Purpose of this document

This document is intended to provide background information and a framework for discussions on ways to reduce dissolved phosphorus runoff from croplands into Lake Erie. While this document was produced to serve as a basis for discussions among the advisory team members for Grant #833 from the Great Lakes Protection Fund (GLPF) to Heidelberg University, it may also be useful to other groups who are now mobilizing to address this same issue. Our GLPF project team does include farmers from the Sandusky Watershed, soil and water district personnel, extension agents, USDA personnel (NRCS and ARS) and their Canadian counterparts, state agency personnel, agricultural fertilizer industry representatives, area CCAs and cooperatives, Sandusky Watershed Coalition representatives, and university researchers from three states.

We believe that the agricultural community needs to develop a consensus on which BMPs hold the best prospects for reducing dissolved phosphorus loading from the various crop production settings within the Lake Erie Watershed, based on currently available information. While it is true that more research is needed on certain BMPs, it is also clear that pressures to "do something about dissolved phosphorus runoff" are mounting rapidly and, as researchers and managers, we can't wait for new research. That consensus needs to be developed very soon and communicated to all "stakeholders" including the agricultural, environmental, commercial and public communities.

Because so many groups are coming to similar conclusions regarding the need for consensus and action, we are circulating this document in draft form. We welcome feedback from others, as well as suggestions on how this document may best serve to advance that consensus process and subsequent actions.

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"Toolbox" of Best Management Practices (BMP's) to Reduce Loading of Dissolved Phosphorus (DP) to Streams and Ditches in NW Ohio

Background

Over the past decade or more, increased losses of dissolved phosphorus (DP) from agricultural cropland in NW Ohio and resultant eutrophication of the Western Lake Erie Basin have been well documented. The purpose of this "Toolbox" is to compile a list of BMPs that conservation planners and farmers might use or adopt to reduce DP losses to ditches and streams as well as provide insight as to practice function and effectiveness. This focus on DP is not to diminish the importance of BMPs for the reduction of particulate phosphorus losses through the process of erosion and sedimentation. In fact, many of the practices are the same. Rather, the "Toolbox" of BMPs for DP will work to complement a nutrient management plan that addresses all cropland phosphorus loss in a comprehensive manner. Important perspective that demands this approach is that as cropland erosion rates and related losses of particulate phosphorus have decreased, the relative importance of dissolved phosphorus has increased. Not only has dissolved phosphorus runoff as a percentage of total phosphorus loss increased, the total amounts of dissolved phosphorus export have more than doubled since the mid-1990's.

Using conservation tillage to include no-till and conservation buffers, NW Ohio farmers successfully met the challenge to reduce sediment and particulate phosphorus delivery to Lake Erie in the 1980's and 1990's. Now the challenge for farmers is to successfully adopt practices that will reduce delivery of dissolved phosphorus to the Lake. Meeting this challenge will not only improve water in lakes but keep fertilizer dollars in the field. "Toolbox" can help do this!

Scope of the "Toolbox"

Compilation of DP BMP's shown in Table 1 was completed within the following framework:

- Focus primarily on BMP's that would reduce DP losses from commercial fertilizers and soils, since phosphorus contributions from livestock are relatively small in NW Ohio;
- Rate the BMP's according to their effectiveness to reduce DP in NW Ohio;
- Provide relative practice costs and the likelihood of adoption by farmers;
- Develop a suggested combination of DP BMP practices that, in conjunction with other particulate phosphorus BMPs might prove most effective in significantly reducing runoff DP;
- Exclude from the "Toolbox" BMPs that had little or no effect on DP in runoff;
- Determine areas where additional research might be needed to better understand DP BMP function and/or adoption.

