K·STATE
Research and Extension
Department of Agronomy C665

# Phosphorus Facts
## Soil, plant, and fertilizer

Soil Nutrients

Phosphorus (P) is typically present in soils in combination with other elements. It forms complex minerals (inorganic) and organic compounds with only a small amount present in the soil solution. The total phosphorus content of the surface 6 inches may be as little as 200 pounds per acre on sandy soils to more than 2,500 pounds per acre on fine-textured soils. The plant available fraction of the total soil phosphorus is typically low. Application of phosphorus fertilizer, municipal wastes, or manure sources based on a soil test is necessary on many soils to meet plant phosphorus needs.

### Phosphorus in the Soil

Research of the chemistry of soil inorganic phosphorus has shown a complex system of reactions and compound formation dependent on factors such as soil pH; type and amount of soil minerals; amount of phosphorus in the soil; and other soil factors. Likewise, the chemistry of organic soil phosphorus is complex and probably less understood than inorganic soil phosphorus chemistry. Breakdown (mineralization) of soil organic matter and crop residue by soil microorganisms, however, is recognized as being a major contributor of plant-available phosphorus in many soils, particularly in soils with high levels of organic matter.

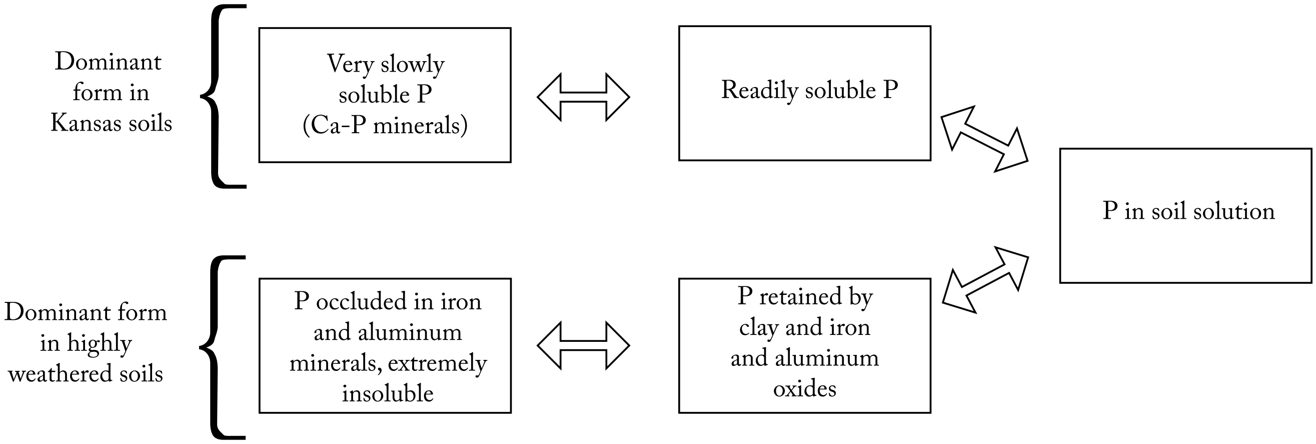
In most soils, phosphorus moves little because of the low amount dissolved in the soil solution. Leaching losses of inorganic phosphorus are generally low. Soil erosion and crop removal are the major ways soils lose phosphorus.

Soluble phosphorus present in the soil solution at any time is usually low. For most soils, the amount of phosphorus dissolved in the soil solution is no more than a fraction of a pound per acre. This means little phosphorus in the soil solution is available for plant absorption in the form of phosphate ions needed for plant uptake. Crops need much more phosphorus than what is dissolved in the soil solution; however, in our soils, a rapid replenishment of the phosphorus in soil solution occurs as plants absorb phosphorus (equilibration). This maintenance of phosphorus in the soil solution by dissolving of phosphorus minerals is the key to the plant-available phosphorus status of the soil.

The amount of phosphorus available to crops depends on the quantity of phosphorus in the soil solution and on the continued release of phosphorus from minerals to maintain the soil solution level of phosphate phosphorus. In Kansas soils, the predominant form of mineral phosphorus is associated with calcium or magnesium complexes (Figure 1). This pool of phosphorus can be considered as a future supply of available phosphorus for plant uptake.

