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Tips for Environmentally Friendly Phosphorus Applications in Indiana

Growers and applicators should carefully apply all fertilizer materials not just to maximize plant nutrient uptake and crop yield, but also to reduce nutrient losses to the environment. Phosphorus (P) fertilizers pose particularly complex and acute environmental risks.

Generally, P is immobile in the soil, but under some conditions P can leave the field and enter waterways with eroded soil particles or with runoff and subsurface drainage waters. P can build up in waterways and freshwater lakes, which can harm wildlife, human health, and businesses.

There is no single and universal answer to the question of how and when to apply P fertilizers. However, this publication does propose P application management tips. These tips correspond to the 4R principles:

1. Right rate
2. Right source
3. Right time
4. Right placement

In each case, the 4R's are specific to Corn Belt cropping systems of differing tillage and crop rotations.

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Forms of Phosphorus

P can be in three forms in the soil: stable P, reactive P, and dissolved P (Figure 1).

Most P in soil is in a stable form and not available to plants.

Soil particles loosely hold reactive P, and it can move into the soil solution to balance plant uptake. Reactive P can also be bound with elements (such as aluminum, iron, calcium, or magnesium) or be tied up in organic matter.

Typically, only about 0.01 percent of all P in the soil is dissolved P, sometimes referred to as soluble P. Dissolved P (DP) in the soil solution is essential for P availability to plants. DP is relatively unstable and can rapidly attach to soil particles and become reactive P. Traditional soil tests measure DP and a portion of the reactive P to represent the amount of P a soil can supply to plants.

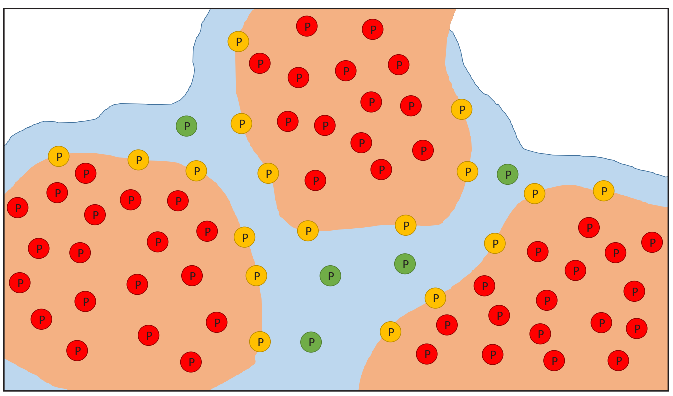

Figure 1. A closer look at P forms in the soil. Red circles represent stable P, which only becomes available over long periods of time. Yellow circles represent reactive P, which can quickly move off soil particles into the soil solution. Green circles represent dissolved P (DP), which moves with water.

P can leave agricultural fields in all three forms. If landowners do not control soil erosion, their land can lose large amounts of P, because most P is bound to the soil particles. Many growers have adopted soil erosion control measures (such as practicing conservation tillage, planting grassed waterways, and stabilizing stream banks), which have been largely successful in controlling this type of P loss.

However, the small fraction of P that is dissolved moves wherever the water moves. Therefore, this type of P loss can occur in surface water runoff and through drainage tiles. When this P is carried to a body of fresh water, the P that is available to plants (all the DP and some of the reactive P) is also available to algae. Adding new sources of nutrients such as P to freshwater systems (a process called eutrophication) can trigger algal blooms, which in turn can negatively affect freshwater ecosystems, businesses, and water safety.

So while controlling erosion has reduced the total amount of P being lost from agricultural fields, the environmental effect of the relatively small amount of DP being lost is important, because this P form is more readily available to algae and is being lost at higher rates than before (Michalak et al., 2013).

1. Apply the Right Rate

The first of the 4R principles for applying P is to apply the right rate.

The first step to applying the proper P rate is to test the soil for each field. Make sure to gather samples that properly account for different soil types in the field, erosion, and the history of P applications and crop removal. For example, if you recently band-applied P, adjust your soil sampling pattern to account for the band position to achieve representative results for the whole field.

Once you receive soil test levels, follow the rates recommended by your state's extension service. For Indiana, Ohio, and Michigan, see *Tri-State Fertilizer Recommendations for Indiana, Michigan and Ohio* (Purdue Extension publication AY-9-32-W), available from the Education Store, www.edustore.purdue.edu. This guide provides fertilizer recommendations in pounds of P_2O_5 per acre.

