(OH)_2H_2PO_4}$$

Note that the soluble (available) phosphorus, in the presence of water and aluminum, combines with the aluminum to form an insoluble compound (phosphorus fixation) and sets some hydrogen free in the soil solution making the soil more acid. Also note that the chemical reaction can be the reverse, starting with the insoluble aluminum phosphates and ending with soluble phosphorus (phosphorus release).

Tricalcium Phosphates In alkaline soils, large amounts of calcium and magnesium and perhaps sodium and potassium will appear in the soil solution. However, most of the phosphorus in such soils will be "fixed" by combining with the calcium. This process often occurs in overlimed or naturally alkaline soils and may be illustrated as follows:

$$\underset{\text{soluble phosphorus compound}}{Ca(H_2PO_4)_2} + \underset{\text{calcium carbonate}}{2\,CaCO_3} \rightleftarrows \underset{\text{insoluble phosphorus compound (tricalcium phosphate)}}{Ca_3(PO_4)_2} + 2\,CO_2 + 2\,H_2O$$

Note that the soluble phosphorus compound (monocalcium phosphate) combines with the calcium carbonate (dissolved limestone) to form an insoluble (unavailable) phosphorus compound (tricalcium phosphate). This process also sets some carbon dioxide and water free. It, too, can be the reverse, starting with insoluble tricalcium phosphate and ending up with soluble monocalcium phosphate.

Organic Phosphorus In organic matter, phosphorus is a constituent of plant materials and the soil micro-organisms which make up the organic matter in soils. This organic phosphorus is released to the soil solution only as the organic matter decays. But it may quickly revert to the insoluble compounds described above if the soils are either acid or alkaline.

Adsorbed Phosphorus As stated earlier, phosphorus may be absorbed by the soil colloids (clay and humas particles). This reaction may be illustrated as follows:

$$\left(\underset{\substack{\text{soil}\\\text{solid}}}{\text{clay colloid}}\ OH^-\right) + \underset{\substack{\text{in soil}\\\text{solution}}}{H_2PO_4^-} \rightleftarrows \left(\underset{\substack{\text{in soil}\\\text{solid}}}{\text{clay colloid}}\ H_2PO_4\right) + \underset{\substack{\text{soil}\\\text{solution}}}{OH^-}$$

Note the negative charge on the phosphorus ($H_2PO_4^-$) in the soil solution. Then note that the phosphorus has become electrically attracted to the clay colloid at the right, displacing the OH^- ion.

This is the phosphorus which, if loosely adsorbed, can be picked off by plant roots if they grow in close proximity to it.

MAKE PHOSPHORUS MORE AVAILABLE

Phosphorus fixation can work to the farmer's advantage. Since phosphorus becomes easily fixed, it does not leach from the soil. Thus, it can be stored without fear of its leaving the soil except by crop removal or soil erosion.

Fixed phosphorus slowly but gradually becomes available for plant use. Enough of it may become available during a year to grow good crops, especially on soils fairly well supplied with it. However, phosphorus can be made more available by good soil management practices.

Liming acid soils will reduce the amounts of iron, aluminum, and manganese in the soil solution and will likewise reduce the amounts of the insoluble phosphorus compounds that are formed in the soil. Also, liming such soils will reduce the acidity level to a point that favors the growth and activity of soil micro-organisms which, in turn, will hasten the decay of organic matter, thus releasing organic phosphorus for plant use.

Avoid Overliming Phosphorus is tied up when there is an excess of calcium and magnesium just the same as it is when there is an excess of iron and aluminum.

Figure 2 illustrates the phosphorus compounds at various acidity levels, and that more phosphorus is available for field crops between

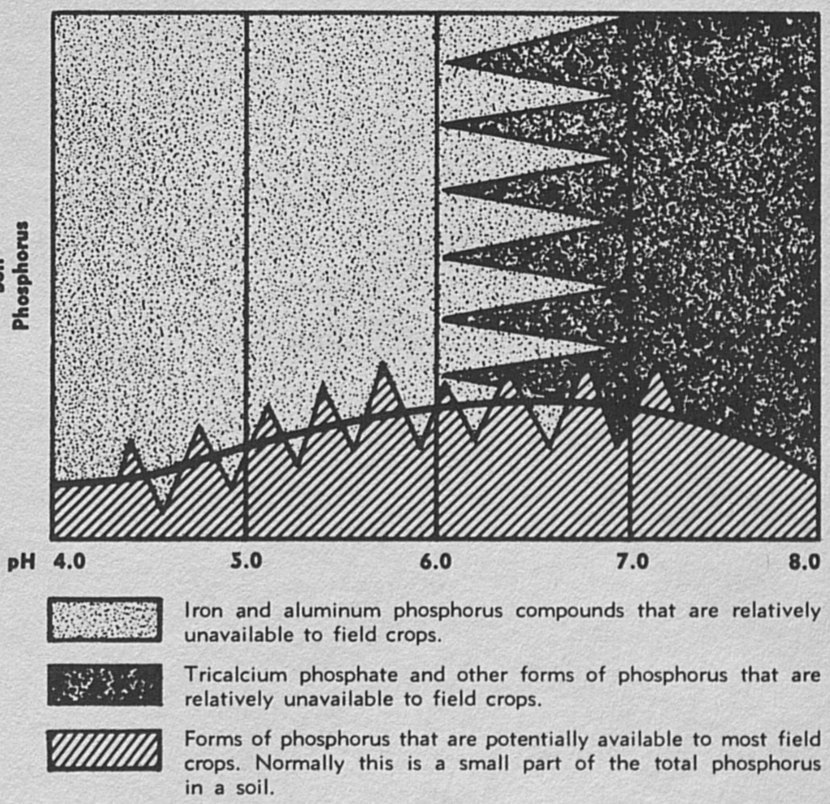


Fig. 2.—Soil pH is a factor determining how much phosphorus is available for plants. Soil pH between 6.0 and 7.0 is best for most field crops.

a pH of 6.0 and 7.0. Some horticultural plants, however, will make greater use of the phosphorus in somewhat more acid soils. This figure also illustrates that there is an exchange of phosphorus from the available forms to the relatively unavailable forms and vice versa.

Applying heavy rates of phosphate fertilizers will increase the amounts of phosphorus "stored" in the soil complex. As total phosphorus in the soil increases, so does the amount that is available to growing crops. Hence, eventually enough phosphorus will be converted from the fixed forms to the available forms so that smaller applications of phosphate fertilizers will supply crop needs.

Row or band applications of phosphate fertilizers will leave the material in contact with a smaller portion of the soil body. This practice will result in less phosphorus fixation than when the fertilizer is mixed thoroughly with the soil. This method may be used when working with low-phosphate soils or limited amounts of phosphate fertilizers.

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