Soil-test phosphorus (like Mehlich-3 used in Kansas) measures the phosphorus supplying capacity of soils, thus estimating the requirement of additional fertilization for optimum plant growth. Levels of soil test phosphorus also provide the likelihood of plant

**Figure 1.** *Pools of various inorganic phosphorus forms in the soil.*



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response to phosphorus application. Evaluation of phosphorus levels also can provide information about the potential risk associated with high testing soils and nonpoint source pollution of surface waters.

Soil test methods used by laboratories do not measure the total quantity of plant-available phosphorus in the soil, but rather measure a fraction of those compounds that maintain plant-available phosphorus in the soil solution. In Kansas soils, those fractions likely include the phosphorus present in soil solution as well as part of the readily soluble and very slowly soluble fractions (Figure 1). The amount of phosphorus measured with a soil test is an index that is related to the fertilizer needs of crops. The soil test value is related to the probability of crop response to phosphorus fertilizer by conducting many phosphorus fertilizer rate experiments on many soils across the state.

## Plant Considerations

Phosphorus is an essential part of metabolic processes that occur within the plant, such as photosynthesis, the synthesis and breakdown of carbohydrates, and a key element for energy transfer. If the soil level of available phosphorus is not adequate for these plant processes, production will be reduced until fertilizer phosphorus is added.

Plants contain less phosphorus than nitrogen or potassium, yet removal of phosphorus by good yielding crops is significant, especially if the total aboveground portion of the crop is harvested (Table 1). Phosphorus removal figures can be useful in combination with other inputs to determine phosphorus application rates. On phosphorus deficient soils, application rates need to exceed removal to increase the available phosphorus in the soil. Very low phosphorus rates applied as starter fertilizer may stimulate growth, but cannot be expected to maintain the available phosphorus in the soil. To maintain the available phosphorus in a soil, the amount of phosphorus fertilizer applied must at least equal crop removal of phosphorus. On soils testing very high in soil test phosphorus, removal can exceed application and not be detrimental to the soil.

Growth stage, plant species, part of the plant sampled, and environmental conditions affect phosphorus concentration in plants. Plant uptake of phosphorus, like other nutrients, proceeds at a faster rate than dry matter production in the early stages of plant growth. For example, in the first 20 days, only 3 percent of the phosphorus needed by a mature grain sorghum crop has accumulated. By early bloom, about 60 days after emergence, 60 percent of the phosphorus that it will accumulate in the entire season has been taken up, while only 49 percent of the dry matter has accumulated (Table 2). In spite of this relatively low amount of the total uptake that occurs early, nutrient availability early in the season is important and phosphorus fertilizer should be applied early to get the most benefit.

Several factors need to be considered when thinking about phosphorus uptake by plants:

1. Plants take up phosphorus almost entirely as the phosphate anion ($HPO_4^{-2}$ or $H_2PO_4^{-}$). The relative amount of each ionic species in the soil solution depends on soil pH. Acid soils favor the $H_2PO_4^{-}$ species, and alkaline soils favor presence of $HPO_4^{-2}$. Plants are able to absorb both species effectively.

**Table 1.** *Plant nutrients removed by various crops*

| Crop | Unit | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|---|
| | | | lbs | |
| Alfalfa | ton | 50 | 11 | 46 |
| Bermudagrass | ton | 25 | 8 | 34 |
| Bromegrass | ton | 28 | 7 | 36 |
| Fescue, tall | ton | 30 | 12 | 42 |
| Corn | bushel | 0.79 | 0.35 | 0.20 |
| Corn silage | ton | 6.56 | 2.54 | 8.20 |
| Grain sorghum | bushel | 0.93 | 0.38 | 0.23 |
| Sorghum silage | ton | 5.75 | 2.73 | 7.63 |
| Wheat | bushel | 1.22 | 0.53 | 0.31 |
| Sunflowers | 100 pound | 2.77 | 1.33 | 0.81 |
| Oats | bushel | 0.60 | 0.25 | 0.16 |
| Soybeans | bushel | 3.54 | 0.83 | 1.01 |
| Native grass | ton | 27 | 9 | 31 |

*Source: USDA.2010. The Crop Nutrient Tool. www.plants.usda.gov/npk*

**Table 2.** *Dry matter and nutrients accumulation as grain sorghum plants develop (medium maturity hybrid).*

| Nutrient | Seedling 0-20 days | Rapid Growth 21-40 days | Early Bloom 41-60 days | Grain Formation 61-85 days | Mature 86-95 days |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| N | 5 | 33 | 32 | 15 | 15 |
| $P_2O_5$ | 3 | 23 | 34 | 26 | 14 |
| $K_2O$ | 7 | 40 | 33 | 15 | 5 |
| Dry Matter | 2 | 15 | 32 | 32 | 19 |