How BMPs Were Selected

The "Toolbox" for phosphorus BMPs is full! The objective here was to sort through that "Toolbox" and to put BMPs for DP in the upper tray of the "Toolbox" where they are more visible. Since many of the practices have benefits for the reduction of both particulate and dissolved phosphorus, criteria were needed for the purpose of BMP selection. Criteria were derived from an understanding of the processes by which phosphorus becomes dissolved, then moves with water in cropland fields. (See References: "Dissolved Phosphorus Sources and Movement in Agricultural Cropland.") Essentially, when highly soluble commercial phosphorus fertilizers are applied to a field surface, they begin to dissolve quickly in the presence of moisture. If there is enough water (rainfall, snowmelt), dissolved phosphorus begins moving downward in the soil profile via infiltration. When precipitation or snowmelt exceeds the infiltration capacity of the soil, water begins to move as surface flow across the soil in the field. Much greater surface flows, along with greater DP losses, happen when large storms of longer duration occur in a day or so after fertilizer application without incorporation. While the first storm after surface phosphorus fertilizer application results in the highest enrichment of phosphorus concentration for runoff or release to the soil, subsequent storms can also result in DP losses from fertilizer residues on the soil surface. Eventually, DP losses revert to release of phosphorus held by the soil. Agronomic soil tests, or more recently, environmental soil tests, are used to assess the extent of DP loss from soils during times of runoff or leaching.

Knowledge of this dissolved phosphorus generation and movement process has been incorporated within numerous state and governmental "Phosphorus Indexes" which assess the risk of a particular field for phosphorus losses to water where environmental damage may occur. Index components address both the sources of phosphorus that contribute to losses plus the transport mechanisms by which source material is moved from the field. Understanding relationships between these source and transport factors lead, in turn, to BMPs to reduce phosphorus loss from a field.

For the DP BMP "Toolbox" in Table 1, sources are commercial phosphorus fertilizers and soil phosphorus measured by soil testing. Transport factors are surface storm or snowmelt runoff and subsurface leaching and drainage (tile). The following criteria are used to evaluate practices for DP BMP selection:

- How does the BMP influence DP concentrations within the field?
- How does the BMP influence storm or surface runoff from the field?

Combining these evaluations results in an assessment of edge of field loading (Concentration X Flow) to streams or ditches. DP BMPs selected are expected, at least overall, to have a positive effect in the reduction of DP loading from the field.

Ample documented work by others aided the selection of the BMP's shown in Table 1. (See References: "Agricultural Best Management Practices.") Rating practice effectiveness proved difficult since research sometimes gave either conflicting views or ranges of results; and much of the research was, of course, not done specifically in NW Ohio. The BMP "Tile Drain Outlet Control" was the best example of difficulty rating practice effectiveness. (See References: "Rating the Effectiveness of Dissolved Phosphorus Best Management Practices.") Even with these difficulties, patterns of practice effectiveness did emerge based on how and to what degree a specific practice impacted either DP concentration or storm runoff in fields representing a variety of cropland conditions across agricultural portions of the United States and Ontario, Canada. To add perspective to the scale of practice effectiveness, some highly effective practices, although ones that would not be adopted on a large scale by cropland farmers, were added to the DP BMP list. "CRP Cover - Trees" is an example, but then use of the field as cropland would be lost. The rating system used for Conservation Practice Physical Effects (CPPE) in Section V of the Ohio NRCS Field Office Technical Guide served as a model for making practice ratings. Other references, however, were used to more accurately rate a BMP with respect to impacts on DP concentrations or storm runoff. OSU Fact Sheet AEX-464-91, USDA-ARS Publication 163 and the SERA 17 Workgroup BMP publications were particularly helpful in this regard.

