Penn State **Extension**

Agronomy Facts 13

Managing Phosphorus for Crop Production

Phosphorus is a macronutrient that plays a number of important roles in plants. It is a component of nucleic acids, so it plays a vital role in plant reproduction, of which grain production is an important result. It is also critical in biological energy transfer processes that are vital for life and growth. Adequate phosphorus results in higher grain production, improved crop quality, greater stalk strength, increased root growth, and earlier crop maturity. For over one hundred years, phosphorus has been applied to crops as fertilizer—first as ground bone and now as some chemical reaction product of ground rock. Yet, for all that experience, its management cannot be taken for granted.

Phosphorus is not lost into the atmosphere—rarely does it leach beyond the reach of roots—and its availability to crops can be accurately estimated by soil testing. The challenge is that phosphorus is a macronutrient in plants but behaves somewhat like a micronutrient in soils. The concentration of soluble phosphate in the soil solution is very low, and phosphorus is relatively immobile in the soil. That is important because crops take up phosphorus only from the soil solution. The crop depends on replenishment of the soil solution with phosphate from the other forms existing in the soil. The rate of replenishment, which determines the availability of phosphorus, is related to soil pH, phosphorus levels in soil, its fixation by the soil, and placement of added phosphorus. The crop manager must deal with each of these factors to avoid crop phosphorus deficiency. Phosphorus deficiency symptoms include reduced growth and yield, delayed maturity, and generally purple coloring along the edge of the lower plant leaves, especially on younger plants.

In addition, the manager needs to consider possible "side effects" of crop production; specifically, nutrient pollution of streams or other surface water near crop fields. Water can be polluted with phosphorus primarily as a result of erosion and runoff of phosphorus in the soil or phosphorus applied either from fertilizer or manure. The amount of phosphorus lost due to runoff of manure, fertilizer, or soil may be relatively small as far as fertilizer costs are concerned. However, these small losses may have serious effects on the quality of water. The main problem with phosphorus pollution is eutrophication resulting in excessive growth of plants and algae in the water. This can seriously limit the use of the water for drinking, industry, fishing, or recreation. Pollution reduction may not be simply a direct economic problem for the farmer, but a responsibility that extends beyond the farm fence.

AVAILABILITY OF PHOSPHORUS TO CROPS

In general, crop use of any nutrient depends on a two-step process: soil supply of that nutrient in an available form, and uptake of that available nutrient by the crop. There are certain constants involved that the crop manager cannot change. Selecting among the options presented by nature constitutes management.

Soil Supply

Figure 1 shows an overview of the behavior of phosphorus in the soil. The soil solution is the key to plant nutrition because all phosphorus that is taken up by plants comes from phosphorus dissolved in the soil solution. Because the amount of soluble phosphorus in the soil solution is very low, it must be replenished by as many as 500 times during a growing season to meet the nutritional needs of a typical crop. Although very little phosphorus is in the soil solution at any time, there is a large amount of phosphorus in most soils. The bulk of the soil phosphorus is either in the soil organic matter or in the soil minerals. A large proportion of the phosphorus in both of these fractions is in very stable, unavailable forms, while a much smaller proportion is in available forms that can dissolve in the soil solution and be taken up by plants. The dynamic and available phosphorus in these fractions, such as phosphorus added in fertilizer or manure, can be quickly fixed into stable, unavailable forms in the soil. This is why, even with optimum management, the efficiency of plant uptake of phosphorus is very low—usually less than 20 percent. At the same time as the soil solution phosphorus is depleted by crop uptake, unavailable phosphorus can slowly be released to more available forms to replenish the soil solution. This slow release can sustain plant growth in many natural systems, but it is usually not rapid enough to maintain adequate phosphorus availability in intensively managed cropping systems without some supplemental phosphorus in the form of fertilizer, manure, or crop residues.