*From: R. L. Vanderlip. 1972. How a Sorghum Plant Develops. Kansas K-State Research and Extension publication. C-447.*

2. Absorption of the phosphate anions, like other nutrients, occurs primarily from the soil solution. Therefore, phosphorus uptake is reduced considerably by dry soil.
3. Because the soil solution concentration of phosphate ions is quite low, absorption of the phosphate ions in most cases occurs against a concentration gradient (known as active absorption) as the phosphorus concentration is greater within the root than in the soil solution phase. This active absorption requires energy derived from root respiration of carbohydrates. Thus, conditions like wet or cold soils that reduce root metabolic activity also slows phosphorus absorption.
4. Absorption of nutrient ions and moisture is greatest near the actively growing tip of each root. Root exploration through the soil as plant roots develop allows new areas of the soil to be nutrient sources. Both the total root surface area and the mass of soil explored by the roots are important for potential nutrient absorption. Plant roots have been estimated to occupy no more than 1 to 2 percent of the total soil volume.
5. Other nutrient ions are absorbed by plants at the same time as the orthophosphate ions. Although most ions are thought to be absorbed independently, there are some demonstrated interactions between nutrients as competition for absorption sites on roots occurs. The plant strives to maintain electrical balance by absorption of positively and negatively charged ions and by exchange of ions from the roots with the soil solution. The presence of ammonium ions ($NH_4^+$) has been shown to have an enhancement effect on phosphorus uptake, especially with starter fertilizers.
6. The concentration of the phosphate ions in the solution also is important to potential absorption. Thus, placement of fertilizer in bands develops temporary zones of higher solution phosphorus concentration allowing for greater uptake early in the season.
7. Phosphorus is known to move little in soil (immobile nutrient) and roots must be close to phosphorus in the soil for uptake to occur. Diffusion of phosphorus to roots generally occurs over no more than a quarter of an inch in fine- and medium-textured soils and up to one inch in course-textured soils. For this reason, placement of phosphorus fertilizer close to the seed is important for efficient early season use of the applied phosphorus.

## Fertilizer Considerations

The Kansas fertilizer law requires that any product sold as a commercial fertilizer must show on the label, or bill of sale for bulk material, a guarantee of minimum percentages of total nitrogen (N), available phosphorus oxide ($P_2O_5$) and water soluble potassium oxide ($K_2O$), commonly referred to as nitrogen, phosphate, and potash.

Although phosphorus does not exist as $P_2O_5$ in fertilizer materials, phosphorus recommendations are made for rates of $P_2O_5$. There are, however, many other situations where the phosphorus content is expressed as elemental phosphorus, and understanding which units are used is important in discussing phosphorus amounts. (To convert from P to $P_2O_5$, multiply P by 2.29 and to convert from $P_2O_5$ to P, multiply $P_2O_5$ by 0.44). Potassium is also expressed regularly as oxide $K_2O$; to convert from K to$K_2O$, multiply phosphorus by 1.2 and to convert from $K_2O$ to K, multiply $K_2O$ by 0.83.

Terms frequently used in discussing fertilizer phosphorus are water-soluble, citrate-soluble, citrate-insoluble, available, and total phosphorus.

**Water-Soluble:** Fertilizer samples are first dissolved in water under standardized conditions. The amount of phosphorus dissolved is measured and expressed as a percentage $P_2O_5$ by weight of the sample.

**Citrate-Soluble:** The fertilizer not dissolved by the water is then placed in a 1 normal ammonium citrate solution and the amount of phosphorus dissolved is measured and expressed as a percentage $P_2O_5$ by weight of the sample.

**Available:** The sum of the water-soluble and citrate-soluble phosphorus is considered available to plants and is the amount guaranteed on the fertilizer label.

**Citrate Insoluble:** The phosphorus fertilizer not dissolved by the normal ammonium citrate is measured and expressed as a percentage $P_2O_5$ by weight of the sample.

**Total:** The sum of the available and citrate-insoluble phosphate is the total phosphorus. Most commercial fertilizers have little of the phosphorus in the citrate-insoluble fraction.

## Manufacture of Phosphorus Fertilizer

Rock phosphate is the raw material used to manufacture most commercial fertilizers. The manufacturing process begins with the production of phosphoric acid. Phosphoric acid is produced either by treatment of the rock phosphate in an electric furnace (dry process) or by acid (wet process).