Table 1. Field Best Management Practices (BMP's) for the reduction of dissolved phosphorus (DP) loading (concentration X flow) to streams and ditches in NW Ohio. (07/29/2011)

	PRACTICE LOCATION		FIELD REDUCTION RATING POTENTIAL		**"TOOLBOX" of BMP's for DP**		
BMP PRACTICE	IN FIELD	EDGE OF FIELD	DRP CONCEN-TRATION	STORM RUNOFF	HOW THE PRACTICE WORKS	RELATIVE PRACTICE COSTS	LIKELY PRACTICE USE *
<u>Nutrient Management:</u>							
Soil testing - agronomic	X		+1	0	Measures phosphorus requirements for optimal crop growth.	Low	High
Soil testing - environmental	X		+2	0	Measures potential for DP losses in surface flow or, at times, in sub soil leaching.	Low	Medium
Vegetative mining	X		+2	0	Uses cropping system to drawdown high soil test levels. May take 15 plus years.	Low	Low
P application rate	X		+5	0	Key component of all P Indexes. Main determinant of DP availability.	Low	High
Variable rate P application	X		+3	0	Results in Improved spatial placement of P fertilizers for crop utilization.	Medium	High
Time of P application	X		+4	0	Considers: rain forecast; saturated, frozen or snow covered soils; growing crops.	Low	Medium
P application method:							
Broadcast, shallow incorp.	X		+1	0	Incorporated 2 to 3 inches within 24 hours of application using full width tillage.	Low	High
Broadcast, AerWay incorp.	X		+1	+2	Can allow DP to infiltrate 6 to 8 inches while maintaining residue cover to slow runoff.	Low	Medium
Band with corn planter	X		+3	0	Placed at corn planting time in a band at least 2 to 3 inches deep.	Low	Medium
Subsurface injection	X		+4	+1	Placed typically in a band more than 5 inches deep. Improved short term infiltration.	Medium	Low
P application location	X		+3	0	Setbacks from watercourses, surface tile inlets, sinkholes, tile blow outs. Avoidance of flood plains, steep slopes or poorly drained soils.	Low	Medium
<u>Conservation Tillage:</u>							
Mulch tillage/residue mgt.	X		-1	+1	P can stratify. Slows runoff, increases infiltration and soil organic matter.	Low	High
No tillage/ residue mgt.	X		-2	+2	P can stratify and enter macropores. Increases infiltration, builds organic matter.	Low	High
Non inversion tillage	X		-2	+2	Reduces compaction and retains residue to promote infiltration. P can stratify.	Medium	Medium
<u>Conservation Cropping:</u>							
Crop rotation	X		+1	+1	Basis for P nutrient uptake, slowing of runoff and increased organic matter.	Low	High
Cover crops	X		+1	+2	P uptake seasonally. Increases infiltration and adds organic matter.	Medium	Medium
Strip cropping	X		+1	+2	Wheat or hay with row crops. Disperses P application. Diversifies cover.	Medium	Low
Hayland planting	X		-2	+3	Permanent cover. Slows runoff and increases organic matter. P can stratify.	Medium	Low
CRP cover - Grass	X		+3	+4	P nutrients not applied. Significant increase in percolation. Retards runoff.	Medium	Medium
CRP cover - Trees	X		+4	+5	P nutrients not applied. Permanently increases percolation and retards runoff.	High	Low
<u>Conservation Buffers:</u>							
Filter strips (grass)		X	+1	+2	P not applied. Need proper design. DP reduction less with time. More infiltration.	Medium	Medium
Filter/recharge areas		X	+1	+2	Grassed areas where water drains from fields. No P applied. More percolation.	Medium	Medium
Riparian strips (trees)		X	+2	+4	P nutrients not applied. P uptake permanent. Greater percolation, runoff dispersal.	High	Low
In field buffers (grass)	X		+1	+3	P nutrients not applied. Slows runoff across landscape. Greater infiltration.	Medium	Medium
Field windbreaks (trees)	X	X	+1	+3	P not applied. P uptake is permanent. Slows overland flow. Greater infiltration.	High	Low
<u>Water Management:</u>							
Controlled traffic	X		+1	+2	Reduces wheel traffic compaction. Improves infiltration. Improves crop P uptake.	Low	Medium
Tile drain outlet control		X	+1	+1	Reduces some storm runoff in soils with preferential flow. Greater P uptake by crops.	Medium	Low
Tile drain inlet control	X		+1	+3	Blind inlets permit greater infiltration and halt direct delivery of water to channel.	Medium	Low
Tile main repair	X		+1	+3	Repair permits greater soil infiltration and halts direct delivery of water to channel.	Medium	Medium
Wetland construction		X	+1	+2	Reductions in DP are less with time. Slows/disperses runoff. Groundwater recharge.	High	Low

* Rating considers present cropland economics, current USDA incentive programs for the practice and continued SWCD assistance with program delivery and practice application.