Organic phosphorus availability depends on microbial activity to break down the organic matter and release

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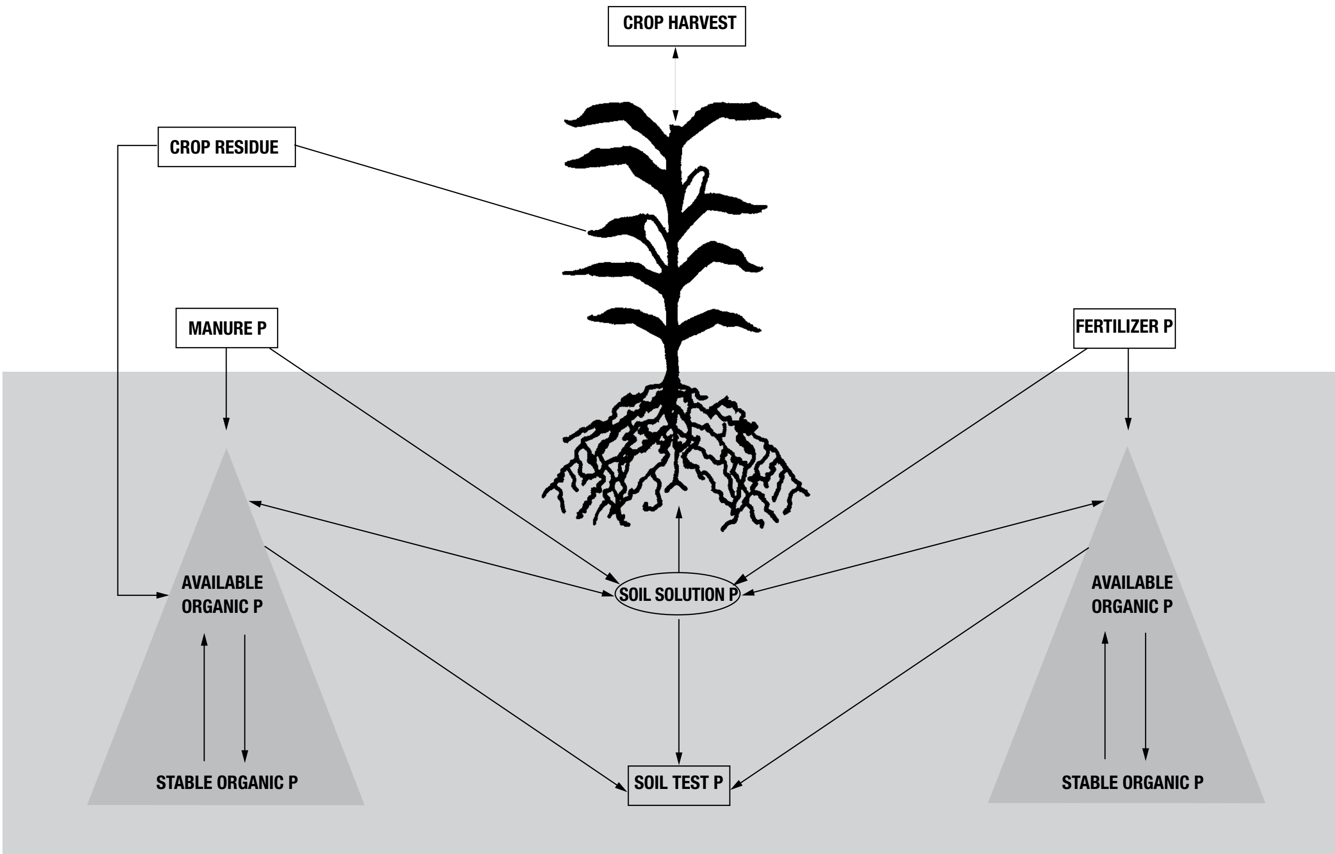
Figure 1. Behavior of phosphorus in the soil-plant system.



this phosphorus into available forms. Thus, availability of organic phosphorus is very dependent on conditions in the soil and the weather, which influence microbial activity. The mineralization of organic phosphorus to inorganic forms is favored by optimum soil pH and nutrient levels, good soil physical properties, and warm, moist conditions. The inorganic phosphorus is bound with varying adhesiveness to iron and aluminum compounds in the soil. Replenishment of the soil solution with phosphate from inorganic forms comes from slow dissolution of these minerals. The solubilities of the compounds holding phosphorus are directly related to the soil pH. The pH range of greatest phosphorus availability is 6.0 to 7.0. At a lower pH, when the soil is very acidic, more iron and aluminum are available to form insoluble phosphate compounds, and therefore, less phosphate is available. At very high pH, phosphorus can react with excess calcium to also form unavailable compounds in the soil.