It is important to only apply fertilizer where it is necessary. The *Tri-State* guide recommends not adding any P if soil test values are 40 ppm or greater (Bray-P1). That's because there is no yield benefit to keeping soils at such elevated P levels. These soils are also capable of increased P loss that can harm water quality. Though it is common practice to apply the amount of P a crop will remove even if soil test values are greater than this 40 ppm level, maintaining elevated available P levels is not profitable and can harm the environment.

There is no universal soil-test P value at which P losses become unacceptable for water quality; however, P losses increase substantially when soil test levels are greater than 130 ppm (Bray-P1) (McDowell and Sharpley, 2001). All P losses depend on more than soil test levels. Losses also depend on soil texture, cation exchange capacity, organic matter content, the field's slope, the grower's management system, and rainfall factors. Calibrate your fertilizer applicator to apply only the intended amount of P (Figure 2).

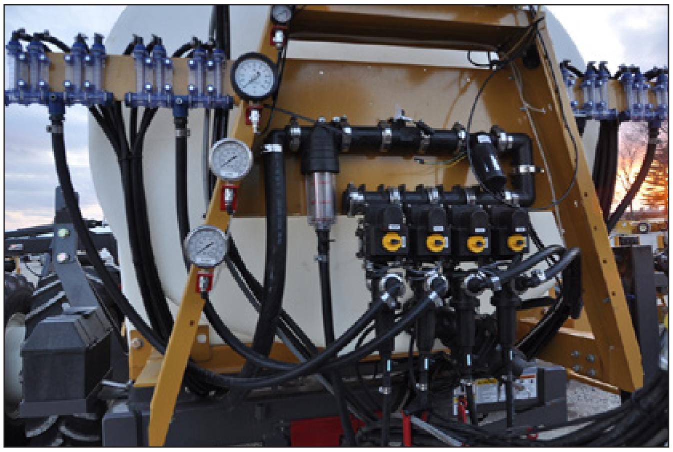

Figure 2. It is essential to accurately calibrate fertilizer application equipment for agronomic and environmental goals. This photo shows a nutrient metering and monitoring system on a SoilWarrior®, which is a strip-tillage implement. Photo provided by Environmental Tillage Systems, Faribault, Minnesota.

Starter Fertilizers

Applying a starter fertilizer can help improve corn's early growth, especially in systems that have high residue and cool spring soil temperatures. While the proximity of P relative to the corn seed does not limit the rate of starter, the rate may be limited by the amount of N or K also contained within the starter.

For example, the *Tri-State* guide recommends applying no more than 100 pounds of N + K_2O per acre in a typical 2 x 2-inch band at seeding. If you apply a starter fertilizer, be sure to subtract the amount of N and P_2O_5 in the starter from the total recommended rates for these nutrients.

Two-year Fertilizer Programs

It is common for some farms in corn-soybean rotations to follow a two-year P fertilizer application program. Fertilizer for corn and soybeans are often applied together (typically before the corn crop) to save time. Biannual applications must be applied with special care because P will be more concentrated with a higher application rate. When P fertilizers are concentrated, more P is in the DP form, which is at risk for leaving the field if intense rains follow broadcast application. However, if the biannual application is applied under ideal conditions the risk of loss is reduced because the fertilizer's DP will only be vulnerable to loss once every two years.

2. Choose the Right Source

The second of the 4R principles for applying P is to choose the right source.

Be sure you understand the amount of P that is available (P_2O_5) in the fertilizer you choose (Table 1). Be aware that P fertilizer sources may also contain other nutrients. Be sure to account for these other nutrients so you do not over apply them when you apply the recommended rate of P.

Inorganic (commercial fertilizer) and organic P (manure) sources can vary in the proportion of their total water-soluble P or P_2O_5 (Table 1). The water-soluble portion will stay in the DP form unless it becomes fixed to the soil by contacting soil particles through incorporation or through the slower process of diffusion.

Table 1. Fraction of water-soluble P in common fertilizer materials.