The dry process produces a pure and more expensive phosphoric acid (white or furnace acid) used primarily in the food and chemical industry. There is some use of furnace acid in fertilizer manufacture. One such fertilizer uses furnace acid, potassium hydroxide, urea, and aqua ammonia. These products are generally more expensive to manufacture due to the added cost of the materials used.

The wet process involves treatment of the rock phosphate with sulfuric acid producing phosphoric acid (green or black acid) and gypsum, which is removed. The resulting wet process acid contains some impurities and sulfur but is less expensive to produce. The impurities in wet process acid have not been a problem in the production of dry fertilizer. Improved technology in recent years has developed processes for removal of some impurities from the wet process acid.

The amount of impurities in either dry or liquid fertilizer is quite small and causes no toxic effects to crops. Either treatment process (dry or wet) produces orthophosphoric acid. No difference in availability to plants exists due to the method of converting rock phosphate to phosphoric acid.

**Table 3.** *Common phosphorus fertilizer sources*

| Source | Nitrogen content (%) | $P_2O_5$ content (%) | Water soluble $P_2O_5$ (%) |
|---|---|---|---|
| Phosphate rock | 0 | 34 | 0-10 |
| Phosphoric acid | 0 | 54 | 100 |
| Triple superphosphate | 0 | 45 | 85-95 |
| Monoammonium phosphate (MAP) | 11 | 52 | 90-95 |
| Diammonium phosphate (DAP) | 18 | 46 | 90-95 |
| Ammonium polyphosphate | 10 | 34 | 100 |

## Phosphorus Sources

Selection of a phosphorus fertilizer source can be confusing, as many products exist on the market, with each having unique characteristics that are touted by the manufacturer. Characteristics often mentioned include: degree of water solubility, liquid versus dry fertilizer, and ortho versus polyphosphates (Table 3).

**Water Solubility:** Water solubility of phosphorus fertilizer has been studied for years and it is generally agreed that water solubility is a desirable trait in phosphorus fertilizer. Water solubility is most important where availability of the phosphorus for immediate plant uptake is needed, such as starter fertilizer. Even with starter fertilizers, 100 percent water solubility of the phosphorus is not necessary. Based on research of phosphorus fertilizers of varying water solubility, fertilizers with water soluble phosphorus contents of 50 percent or greater are equal for the most responsive crops even on soils testing low in available phosphorus. Most phosphorus fertilizers on the market today have a water-soluble phosphorus content of 75 percent or more, making water solubility as a selection criterion unimportant.

**Liquid** vs. **Dry:** Liquid or dry fertilizer application does not change utilization of the phosphorus. Utilization is related to factors such as application method, crop growth characteristics, soil phosphorus level, and climatic conditions. The amount of water in a liquid fertilizer is insignificant compared to the moisture already in the soil. If fertilizer is applied to extremely dry soil, liquid fertilizer will not stay in solution and dry fertilizer will not dissolve. If the soil has good moisture, then the liquid fertilizer will stay in solution and dry fertilizer will dissolve.

Liquids do have some advantage in preparing specific blends of more than one nutrient; a homogenous mixture can be formulated, whereas, dry bulk blends involve mixing individual materials. Dry bulk blends rely on uniform sized particles of each component of the blend to minimize segregation and uneven fertilizer spreading in the field. Selection of a liquid or dry phosphorus source should be based on adaption to the farmers operation and price rather than expected agronomic advantage.

**Ortho vs. Polyphosphate:** Polyphosphate fertilizers are manufactured by heating orthophosphoric acid, which results in water splitting from the ortho ions bonding them into chains of various lengths (primarily two phosphate chains). The term "poly" is used to indicate various length phosphorus chains exist in the fertilizer. The manufacturing process does not convert all of the ortho ions into polyphosphate ions. Most polyphosphate fertilizers will have 40 to 60 percent of the phosphorus remaining in the ortho form. Research has shown polyphosphates to be equal to orthophosphates as starter fertilizers.

In the soil, polyphosphate ions are readily converted to orthophosphate ions by adding water back to the polyphosphate ions (hydrolysis), which is the reverse of the process in its manufacture. An enzyme, pyrophosphatase, abundant in most soils, enhances this process. The conversion of polyphosphates to orthophosphates is fast. With broadcast applications to warm, moist soils, much of the polyphosphate will be converted to orthophosphate within two to three days after application.

