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Reducing Loss of Fertilizer Phosphorus to Lake Erie with the 4Rs

Algal blooms in Lake Erie have been getting worse in the past few years. Phosphorus (P) has often been considered the nutrient controlling such blooms. The loads of dissolved P in the rivers draining into Lake Erie vary greatly year-to-year, but higher loads have become more frequent in recent years than in the mid-1990s. Agriculture is one of several sources of dissolved P.

This article outlines how crop producers in the Lake Erie watershed can reduce losses of P by adopting a 4R Nutrient Stewardship approach to guide their fertilizer application practices.

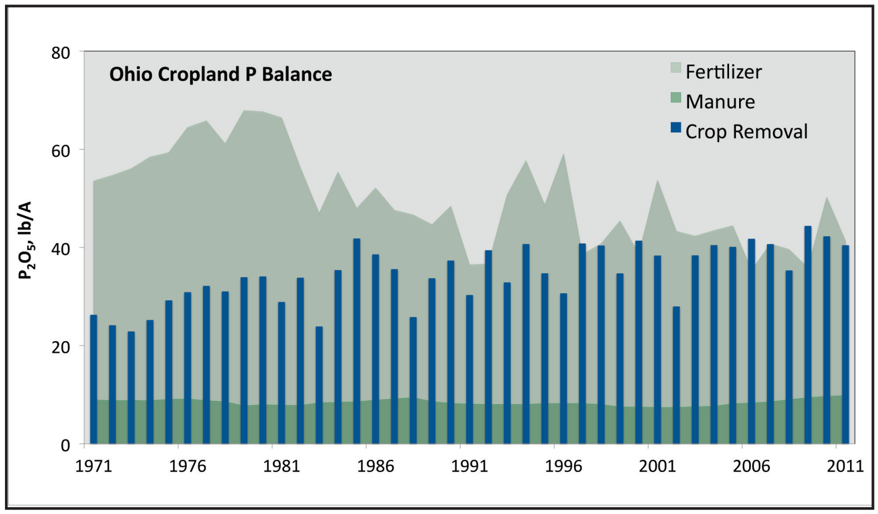

Figure 2. Phosphorus balance trend over time for Ohio cropland. *2011 fertilizer estimated.

Background

Much of the cropland of the Lake Erie watershed is found in Ohio, with smaller areas in Indiana, Michigan and Ontario (**Figure 1**). Almost half of Ohio cropland drains into Lake Erie. In the Western Lake Erie drainage basin, over 72% of the land area is in crops (USDA-NRCS-CEAP, 2011), and about 60% of cropland is in conservation tillage. Most of the conservation tillage consists of no-till soybeans, along with much of the smaller area planted to wheat. Most corn is grown with conventional tillage (USDA-NRCS, 2011). Thus most of the land receives "rotational tillage."

Farms are getting fewer and larger. The proportion of Ohio cropland in farms over 1,000 acres in size increased from 12% in 1978 to 35% in 2007 (calculated from USDA-NASS, 2009). With farmers choosing larger planters and fewer stops to refill bins, there appears to be a trend to less band application and more broadcasting of P fertilizer.

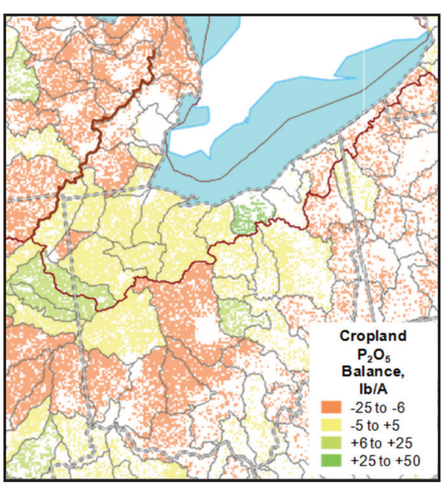

Figure 1. Dots reflect the density of cropland, and their color its P balance (IPNI, 2012).

Is too much P being applied?

In most of the Lake Erie watershed, about as much P was removed by crops as applied in fertilizer and manure in 2007 (**Figure 1**). Current rates of application of P have declined to the point where, on average, the amount in fertilizers and manures applied to the land is in approximate balance with the amount removed with crop harvest (**Figure 2**). In the figure, manure includes only recoverable portion of amount excreted. Fertilizer sales for 2011 are estimated as the average of the previous 5 years. For further details on assumptions, see Bruulsema et al. (2011).

Are soil test levels too high?

Between 2005 and 2010, the frequency of soils testing above 50 ppm declined, and the frequency of those testing within the maintenance range has increased (**Figure 3**). The critical level and maintenance limit values shown are for corn and soybeans; wheat and alfalfa require higher levels. There is opportunity to draw down soil P on about 35% of Ohio's cropland.