	Source	Analysis[1]	% of P That Is Water Soluble[2]
Manure[3]	Dairy	—	14-70
	Swine	—	39-72
	Broiler	—	55-67
Inorganic[4]	Monoammonium Phosphate (MAP)	11-52-0	90-95
	Diammonium Phosphate (DAP)	18-46-0	90-95
	Triple Superphosphate	0-44-0	85-95
	Ammonium Polyphosphate	10-34-0	100

[1]Product anaylsis presented as percentage of N-P-K — total N - available P (P_2O_5) - exchangeable K (K_2O).

[2]The percentages for organic (manure) sources represent total P; the percentages for inorganic sources represent P_2O_5.

[3]Adapted from Dou et al. (2000) and He et al. (2004). Specific values depend on diet and storage.

[4]Adapted from Leikam et al. (2013).

Manure (Organic) Sources

Applying animal manures as fertilizer is the most environmentally efficient method of disposing of them, but frequently applying to the same fields can lead to very high soil-test P values. Because it is expensive to move manures long distances to fertilize fields, it is common to see high P levels in fields close to the manure source.

High P levels can also occur in areas where applicators are basing manure application rates on their N content. However, when soil-test P levels become excessive, you also must account for the manure's P content. The

Indiana USDA-Natural Resources Conservation Service provides specific guidelines in *Nutrient Management* (Code 590), available at efotg.sc.egov.usda.gov/references/public/IN/590_Nutrient_Management.pdf.

While P forms in manure are generally less soluble than commercial fertilizers (Table 1), as rates of manure increase the amount of P in the DP form also increases. Furthermore, because manure is often applied on already high-testing soil, higher than expected levels of DP can accumulate, especially if the manure is not mixed into the soil to allow the DP to attach to soil particles.

For these reasons, we strongly recommend that you incorporate all manure applications (Figure 3). As time passes, manure breaks down and releases more plant-available P, which you should acknowledge when making future nutrient management decisions.

Figure 3. It is important to incorporate manure and inorganic fertilizer to reduce surface losses of P. Photo provided by Environmental Tillage Systems, Faribault, Minnesota.

Nutrient concentrations in manures vary by livestock species, diet, and storage. The only way to determine the actual nutrient content of a specific manure source is to send a homogenized sample to a lab for analysis. P concentrations are typically 1.7-2 percent for dry poultry and swine manures and 0.5-1.2 percent for dry beef and dairy manures.

Inorganic Sources

Several inorganic P fertilizers are on the market. These fertilizers have a known, guaranteed analysis and are available in liquid and dry forms.

Liquid forms are generally more expensive but easier to transport and store. For example, ammonium polyphosphate (10-34-0) is a common starter fertilizer.

Dry fertilizers, although cheaper, are more difficult to store. Two common dry P fertilizers are diammonium phosphate (DAP, 18-46-0) and monoammonium phosphate (MAP, 11-52-0).

There are also specialty inorganic fertilizer products that include micronutrients. These specialized sources may be useful in specific situations, but you should consider if the extra expense is worth the benefit. Because inorganic products contain 85-100 percent water-soluble P, environmentally significant losses can occur if you apply high rates without incorporating it into the soil.

3. Apply at the Right Time

The third of the 4R principles for applying P is to apply at the right time.

When you apply P does not generally affect final crop yield, but timing can significantly affect the environment. The percentage of P that is water-soluble and remains dissolved is most detrimental to water quality (Table 1). Hence, it is important to avoid applying P fertilizer (whether manure or commercial fertilizers) when the ground is frozen, snow-covered, saturated, or just before heavy rains (Figure 4).

Figure 4. Applying manure or fertilizer on snow-covered ground (as shown here in north-central Indiana) greatly increases the amount of DP that is lost after the snow melts. That's because the P is less able to bind to soil particles. Photo by Tony Vyn.

Fall Applications

Applying fertilizers in the fall can be most convenient for farm operators. Generally, prices are lower in the fall, and there is more time to complete fieldwork. However, if you choose a P source that also has an N component, understand that overwinter losses of the N can be high, especially if there is a wet spring.

DP can also leave the field under these conditions. The longer concentrated P granules are in the field before plant uptake or fixation to soil particles, the more P can be lost. However, if you incorporate the P fertilizer or leave it in the field long enough before a runoff event, you may reduce the amount of DP loss.