In Table 1, the numeric values in the Field Reduction Rating Potential columns should be interpreted as follows:

-2	somewhat moderate negative effect	+2	somewhat moderate positive effect
-1	minor negative effect	+3	moderate positive effect
0	little or no effect	+4	somewhat major positive effects
+1	minor positive effect	+5	major positive effects

How the Practice Works - Details for Use in NW Ohio

For a detailed description of the BMPs shown in Table 1, review Section IV of the Ohio NRCS Field Office Technical Guide: Practice Standards and Specifications. In some cases, the practice listed is a component of the overall standard. For example, "Phosphorus Application Method" is a component of "Nutrient Management", practice standard "590".

Soil Testing - Agronomic (includes grid or precision testing) Traditional soil testing, using Mehlich 3 or similar extraction processes, is an excellent tool to measure plant available phosphorus within soil in order to determine amounts of phosphorus fertilizers needed (or not needed) for optimal crop production. Both appropriate soil testing and appropriate fertilizer application recommendations based on those soil test results are important for phosphorus nutrient management. (See References: "Phosphorus Soil Testing.") According to researchers at Ohio State University, there is no agronomic benefit to applying fertilizers when soil test values exceed 60 ppm Mehlich 3 P (Mullen and Dayton, 2010). At soil test levels above 60 ppm the potential for release of excess soil phosphorus to runoff or leaching increases, which heightens the risk of environmental damage to streams and lakes. The State of Ohio recommends that special management steps be taken to limit phosphorus application in fields testing over 50 ppm Bray 1P and to cease application in fields testing over 150 ppm Bray 1P. These standards use agronomic soil test values to avoid unneeded phosphorus fertilizer applications where their use may risk damage to the environment.

Soil Testing - Environmental Environmental soil testing is intended to specifically measure amounts of soil phosphorus available to runoff or leaching following rainfall or snowmelt. (See References: "Phosphorus Soil Testing.") Generally, as soil test phosphorus increases, the concentration of DP in runoff increases. This is especially true when soil test phosphorus values climb beyond the critical levels. Environmental soil testing approaches may differ from standard agronomic soil test methods so that estimates of potential phosphorus losses from a field are more precise. One example would be an extraction using only distilled water. Another might calculate degree of soil phosphorus saturation using knowledge of soil chemistry related to iron and aluminum oxides and hydroxides present. To make even more accurate estimates of phosphorus loss potential, environmental soil tests frequently measure the degree of phosphorus stratification within the 0 to 8 inch surface soil profile typical of Ohio soils. A combination of fertilizer application method, presence of decayed crop residues and a reduction in tillage can result in the accumulation of phosphorus near the soil surface where there is a higher risk for dissolution in runoff water. Past studies suggest that the critical zone for soil phosphorus interaction with runoff is the 0 to 2 inch surface layer (Voss and Griffith, 1998.) More recent research shows that the 0 to 2 centimeter depth may be the layer of greatest interaction (Pierzynski, 2004.) Envision stratified phosphorus soil testing as taking the "blood pressure" of the soil. While the lower "pressure" is important for agronomic reasons, the upper "pressure" is important for environmental reasons. A final important value of stratified soil phosphorus testing is that it provides an integrated summary of how phosphorus nutrients were managed in a field over recent history. Information provided by advances in environmental soil testing will permit improved phosphorus nutrient management both within and beyond field boundaries.