Crop Uptake

Crop response to phosphorus depends on the availability of phosphorus in the soil solution and the ability of the crop to take up phosphorus. The availability of phosphorus in the soil solution has already been discussed. The ability of a plant to take up phosphorus is largely due to its root distribution relative to phosphorus location in soil. Because phosphorus is very immobile in the soil, it does not move very far in the soil to get to the roots. Diffusion to the root is only about $^1/_8$ of an inch per year, and relatively little phosphorus in soil is within that distance of a root. Thus, the roots must grow through the soil and basically go get the phosphorus the plant needs. Therefore, root growth is very important to phosphorus nutrition. Any factor that affects root growth will affect the ability of plant to explore more soil and get adequate phosphorus. Soil compaction, herbicide root injury, and insects feeding on roots can all dramatically reduce the ability of the plant to get adequate phosphorus. Young seedlings can suffer from phosphorus deficiency even in soils with high available phosphorus levels because they have very limited root systems that are growing very slowly in cold, wet, early season soil conditions. This is why some crops respond to phosphorus applied at planting in starter fertilizers even in relatively high phosphorus soils. (Starter fertilizer management is discussed later in this fact sheet. See also *Penn State Agronomy Facts 51: Starter Fertilizer*.)

MANAGING SOILS FOR PHOSPHORUS

The availability of phosphorus to crops is more than just having phosphorus in the soil. It will depend on soil pH, how supplemental phosphorus is applied, crop root growth, and the other management factors that influence root growth.

Soil Test

The most important tool in phosphorus management for crops is a soil test. Soil testing reveals soil pH and the soil phosphorus levels, and determines the recommended application amount of phosphorus for the crop to be grown. Consistent and representative soil sampling is very important for correct interpretation of soil test results. Take as many cores as practical. Sampling depth is extremely important for both pH and phosphorus, especially in reduced- and no-tillage systems where there is little or no mixing to homogenize the soil. In Pennsylvania, the recommendation is to sample to "plow depth," even in no-till fields where phosphorus is concentrated within several inches of the soil surface.

There is no specific "available" fraction of phosphorus in soils. The available phosphorus is what is in solution plus what can be expected to become soluble from minerals and organic matter over the growing season. Therefore, soil tests cannot extract the exact available amount from the soil, but rather an amount that reflects what might become available. Research on Pennsylvania soils is then used to interpret the amount extracted by the soil test in terms of what is required for optimum crop production. This research has shown that on our soils, if the Mehlich 3 soil test used, in Pennsylvania extracts between 30 and 50 parts per million (ppm) phosphorus are optimum for production of agronomic crops. Below 30 ppm phosphorus, additional phosphorus must be applied to build up the soil for optimum crop production. Above 50 ppm phosphorus, there will be no benefit to adding additional phosphorus. In some cases, applying a small amount of phosphorus as a starter on soils testing above 50 ppm may be beneficial. In the optimum range range—between 30 and 50 ppm phosphorus—phosphorus is often recommended to offset crop removal (Table 1) and thus maintain the soil in the optimum range over time. Current phosphorus recommendations for agronomic crops in Pennsylvania can be found on the Agricultural Analytical Services Laboratory website, **agsci.psu.edu/aasl**.

Phosphorus Materials

The common phosphorus fertilizers, their sources, and some important properties are listed in Table 2.

Inorganic Phosphorus Fertilizers

By Pennsylvania law, mineral phosphorus materials sold as fertilizer must be labeled with the percentage "available phosphoric acid," which is defined as the amount of fertilizer phosphorus that dissolves in neutral ammonium citrate. This analysis must be given as a percent P_2O_5 in the material. Fertilizers do not really contain any P_2O_5, but this expression is a carryover from past analytical methods. Fertilizer recommendations are also given as pounds of P_2O_5 per acre and based on the amount of this "available phosphoric acid" that should be available to the crop over the period of the growing season. Mineral phosphorus materials

Table 1. Typical crop nutrient removal for phosphorus.