Spring Applications

Applying P fertilizer in the spring is closer in time to plant uptake, so could reduce P loss to the environment. However, you need to monitor the weather to avoid applying fertilizers soon before heavy spring rains. Several studies have found that when it rains one or two days after broadcast applications (when P fertilizer is still highly concentrated in granules or on the surface) up to 10 percent of the total P applied can be lost. Soils in the spring are generally more saturated than in early fall; thus spring rains are more likely to produce runoff and carry DP offsite.

Applications at Planting

Applying starter fertilizers at planting (whether in-furrow or banded) helps split P applications. Growers can reduce the risk of P loss to the environment when they switch from making a single high-rate application, to making two lower-rate applications before planting and at planting. The split applications lower the concentration of P in both time and space.

Summer Application

Crop rotations that include winter wheat or oats can allow for summer P application after cereal harvest. Researchers have observed significant reductions in DP and total P losses with this application time because DP has a longer time to become fixed to the soil (Smith el al., 2015).

4. Choose the Right Placement

The last of the 4R principles for applying P is to choose the right placement.

Placement choices, like timing, may affect the environment and management practices more than crop yield. If you do not immediately incorporate fertilizers with high solubility (Table 1), large amounts of P will stay dissolved and be more prone to loss from the field. The tillage system you use greatly affects P fertilizer placement options. Figure 5 shows how available P can stratify in the soil with different P placement options.

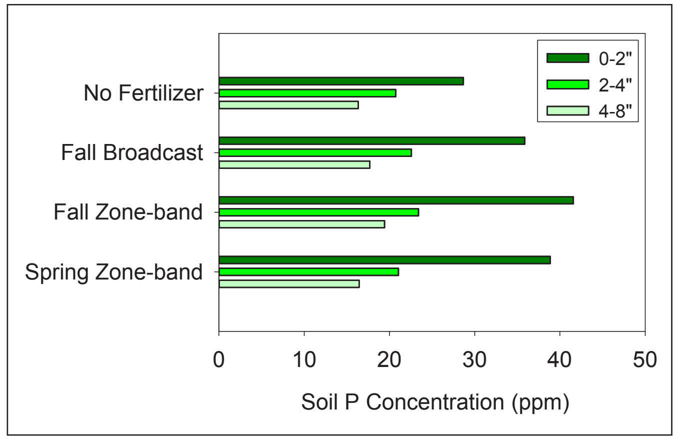

Figure 5. This graph shows soil-available P concentrations in the center of corn rows following planting at three depths with different P timing and placement techniques. A rate of 60 pounds of P_2O_5 per acre was applied as the Mosaic Company's MicroEssentials® SZ™ to high organic matter, silt loam soils (0-8 inch soil test P level: 20.5 ppm) in West Lafayette, Indiana. The broadcast P was not incorporated. Zone-banded placement was done with a coulter-based strip-till system. Source: Winters and Vyn, 2014.

Surface Broadcast (Not Incorporated) Placement

Broadcast application is the fastest and most fuel-efficient P fertilizer placement method. You can use this method with any tillage system, but it will usually be incorporated in conventional tillage programs (see next section). Surface broadcasting in no-till systems results in very slow gains in plant-available P at deeper soil zones and considerably higher P concentrations at the surface compared to fall plow (Figure 6).

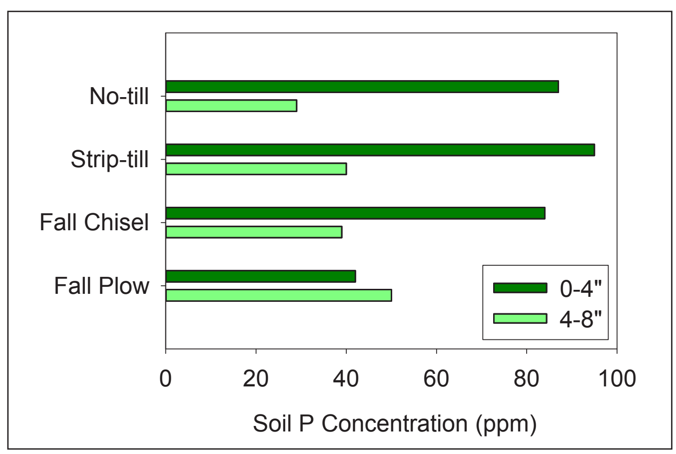

Figure 6. Distribution of soil-available P concentrations after 40 years of different tillage systems with equal post-harvest broadcast P_2O_5 applications on a Drummer silty clay loam (0-8 inch soil test P level: 58 ppm) in West Lafayette, Indiana. Source: Vyn and West, 2015.