<u>Vegetative Mining</u> Sometimes called "crop drawdown" or "soil test drawdown," vegetative mining is a good option for lowering high soil test phosphorus values by the removal of crop biomass. Research indicates that when soil test phosphorus values exceeds critical levels required for optimal crop production, fertilizer phosphorus can be reduced or omitted without impacting yield potential. While the production of hay or silage crops might drawdown soil test phosphorus levels more quickly, the production of high yielding annual crops can be quite effective in "mining" as well. Drawdown occurs more rapidly in fields where initial soil test values are well beyond critical levels and in fields with low cation exchange capacity (CEC) or low organic matter (OM). At best, reduction in soil test values from vegetative mining occurs in 3 to 5 years, but in some fields reductions do not occur for 15 years or more. The fact that drawdown occurs more rapidly in fields having low organic matter indicates that BMPs which increase amounts of soil organic matter are of key importance in retaining DP within soils. Farmers are often reluctant to use vegetative mining and would prefer to use at least some phosphorus fertilizers when planting crops (corn, wheat) responsive to phosphorus.

<u>Phosphorus Application Rate</u> Rate or amount of fertilizer applied per acre is a DP BMP of key importance. Where no or little application is made, there is simply no or little opportunity for DP generation from the product. Typically, new phosphorus fertilizer applications can result in runoff DP concentrations much higher than would occur in runoff from unfertilized soils in NW Ohio.

<u>Variable Rate Phosphorus Application</u> This practice takes advantage of gridded field soil testing and fine tunes application rates spatially within a field. The practice helps ensure more effective and efficient use of any phosphorus fertilizers that are applied.

<u>Time of Phosphorus Application</u> Timing is a key management decision that can impact the entire DRP generation and movement process. Avoiding application of phosphorus fertilizers prior to rain storms on saturated soils or on frozen or snow covered soils are important examples. Applying phosphorus nutrients closer to the time of crop or cover crop utilization is another important timing factor from the standpoint of DP loss from fields.

<u>Phosphorus Application Method</u> The operating principle here is clear. When phosphorus fertilizers are placed in a location that minimizes interaction with rainfall and runoff and maximizes uptake within soil or crops, the potential for generation of DP is significantly reduced. As placement depth increases, the runoff potential decreases. Broadcasting with no incorporation actually heightens the risk for generation of high DP concentrations in both runoff water and water leaching into the soil during or

after a storm. Broadcasting phosphorus fertilizers on crop residues followed by use of an AerWay aerator (vertical tillage using rolling 8 inch tines to fracture and loosen soil) or some similar tool would to some extent permit infiltration of dissolved phosphorus and slow runoff, especially where surface compaction may have existed. Most research with the AerWay, however, has been done with animal manures. The banding of phosphorus fertilizers with a corn planter is an effective way to place phosphorus fertilizers below the 0 to 2 inch zone where rapid phosphorus dissolution can occur. Banding also places phosphorus near corn roots for efficient uptake by the crop. Currently larger farm operations having larger fields often replace older planters with new and wider ones lacking features to band apply phosphorus at planting time. This effective banding method is not then and option to these farmers. Subsurface injection (5 inches or more deep in widths to match next corn crop) of phosphorus fertilizers is the most effective method for reduction of high DP concentrations at the soil surface and the injection tool fractures soil sufficiently to increase short term infiltration. Improved phosphorus uptake by crop roots also occurs with placement beneath the row, when surface soils may be dry and when soil test phosphorus is low. Retaining crop residues while using shallow incorporation, banding with a corn planter or subsurface injection will further retard storm runoff.

Phosphorus Application Location   Application location is a second key management decision that impacts the amount of DP in runoff. Application "setbacks" from areas of concentrated flow, surface tile inlets, tile "blow outs" or sinkholes can measurably reduce the potential for off field movement of phosphorus fertilizers with runoff. These "setbacks" minimize direct delivery of DP to areas of surface runoff and create distances where DP has an opportunity to infiltrate the soil and later be removed by crops. In a similar manner, avoiding phosphorus fertilizer applications in flood plains, on steep slopes or poorly drained soils can be of equal importance. Type of application method can work in tandem with this practice to reduce potential for DP loss from fields.