CROP (UNITS)	PER UNIT OF YIELD P_2O_5	TYPICAL YIELD PER ACRE	REMOVAL FOR GIVEN YIELD LB/A P_2O_5
Corn (bu)	0.4	125 (bu)	50
Corn silage (T)[1]	5.0	21 (T)	105
Alfalfa (T)[2,3]	15.0	5 (T)	75
Cool-season grass (T)[2,3]	15.0	4 (T)	60
Wheat/rye (bu)[4]	1.0	60 (bu)	60
Oats (bu)[4]	0.9	80 (bu)	70
Barley (bu)[4]	0.6	75 (bu)	45
Soybeans (bu)	1.0	40 (bu)	40
Small grain silage (T)[1]	7.0	6 (T)	40

[1] 65% moisture.
[2] For legume-grass mixtures, use the predominant species in the mixture.
[3] 10% moisture.
[4] Includes straw.

Table 2. Description of common phosphorus fertilizer materials.

MATERIAL	ANALYSIS	COMMENTS
Calcium orthophosphates	Manufactured by treating rock phosphate with acid	
Ordinary superphosphate	20% P_2O_5, 90% water soluble, 8–10% sulfur	Not used anymore in commercial crop production; replaced by triple superphosphate
Triple superphosphate	46% P_2O_5, 95% water soluble, no sulfur	Common material used in no-nitrogen blends
Ammonium phosphates	Manufactured by reacting anhydrous ammonia with phosphoric acid	
Monoammonium phosphate MAP	52% P_2O_5, 11% N, 100% water soluble	Very high phosphorus analysis; excellent material for use in starter fertilizer
Diammonium phosphateDAP	46% P_2O_5, 18% N, 100% water soluble	Most common phosphorus fertilizer. Used extensively as the basis for blended fertilizers
Ammonium polyphosphate	Solid: 55% P_2O_5, 11% N Liquid: 34% P_2O_5, 10% N	Liquid form is very common N and P fluid fertilizer
Miscellaneous phosphates		
Rock phosphate	27–45% total phosphorus	Very low water solubility; must be finely ground to be effective; increase rate three to four times that recommended for soluble P fertilizer

that have not been reacted with acid, such as raw rock phosphate and basic slag materials, must also be labeled with the total P equivalent and the material's degree of fineness. The phosphate availability of phosphorus materials that have not been reacted with acid is low, as the availability then depends on reaction in acidic soil; particle size determines the speed of that reaction. Bone and other natural organic phosphate materials must be labeled only with the total P content. Don't confuse total P with available P—the availability of phosphorus in these forms depends on the mineralization, or breakdown, of the material by bacteria in soil and cannot be guaranteed.

Immediate phosphorus availability can be defined by the percentage of the available P that is water soluble. This is not a labeling requirement, but it is described for various materials in Table 2. A high percentage of water solubility is important for short-season, fast-growing crops, crops with a restricted root system, crops receiving a starter fertilizer application, and crops grown in a low-phosphorus soil where less than optimum rates of phosphorus are applied. Where the importance of high water solubility, or quick reaction in the soil, is not so great (such as in fertilizing a permanent pasture or where soil phosphorus levels are already optimum), a more economical form of phosphorus can be applied. Most of the common phosphorus fertilizer materials are highly water soluble (Table 2).

Although the calcium orthophosphate fertilizers are manufactured by reaction with an acid, they do not acidify the soil. The ammonium phosphates and the ammoniated superphosphates, on the other hand, do ultimately have an acidic effect on soil because of the ammonium nitrogen that they contain—not because of their phosphate content.

The physical form of the applied phosphorus does not make any difference to the plant if the materials have similar chemical properties. The same reactions eventually occur in soil whether liquid or solid fertilizer is applied. Though all of the phosphorus in true solution fertilizer will be water soluble, the same materials applied in dry form are just as efficient.

Manure Phosphorus

Average manure phosphorus values for various animal types are shown in Table 3, but however good the averages are, the manure phosphorus content on individual farms may vary considerably from the average. The true value can only be known by manure analysis.