A recent upsurge in soil sampling is also evident in **Figure 3**. Ohio State University recommends that each 25-acre parcel of cropland be sampled once every 3 to 4 years. Annual soil sample volume expected from following this recommendation would be about 125,000 soil samples. In 2010 almost twice that number of soil samples were analyzed.

The trends in nutrient balance and soil test levels do not explain the recent increase in dissolved P in the rivers. A closer look at management practices may be necessary to understand how to control the loss of dissolved P.

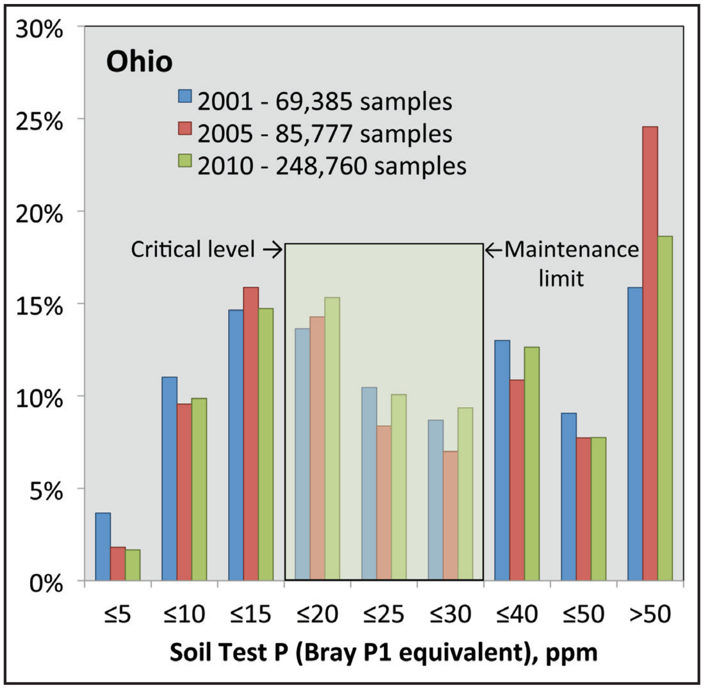

Figure 3. Frequency distribution of soil test P levels for Ohio cropland (IPNI, 2010).

Can 4R crop nutrient practices reduce P loss?

Applying crop nutrients with 4R Nutrient Stewardship requires attention to source, rate, time and place. Listed following are some preliminary considerations on each. Further detail is provided in the sections beyond.

Source. Can a controlled-release product help reduce P losses? Plants need the same form of P—dissolved P—that makes algae thrive. In the soil, dissolved P (especially in small amounts) tends to become less available due to adsorption to the surface of soil particles. When larger amounts of dissolved P are placed in contact with smaller amounts of soil, more of the applied P remains available. This is one of the reasons why band application or point injection can be more effective in supplying P to the crop. The most important property of the source is its suitability for band or point placement.

Rate. Will reduced rates reduce P loss? The crop nutrient balance in **Figure 2** shows that average application rates of fertilizers and manures are no longer in surplus of crop removals. The watershed includes high P soils needing drawdown as well as soils testing below the maintenance range (**Figure 3**), so it is important that each field receive the right rate for its soil test. There is also opportunity in some fields for variable-rate application. When zones within fields show strong differences in soil test P, variable-rate application can help prevent both deficiencies and accumulations of excess P.

Time. Can time of application reduce P loss? Applying close to the time of plant need minimizes the time for chemical reactions with the soil and may improve P availability to the crop. In most soils with optimum P levels, however, there is little difference in availability between fall and spring application. To minimize losses, it is important to apply when the risk of runoff is low, particularly with broadcast applications. Runoff events are more frequent in late fall, winter and early spring. Ideally all P would be applied at planting, but this could require a major reworking of how fertilizer is stored, and how it is applied. Broadcast application of P on frozen or snow-covered soil in the winter is never the right time, no matter what the source. Even though the loss of P in runoff is not enough to reduce crop yield or long-term P use efficiency, it can be more than enough to harm water quality.

Place. Why is placement so critical? Two main reasons. First, placing below the top 2 inches in the soil helps minimize stratification in soils managed with no-till, conservation tillage, or even ordinary chisel plowing (**Figures 4 and 5**). Stratification of soil P can develop in any soil that is not moldboard plowed. When the soil test P of the top 2 inches increases, so does the concentration of dissolved P in runoff water. Second, P fertilizer is soluble P. Leaving it on the soil surface dramatically increases the concentration of dissolved P in any runoff that happens to occur within a few weeks after application. So the right place to put P is **close to the roots of the plants that need it.** Many crops, especially corn, have a special need for P early in the growing season. With or near the seed is a good place for P. If the bin for granular fertilizer has become impractical for your new large planter, look into air carts or other injection systems that can place P in concentrated points or bands near seedlings. Right place can also include keeping back from sensitive areas such as those close to surface waters, drainage ditches and tile inlets.