Conservation Tillage (Residue Management)   While these practices alone, or in conjunction with fertilizer application methods, can do a great deal to speed infiltration and retard runoff, their use over time results in an accumulation of phosphorus near the soil surface where interaction with surface runoff occurs. Once infiltration is exceeded and runoff begins, soils under various forms of conservation tillage can transfer greater amounts of phosphorus to surface runoff than would result from soils without stratification. Thus, the potential for conservation tillage to increase DP concentrations in surface runoff is high. Even in the absence of significant amounts of surface runoff, the existence of macropores formed under conservation tillage, especially no-till, can permit DP losses to tile from smaller rains and saturated soil conditions. Non-inversion tillage is generally done to reduce compaction at depth (narrow straight shank rippers run at 8 inches or more deep) or near the surface (an AerWay aerator, for example). Both tools promote infiltration and retard runoff but the effect is not permanent and stratification of phosphorus still remains. A highly positive long term impact of conservation tillage is to increase soil organic matter which improves greatly the capacity of soils to hold more water and adsorb larger amounts of phosphorus nutrients. Consideration of soil as a living biological entity -- not just "dirt" -- aids the concept of residue management.

Conservation Cropping   This practice affords farmers options for selecting types of annual or perennial crops and the sequence in which they are grown to maximize production and profitability. High yielding crops not only remove large amounts of phosphorus from soils but also produce large amounts of organic matter which improve soil tilth. Cover crops can extend these benefits during portions of the year when production crops are not growing. Strip cropping, an option not normally used in NW Ohio, does diversify fertilizer application methods and decrease surface runoff potential for a given field each year. While phosphorus can stratify in soils with several years of hay land production, grass/legume cover can significantly slow cropland runoff. A common thread among all conservation cropping systems is their ability to uptake soil phosphorus, build organic matter and slow runoff. "CRP-grass" and "CRP-trees" are listed as DP BMPs that are highly effective, but the cropland function with these land use conversions is lost. CRP program modification, however, might enable establishment of grass/legume cover for a period of 3 to 5 years within current cropping rotations.

Conservation Buffers   Buffers add diversity to the agricultural landscape and by location and design create opportunities to both decrease DP concentrations and especially slow runoff. Proper design, installation and maintenance are required to permit buffer effectiveness over the long term. Permanent buffers with a diversity of vegetation yield the greatest benefits. Riparian or streamside buffers that include trees, shrubs and grass are examples. Grassed filters along ditches or streams, while highly effective in trapping sediment, do little to remove dissolved pollutants like DP from runoff passing through the grass. During early years of establishment, grassed filters provide some uptake of DP, but this benefit lessens with time. Stratification of phosphorus within grassed filters can also occur as sediments deposit and vegetative material decays. Filter recharge areas are similar in some respects to grass filter strips but are designed and strategically located to infiltrate and slow runoff as it flows into and through lower portions of drain ways leaving a field. Periodic harvesting or removal of grass vegetation from filters can lessen the risk of phosphorus accumulation at the soil surface and improve DP uptake in new vegetative growth. "In-Field Buffers" of either trees or grass are another option for improving infiltration and retarding runoff, especially in fields with long continuous slopes. In-field buffers of greater width would be more effective in such cases. Another benefit of most buffers is the reduction or elimination of phosphorus fertilizer application to those runoff sensitive portions of a field. Fertilizer rates in the field are then somewhat reduced and application setbacks are well defined.