Phosphorus in animal wastes is generally less water soluble than fertilizer phosphorus. However, over a normal growing season the availability of manure phosphorus is usually similar to fertilizer phosphorus and can be substituted on a 1-to-1 basis. Even so, manure is not a substitute for starter fertilizer because it ordinarily has a lower water-soluble phosphorus content. As long as physical losses do not occur, handling or application methods do not affect phosphorus content or availability.

Phosphorus from manure applications can be a potential pollutant. There are several reasons for this. First, as livestock and poultry farms have become more intensive, greater amounts of feed are imported onto the farms resulting in accumulation of excess nutrients in manure beyond what can be used by the crops on the farm. Even when there is no overall excess of nutrients on the farm, application of manure nutrients is commonly done based on meeting the nitrogen requirement of the crop with the nitrogen content of the manure. Since the relative amounts of nutrients required by crops are different from the relative amounts contained in most manures, there will usually be an excess of phosphorus and potassium (K) applied in this system. This is illustrated with corn and dairy manure in Figure 2. Notice that when manure is applied to exactly match the available nitrogen requirement of the crop, almost twice as much phosphorus is applied as is required by the corn crop. The relative differences will vary with different crops and manures, but a similar trend will be observed.

Ultimately we need to move toward a better overall balance that minimizes the application of excess nutrients. In the meantime, management strategies are being developed to help farmers make decisions about when, where, and how to apply their manure to maximize the agronomic and economic benefits from the manure nutrients and minimize the potential environmental impact. Since the major losses of phosphorus from fields is through runoff and erosion, best management practices that reduce these processes can be very helpful in minimizing the environmental impact of the excess phosphorus that is applied. An important tool in making these management decisions is the Phosphorus Index, which helps evaluate the sources of phosphorus and the potential transport of phosphorus from the farm fields to give an indication of the risk of phosphorus pollution and to guide improved management.

Finally, there are interactions between phosphorus and other nutrients that can affect crop production. When the ratio of phosphorus to zinc (Zn) in a soil becomes excessively high, a phosphorus-induced Zn deficiency may result that can limit yield. However, few cases of Zn deficiency are found in Pennsylvania in spite of many corn fields testing high or excessive in phosphorus. Manure application that results in soil phosphorus buildup also contributes Zn to the soil. Therefore, phosphorus-induced Zn deficiency is usually only seen when excessive soil phosphorus levels are due to phosphorus fertilizer and not to manure application. Often when there is concern about zinc deficiency, farmers will add zinc to the banded fertilizer, which usually also contains a high level of phosphorus. This practice will likely reduce the effectiveness of the added zinc. A more efficient approach is to broadcast zinc every few years on soils that are known to respond to added zinc.

Placement

Because of phosphorus immobility and soil fixation, placement of fertilizer phosphorus can affect its availability to plants. Fertilizer that is broadcast and plowed down is mixed uniformly with a large amount of soil. Thus, the probability of root contact with the fertilizer is maximized. At the same time, though, added fertilizer is in greater contact with absorbing surfaces in the soil, thereby increasing phosphorus fixation. When the fertilizer is applied as a concentrated band, contact with the soil—and thus fixation—is minimized. However, lack of phosphorus movement from point of placement also means that the number of roots in contact with the fertilizer may be less then when broadcast and plowed down. The greater the ability of the soil to fix phosphorus, the greater the importance in overriding the fixation capacity with a concentrated band. Crop response to fertilizer phosphorus placement is further complicated by crop root characteristics, soil phosphorus levels, and soil temperature.

Placement limitations imposed by sod crops and no-till culture often result in an accumulation of nutrients near the soil surface (Figure 3). Provided proper residue management is practiced, corn root distribution appears to respond to differences in soil moisture and nutrient location in no-till culture with greater root density within the surface 6 inches of soil (Figure 3). Nutrient uptake of surface-applied fertilizer equals or exceeds uptake under conventional-till management.

Table 3. Average manure P analyses. (Actual analyses vary considerably from farm to farm. Manure analysis is strongly recommended.)

DAIRY	
Lactating cows	4 lb/ton or 13 lb/1,000 gal
Dry cows	3 lb/ton
Calves and heifers	2 lb/ton
POULTRY	
Broilers	75 lb/ton
Layers	55 lb/ton
Turkeys	80 lb/ton
SWINE	
Gestation	35 lb/1,000 gal
Lactation	20 lb/1,000 gal
Nursery	40 lb/1,000 gal
Farrow to feeder	35 lb/1,000 gal
Grow finish	55 lb/1,000 gal

Is Band or Broadcast Application the Better Method?