Polyphosphates are primarily marketed as liquid ammonium polyphosphate fertilizers. The removal of water in the manufacturing process gives a substantially higher phosphorus analysis compared to ammonium orthophosphate clear liquid, reducing transportation costs and volume per acre to get the same phosphorus rate. The polyphosphate liquids also are more convenient for the fertilizer dealer to handle and allow for formulation of blends not possible with orthophosphate clear liquids. However, no consistent advantage has been shown between ortho and polyphosphates in crop response and plant availability should therefore be considered equal.

## Phosphorus Application Method

Many phosphorus application options exist for producers, these options are heavily dictated by phosphorus application objectives or equipment availability. These application methods include broadcast, starter, banding, or any combination of these.

**Broadcast**: Historically, broadcast applications were chosen based on equipment designs and phosphorus sources. Additionally, conventional tillage allowed broadcast phosphorus fertilizer to be incorporated and adequately mixed within the tillage zone. Currently, the increase in minimum or no-tillage decreases the potential of soil mixing. Regardless, the mechanics of application method should be matched with the objectives of phosphorus fertilization. Broadcast fertilization is an excellent way to fertilize, specifically in phosphorus deficient soils that need to have the phosphorus level increased. The physical aspect of broadcast fertilization increases the volume of soil coming in contact with phosphorus fertilizer, resulting in an increase in phosphorus in the bulk of the soil (in portions of the soil that will not have phosphorus removed by plants).

**Starter**: A “starter application” may include phosphorus fertilizer application with the seed, directly above the seed on the soil surface, or some given distance vertically and horizontally from the seed (most typically 2 inches by 2 inches). Starter phosphorus application is important due to the relative close proximity of the phosphorus fertilizer to the seed. For these reasons, starter phosphorus is the most commonly responsive application method, especially in no-tillage production. Starter phosphorus is commonly recommended when soil test phosphorus is low enough that a higher concentration of phosphorus is needed to supply sufficient phosphorus to the plant or when soil test phosphorus is high enough that additional phosphorus response will only be gained by starter application.

**Banding**: Although starter application is technically a form of banding, band application generally refers to a phosphorus application in a concentrated zone either on or below the soil surface, which occurs separate from planting. Some have speculated that banding at specific depths may increase yields in conditions where phosphorus concentration decreases with depth (phosphorus stratification). However, recent data show that there is neither a benefit nor a detriment from applying phosphorus in a band near the crop row.

## Phosphorus and the Environment

Phosphorus movement in runoff from agricultural lands to surface waters can be a significant environmental concern. The increase in phosphorus levels in surface water promotes an aggressive and undesirable algae growth with the consequent depletion of oxygen known as eutriphication. Phosphorus movement from field is typically affected by transport mechanisms, phosphorus sources, and management factors. The transport mechanisms include potential for erosion, rainfall, and irrigation. The phosphorus sources include the soil phosphorus content, and the form of phosphorus applied such as fertilizer and manures. The management factors include method of application, placement, and timing that may affect the risk of phosphorus loses from agricultural fields.

Adequate management and soil conservation practices that ensure low erosion and runoff from fields would also reduce potential phosphorus loses. Soil conservation practices such as conservation tillage increase water infiltration and reduce erosion and runoff. This can be particularly important for fields with high levels of phosphorus as measured by soil test phosphorus. Phosphorus loss from agricultural land is highly undesirable from the agronomical standpoint, since this is likely a phosphorus source that otherwise can be utilized for optimum crop production.

## Summary

Phosphorus fertilizer does not remain dissolved in the soil water for long since soils adsorb phosphorus. As a result, recovery (utilization) of phosphorus by plants is usually less than 30 percent in the first year after application and in some cases is 10 percent or less. In Kansas soils, however, the applied phosphorus that is not recovered in the year of application will be retained in the soil and be taken up by crops in succeeding years, and is expressed in the soil test phosphorus. The first step in putting a phosphorus fertilization program together is to soil test to determine the need for phosphorus. Once the need for phosphorus is established, application methods should be considered. Band placement can improve uptake on low and very low testing soils. Knowing that phosphorus is equally available from various products, selection of a phosphorus fertilizer should be based on its suitability for the application method and adaptation to the farmer's operation and economics.

**Dorivar A. Ruiz Diaz**
Soil Fertility and Nutrient Management Specialist

**David B. Mengel**
Soil Fertility and Nutrient Management Specialist

**Kent L. Martin**
Southwest Area Crops and Soils Specialist

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