Water Management   The major functions of water management DP BMPs is to slow, delay or retard the amounts of either surface flow or subsurface leaching in a field. Benefits to DP concentration reductions are little or minor. Controlled traffic, which limits wheel traffic compaction to strips throughout the field (50 percent of field area or sometimes more), slows surface runoff by improving infiltration. Improved soil structure that results enables greater phosphorus utilization by crops. Tile drainage outlet controls can reduce a portion of runoff, especially where preferential flow may be significant. Retaining tile or drainage water during the growing can also serve to irrigate crops which can improve phosphorus nutrient uptake and crop yields. Without careful management, however, this practice could result in wet soils at the time of a runoff event and cause greater runoff amounts than a system without outlet controls. Tile drain inlet control and tile main repair serve a similar purpose. Replacing a surface tile inlet with a "blind" inlet (coarse stone over tile but covered with 6 to 10 inches of soil) or repairing a tile "blow out" within a drain way both work to halt or delay the direct entry of surface water to tile drainage systems. This delay permits greater infiltration and allows other edge of field DP BMPs (filter strips, recharge areas, etc.) to function as planned. Wetland construction (enhancement, restoration or creation) slows runoff, increases evaporation and recharge of ground water but does little to reduce DP concentrations in storm runoff over the long term.

A Usable Combination of DP BMPs for NW Ohio

The field DP BMP table not only estimates practice effectiveness for reduction of DP concentrations and storm runoff but also shows relative practice costs and the likelihood that practices might be used by farmers. With this perspective, the following practices might best work to address increasing levels of DRP in runoff from NW Ohio cropland.

Soil Testing - Agronomic (includes grid or precision testing) Adopt stratified testing as an integral part of standard agronomic testing. Information documenting both horizontal and vertical distribution of phosphorus within the soil profile would permit greater evaluation of past phosphorus fertilizer management within a field and quantify soil test levels where fertilizers might better be managed in the future from the standpoint of environmental concerns. Soil test organic matter levels will be important in evaluating overall results of conservation cropping and tillage systems being used. Costs of this practice are low.

Phosphorus Application Rate Carefully scrutinize the application of additional commercial phosphorus fertilizers where soil test phosphorus exceeds critical levels for crops planned within the rotation. Farmers can benefit economically if fertilizers are not needed for crop production. Use "Vegetative Mining" where soil test levels well exceed critical levels.

Phosphorus Application Method Place any required additional phosphorus fertilizers at depth within the soil to ensure product retention within the field. For example, 5 to 7 inch placement would be better than 2 to 3 inches; but 2 to 3 inches would be better than surface application without incorporation. This practice may pose some economic hardship to farmers, but it can make significant improvements for water quality. Proper placement of phosphorus fertilizers at depth in the soil may negate the need for other DP BMPs such as setback distances.

Time of Phosphorus Application Apply phosphorus fertilizers closer to the time of crop utilization. Application at other times raises concerns with saturated soils, frozen or snow covered soils and prolonged fertilizer exposure to runoff and leaching, often in the absence of phosphorus uptake by a growing crop. While the apparent cost of this practice is relatively low, the practicality of applying needed phosphorus fertilizers for all crops in a large farming operation during the growing season can have added costs due to logistics, equipment and product storage.

Conservation Cropping/Tillage (Residue Management) Select a system that will optimize crop production from fertilizer inputs, increase infiltration, slow runoff and raise soil organic matter levels. Less tillage is better than more tillage; and more organic matter grown (includes cover crops) is also better than less organic matter. Many of the DP BMPs in this arena are already used by most farmers and costs of adoption are low to medium.

Conservation Buffers Utilize buffers to help define setbacks from ditches or streams and to provide areas that slow runoff and permit infiltration. Cost of many of these practices is medium to high but incentive payments within government programs often assist with establishment. The likelihood of adoption is typically less for permanent "tree" buffers than for "grass" buffers.

Water Management Give added emphasis to these BMPs which will either reduce compaction or halt direct delivery of surface water to sub surface tile systems. Positive aspect is that reducing compaction through controlled traffic increases crop yields. Negative aspect is that slowing runoff through "blind" inlets or tile outlet control may be viewed as impairing agricultural drainage. Most farmers would welcome assistance or support to repair large broken tile mains or "blow outs".