The answer to this question depends mostly on the soil phosphorus status. On soils with optimum to high levels of phosphorus, banding has less advantage and broadcast applications are generally adequate (sometimes superior to banding). Row crops in general, and corn in particular, appear to yield better when soils contain relatively high levels of phosphorus throughout the rooting profile. In tests with the recommended phosphorus application split between band and broadcast, versus all by one method, the

Figure 2. Imbalance between crop nutrient requirement and manure nutrient content.

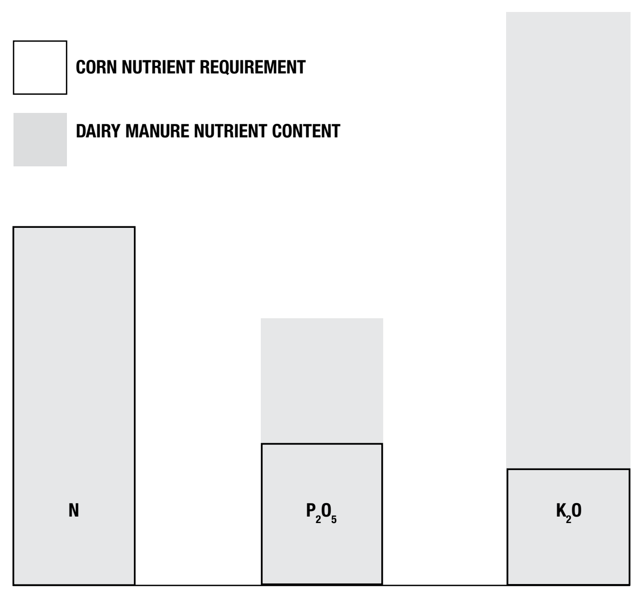
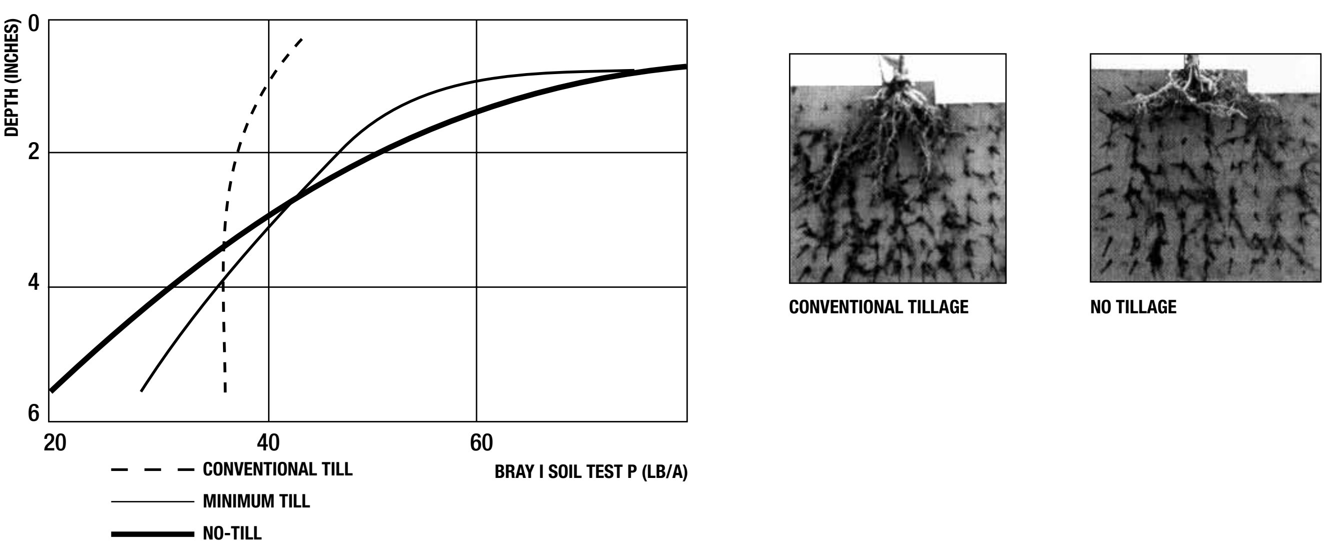