What are some realistic application options?

Placing P in a band at planting lowers the risk of its loss in runoff and tile drain flow. So why don't all farmers do so? **Table 1** outlines the advantages and limitations of some of the options for fertilizing a crop rotation involving corn, soybeans, and possibly wheat. It presumes that soil test levels are in the optimum (maintenance) range and that the most common tillage practices (chisel plow before corn, no-till for soybeans or wheat) are used, unless otherwise stated. Options 1 through 3 are currently used most often. Where possible, moving from option 1 to 2 and to options 3 through 5 would represent progress in reducing risk of dissolved P loss.

Options 4 and 5 attempt to combine ideal placement with the advantages of fall application. On many of the flat clay soils of in the Lake Erie watershed, good crop yields are possible but only when fieldwork and planting are done at just the right time, and soil compaction is minimized. In practice, this translates into a need to simplify spring operations and streamline planting, and fall application

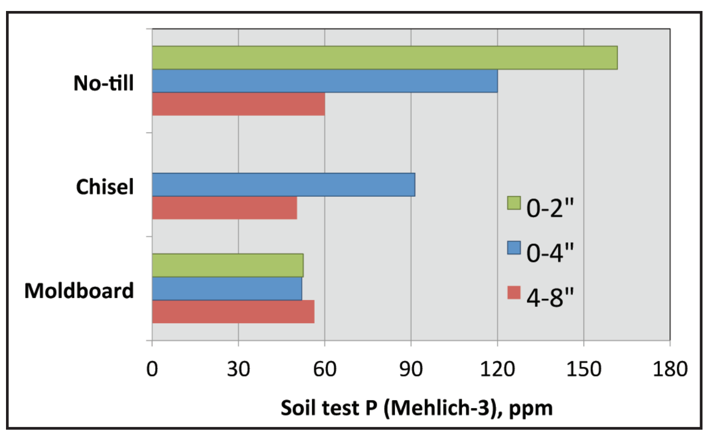

Figure 4. Soil test P distribution with depth in a long-term tillage experiment on a poorly drained Chalmers silty clay loam soil near West Lafayette, Indiana. Moldboard and chisel plots were plowed annually to a depth of 8 inches. Data from Gál (2005) and Vyn et al (2000).

Table 1. Advantages and limitations of selected P fertilizer application practices, combinations of source (S), rate (R), time (T) and place (P).

P Application Practice	Advantages	Limitations
OPTION 1 S – MAP or DAP R – removal rate for rotation T – fall after soy before corn P – broadcast	• Minimal soil compaction • Allows timely planting in spring • Lowest-cost fertilizer form • Low cost of application	• Risk of elevated P in runoff in late fall and winter • Low N use efficiency
OPTION 2 S – MAP or DAP R – removal rate for rotation T – spring before corn P – broadcast	• Minimal soil compaction • Better N use efficiency • Low-cost fertilizer form • Low cost of application	• Risk of elevated P in spring runoff before incorporation • Potential to delay planting • Retailer spring delivery capacity
OPTION 3 S – MAP or fluid APP R – removal rate for crop T – spring P – planter 2" x 2" band	• Best N efficiency • Low risk of elevated P in runoff • Less soil P stratification	• Cost and practicality of planting equipment with fertilizer capacity • Potential to delay planting • Retailer delivery capacity • Cost of fluid versus granular P
OPTION 4 S – MAP or DAP R – removal for crop or rotation T – fall after soy before corn P – zone placement in bands	• Low risk of elevated P in runoff • Better N and P efficiency • Maintain some residue cover • Allows timely planting in spring • Less soil P stratification	• Cost of RTK GPS guidance • Cost of new equipment • Requires more time than broadcast
OPTION 5 S – fluid APP R – removal for crop or rotation T – fall after soy before corn P – point or spoke injection	• Low risk of elevated P in runoff • Better N and P efficiency • Maintain good residue cover • Allows timely planting in spring • Less soil P stratification	• Cost of RTK GPS guidance • Cost of new equipment • Cost of fluid versus granular P • Requires more time than broadcast

of P may help growers meet that need. New equipment is becoming available for rapid band application in combination with strip-till, zone-till or no-till systems.

How can soil P stratification be kept to a minimum?

Runoff water, and even some tile drain water arising from preferential flow, interacts mainly with the top inch or less of the soil profile. Thus P applied on the surface and the soil test P level of the surface soil strongly control the amount of dissolved P in water that leaves the field. Comparing strict long-term no-till to annual moldboard plowing, soil test P levels in the top 2 inches of soil can be three times higher than in the 4 to 8 inch depth (**Figure 4**). Annual chisel plowing resulted in about half as much stratification as no-till, at least in the top 4 inches. In this Purdue University study, P was applied broadcast in the fall prior to tillage. Corn yields were 5 to 15% lower in no-till compared to tilled plots. The lower yields and lower P removal may explain the higher overall soil test P levels in no-till, or it may be due to the higher organic matter in the surface layer protecting the P from fixation by the soil, or simply less mixing of fertilizer with soil.