An example of Phosphorus Fertilization Practices in a corn-soybean-corn-soybean-wheat rotation under conservation tillage management

YEAR 1: Plant corn using some form of strip tillage or conservation tillage. In late summer or early fall after YEAR 5 wheat harvest, where some form of chisel plowing or other tillage is frequently done, broadcast but incorporate phosphorus fertilizers required for both corn and the following soybean crop (YEAR 2). In cases where soil test buildup may be needed for the wheat portion of the rotation, apply additional phosphorus fertilizer. Subsurface injection would be a second option where the goal is to maintain crop residues on the soil surface. A portion of the phosphorus required for these two corn-soybean years could be banded with a corn planter equipped to do so.

YEAR 2: Plant soybeans using either no-till or some other form of conservation tillage.

YEAR 3: Plant corn using either no-till or fall strip tillage. In fall after YEAR 2 soybean harvest, fall subsurface inject in bands phosphorus fertilizers required for both corn and the following soybean crop (YEAR 4). If injection is not possible due to wet soils or lack of equipment, band apply required phosphorus with the corn planter.

YEAR 4: Plant soybeans using either no-till or some other form of conservation tillage.

YEAR 5: No-till wheat. (NOTE: Avoid fall broadcast phosphorus fertilizer application prior to planting wheat.)

Areas in Need of Further DP BMP Research

In the formulation of this DP BMPs list, several areas in need of additional research were evident, especially for NW Ohio.

Soil Testing - Agronomic Updated research is needed on how current hybrid crops respond to various soil test phosphorus levels. Also, it is important to have better knowledge of how wheat yields are impacted when fall broadcast phosphorus applications are not made. Does the "Tri-State Fertilizer Guide" need revision?

Soil Testing - Environmental There needs to be improved understanding of how soil test phosphorus values just beyond critical levels begin to influence concentrations of DP in runoff and leaching. Should there be an environmental concern between critical levels and the 150 ppm soil test phosphorus level used widely (Ohio, Michigan, Indiana, Ohio NRCS) as an indicator of environmental risk?

Vegetative Mining Documentation that crop yield potential is not jeopardized when phosphorus fertilizers are not applied above critical soil test level for specific crops is needed. Research of cropping methods or systems that would most quickly drawdown elevated soil test phosphorus values, especially when they are high at or near the soil surface, is needed.

Phosphorus Application Method Evidence to measure the effectiveness of the AerWay aerator (or other vertical tillage tools that could produce similar results) for reducing DP concentrations and storm runoff is necessary. Research should evaluate the potential of AerWay use to move phosphorus fertilizers into the soil by improving capacity of soils to infiltrate first storm runoff. This potential might also enable greater phosphorus leaching from soils having accumulation of phosphorus near the surface. What impact the disruption of macropores in the 0 to 8 inch soil layer has on soil adsorption of phosphorus also needs evaluation as part of this effort.

Conservation Cropping/Tillage Systems An improved understanding of soil organic matter trends in NW Ohio is needed to provide perspective on the health and function of systems currently used. Such research could also evaluate the extent current systems can retain water and nutrients. Research on the impacts of long term continuous no-till on both DP concentrations and storm runoff amounts is needed. Improved knowledge of DP concentration changes with movement through a soil profile under long term no-till is important.

Conservation Buffers Better knowledge of which practices are really most effective for DRP reduction is really needed, along with a social-economic evaluation of practice adoption relating to costs or inconvenience.

Water Management This area is probably most in need of research in NW Ohio. The practices listed in the area of water management do function to lessen DRP impacts on field runoff, but the entire subject of subsurface drainage requires scrutiny in many areas. How does the current trend of increasing subsurface drainage intensity relate to overall flow volumes and DRP movement? What fraction of storm runoff from fields may actually be subsurface contributions? How do increases in preferential flow as a result of less tillage impact runoff volumes through tile? How does preferential flow affect the capacity of soils to adsorb DRP? Or does preferential flow serve primarily as transport pathway to tile after recent phosphorus fertilizer application or when soil test phosphorus levels are great? How much permanent vegetative cover and in what field or watershed locations is needed to measurably reduce runoff peaks?

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