Figure 3. Distribution of soil test (Bray I extractable) phosphorus after two years of different tillage practice and rooting pattern in conventional and no-till corn. (Source: J.K. Hall, The Pennsylvania State University)



maximum yields have been obtained with a combination. The advantage to building up the general soil level of phosphorus is probably due to the need of all roots to take up some phosphorus, while banding near the seed can reduce fixation and increase uptake early in the season.

Small grains, on the other hand, have limited rooting systems and thus less capacity to explore soil. In addition, they are short-season crops and often grown in cooler temperatures. Therefore, phosphorus placement seems more critical for small grains than for row crops and perennials. Greater yield response to banded phosphorus is common, especially on low-phosphorus soils or soils with a greater ability to fix phosphorus. Recommendations of incorporated broadcast phosphorus for small grains have frequently been higher than if the phosphorus were banded because higher soil phosphorus levels compensate for reduced phosphorus uptake ability of the crop. Where soils are built up to optimum or above phosphorus levels, however, banded or broadcast P can be equally effective.

Starter Fertilizer

Starter fertilizer is a specific band application at a specific time. Even if you are planning to broadcast the majority of the required phosphorus as fertilizer or manure, a banded starter application may be important for spring-planted crops, particularly corn. Limited root growth—combined with cold and wet soils early in the season, especially in no-till fields—reduces the availability of phosphorus and the plant's uptake ability. Early plant vigor and final yield are often improved by starter phosphorus applied close to seedling roots, even when soil phosphorus levels are high or when manure has been applied. Phosphate applied in combination with ammonium N results in greater phosphorus uptake. Phosphorus itself has a low salt effect and may be placed close to the seed. However, if applied with N and K the rate should be limited so as to supply no more than 70 pounds total of N plus K_2O if placed 2 by 2 inches from the seed. High water solubility of the starter phosphorus source is important, and the ammonium phosphates meet that criteria as well as supplying N. However, diammonium phosphate (DAP) reacts with soil water to produce ammonia, which can be toxic to seedling roots. Therefore, the rate of DAP used as a starter source of N and P should be kept low and placement should be at least 2 inches from the seed to be safe.

The best time to think about starter fertilizer for alfalfa establishment is in the years before rotating a field to alfalfa. Yield response to starter fertilizer is most likely when the alfalfa seedlings will be stressed by low fertility levels or adverse soil or moisture conditions. High soil phosphorus levels are required by the forage, so plan ahead by building phosphorus levels into the optimum range during the last year of corn, and soil test in the fall prior to alfalfa establishment. If fertility is optimum by planting time, starter fertilization can usually be omitted. See *Agronomy Facts 51: Starter Fertilizer* for more detail.

SUMMARY

Crop phosphorus nutrition depends on the ability of the soil to replenish the soil solution with phosphorus as the crop removes it and the ability of the plant to produce a healthy and extensive root system that has access to the maximum amount of soil phosphorus. There are many good fertilizer sources of phosphorus, and manure is an excellent source of phosphorus for crops. Application of fertilizer and manure must be done to maximize the chemical and physical availability of the phosphorus to crops while minimizing the risk that the phosphorus might be lost to the environment by runoff or erosion. Conservation best management practices are critical to good phosphorus management.

Recommendations

- Test soil to determine pH and phosphorus levels and lime and fertilizer recommendations.
- Use lime to raise and maintain soil pH in the range of 6.0 to 7.0.
- Match the phosphorus fertilizer to the crop, soil phosphorus level, and purpose of the fertilizer.
- Use a starter fertilizer when planting in cold, wet soils—particularly when soil tests are not high.
- Account for the phosphorus in manure and recognize that excess phosphorus may be applied with manure; try to balance this over the crop rotation.
- Let soil phosphorus levels, crop, and soil characteristics guide your decision on fertilizer and manure rates, timing, and methods of application.
- Use best management practices to reduce erosion and runoff to avoid phosphorus losses and protect water quality.

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