When you do not incorporate P fertilizers into the bulk soil there is less soil-P sorption, and this will increase DP at the soil surface. This means that if you do not practice mechanical incorporation plant-available P will build up in the surface and become more stratified. If the majority of soil-test P is within the first few inches of soil at the surface, then it may become unavailable in dry surface soil conditions, because most P is taken up through diffusion. On the other hand, if rains cause surface runoff, the most enriched soil will be lost along with higher levels of dissolved P.

This high level of P stratification can occur in several tillage systems (Figure 6). Residue on the soil surface can slow the loss of P-enriched soil more than bare soil. However, surface residue does not reduce the amount of lost DP, which several researchers (including Gächter et al., 1998) found can be as much as 89 percent of total P loss. Research by Gaynor and Findlay (1995) and others suggests that multi-year no-till practices create soil macropores that can exacerbate the transport of DP from the surface through the soil and directly into tile lines.

Incorporated Placement

Incorporating P fertilizer with some type of tillage significantly reduces DP concentrations in surface runoff. Incorporating fertilizer also means more of the root zone will become enriched with available P, which may increase plant uptake. Moreover, more P will move from the DP form to the reactive form with incorporation.

Growers can use a variety of implements to incorporate P fertilizer, but incorporation depth will change drastically depending on the intensity of your tillage system (see Figure 6). However, if you till the whole surface of a field to incorporate fertilizer, you also may increase erosion, thus raising the amount of P lost with the sediment.

Strip-till systems offer an alternative to tilling the whole surface and control erosion nearly equivalent to no-till (except on steep slopes). In strip-till systems you can incorporate fertilizer with shanks, coulters, or knives.

Deep-band Placement

Placing P in a concentrated band at least 5 inches below the surface is referred to as deep-band placement. Special row equipment places the fertilizer (Figure 7).

Figure 7. You can incorporate fertilizer with shanks, coulters, or knives. This producer in Frankton, Indiana, is using a deep-banded strip-till system. Incorporation decreases DP loss in surface runoff. Photo by Tony Vyn.

Past Indiana research has shown that deep banding does not significantly improve corn yields relative to other P placement methods. But the shanks loosen soil deeper in the profile, which may improve crop yield by physically improving soil conditions below the rows.

Providing a more concentrated P zone in the soil can increase root uptake from that area and compensate for low P availability in the rest of the soil. However, deep banding can complicate soil sampling, which must account for the uneven distribution of nutrients.

Also, if you apply P with high levels of N in a deep band for several years, the soil pH in the band can become so acidic that less P is available to plants. The position of the lower pH zone then can make it difficult to correct via lime application. Varying the position of the deep band each year using GPS-guidance may reduce its detrimental effects and distribute P enrichment to a greater soil volume.

Placing the fertilizer P below the surface reduces the risk of DP runoff directly from the most recent P fertilizer application to almost zero. However, it is not clear how this placement method affects subsurface P loss over time.

Planter Placement

In addition to the previously mentioned agronomic benefits of incorporating P, injecting P starter fertilizers either in-furrow or 2 inches to the side and 2 inches below the seed (a 2 x 2 band) reduces the risk of DP runoff. Starter applications place P close enough to seedling roots so that it can be taken up as soon as corn seedlings transition from relying on P in the seed to available P from the soil.

Cover Crops

Cover crops have been used as "catch crops" to reduce N losses, and many wonder if cover crops can do the same for P. Cover crops have been shown to take up P in the fall and, as they break down, release plant-available P back into the soil.

However, while researchers have found cover crops release P when decomposing, that does not mean they will increase P uptake in the following crop (Kuo et al., 2005). A few research trials suggest that P release from some cover crops during decomposition may increase P in runoff water, but the complex effects of cover crop systems on water infiltration versus runoff and timing of P release need further research.

Conclusion

There are many factors to consider before you choose a P application program. With increasing problems associated with DP in surface waters, it is important to consider the environmental impact of your application system along with its agronomic and economic merits.

Any system that places P fertilizer below the surface without significantly increasing soil erosion will reduce P losses to the environment. Awareness of P loss mechanisms and continued research on optimum methods to improve plant P uptake with less P loss are essential.

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