Two factors cause stratification with no-till or conservation tillage: the accumulation of P in crop residues, and the placement of applied P without soil mixing. Stratification develops within a few years after switching from moldboard plowing, more rapidly when P is applied than when it is not, and more rapidly with broadcast than with band application (**Figure 5**).

What are the implications for dissolved P loss?

Generally, the concentration of dissolved P in runoff is proportional to soil test P levels in the top inch or less of soil. No-till is an important tool for controlling loss of sediment, but it does not reduce—and in fact it may sometimes increase—dissolved P in runoff. Stratification will be less, however, if P is band applied into the soil rather than broadcast on top. Applying P below the soil surface is important to minimize stratification and dissolved P loss in both no-till and chisel-plowed soils.

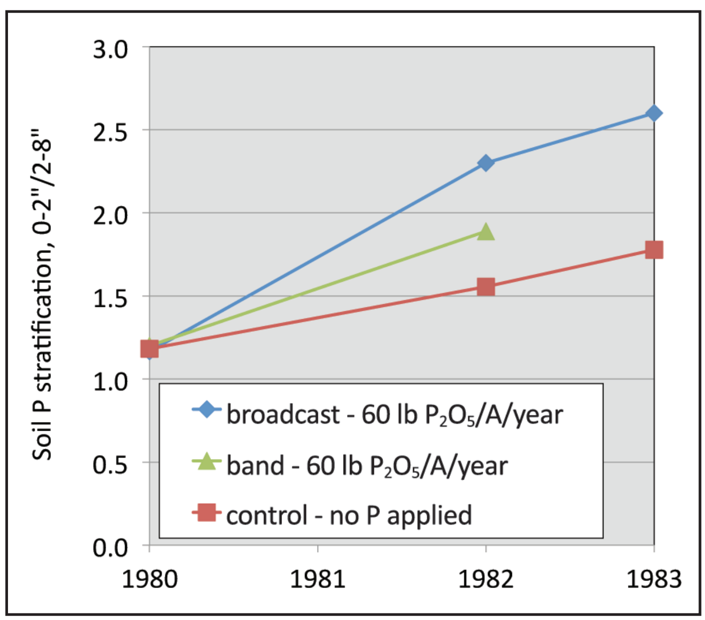

Figure 5. Soil P stratification—the ratio of soil test P in the top 2 inches compared to that in the 2 to 8 inch depth—increased over time more with broadcast than with band application. Silt loam soil near Wooster, Ohio; continuous corn, no-till from spring 1980. Data from Eckert and Johnson (1985).

Where fertilizer P has recently been surface broadcast, runoff water can have high levels of dissolved P.

If P is always band-applied, will soil samples still mean anything?

Band-applied P is indeed quite immobile in the soil, and thus you can expect that a sample taken from a band location will differ sharply from one taken only a few inches away. Nevertheless, there are guidelines for effectively sampling soils with a history of band application.

If the band locations are known, and the P band is narrow (i.e. as occurs in a V-trench associated with single or double coulters as openers) a ratio of 1:20 in-band cores to between-band cores should be used for bands spaced 30 inches apart. If the location of the bands is unknown, a paired sampling approach can be effective: one sample consisting of cores taken at random, and the second consisting of cores each taken at a distance of half the band spacing from each of the first cores, perpendicular to the direction of the bands. Since the greatest deviation from the 'true' soil test P level occurs when the band location is over-sampled, the sample with the lower soil test P level is most likely to be representative (Kitchen et al., 1990).

If the banded zone is wider, as in strip tillage, the ratio should be the same as the strip width to the non-strip width. In strip-till corn-soybean rotation with P applied in the strips 6 inches deep in the fall, a 1:3 ratio of in-row to between row samples seemed adequate to estimate soil fertility (Fernández and Schaefer, 2012).

Summary

There is much yet to be learned through research regarding the best practices to minimize losses of dissolved P. In particular, tillage and drainage management play important and complex roles, not really covered in this article. Nevertheless it is clear that when making choices for source, rate, time, and place of P application, very high priority needs to be given to ensuring that sources of soluble P—be they fertilizer, manure, or other materials—do not remain on the soil surface when runoff-inducing rainstorms occur. With the right equipment, P can be placed below the soil surface even in minimum-till or no-till systems. Managing the soil to maintain optimum water holding characteristics need not conflict with 'right place' for P. Adopting a 4R Nutrient Stewardship approach to continually improve choices for source, rate, time, and place will make a difference for the water quality of Lake Erie. ■

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