AN INTRODUCTION TO

NUTRIENT MANAGEMENT

ADAPTED FROM RICHARD FAWCETT'S
"A Review of BMPs for Managing Crop Nutrients and Conservation Tillage to Improve Water Quality"

For his editorial and technical assistance,
special thanks to Tim Smith, Cropsmith Inc.

For their review, our thanks to:
Julie French, Gordon & Associates
John Hassell, Agrotain International
Dr. Brad Joern, Purdue University
Dr. Eileen Kladivko, Purdue University
Dr. Harold Reetz, Foundation for Agronomic Research
Dan Towery, Ag Conservation Solutions

Produced by the Conservation Technology Information Center
An Introduction to Nutrient Management

The Conservation Technology Information Center (CTIC) is a national non-profit membership organization. CTIC promotes environmentally responsible and economically viable decision-making in agriculture. For information on other publications, survey of tillage practices, CTIC membership, etc., visit us at **www.conservationinformation.org** or contact us at:

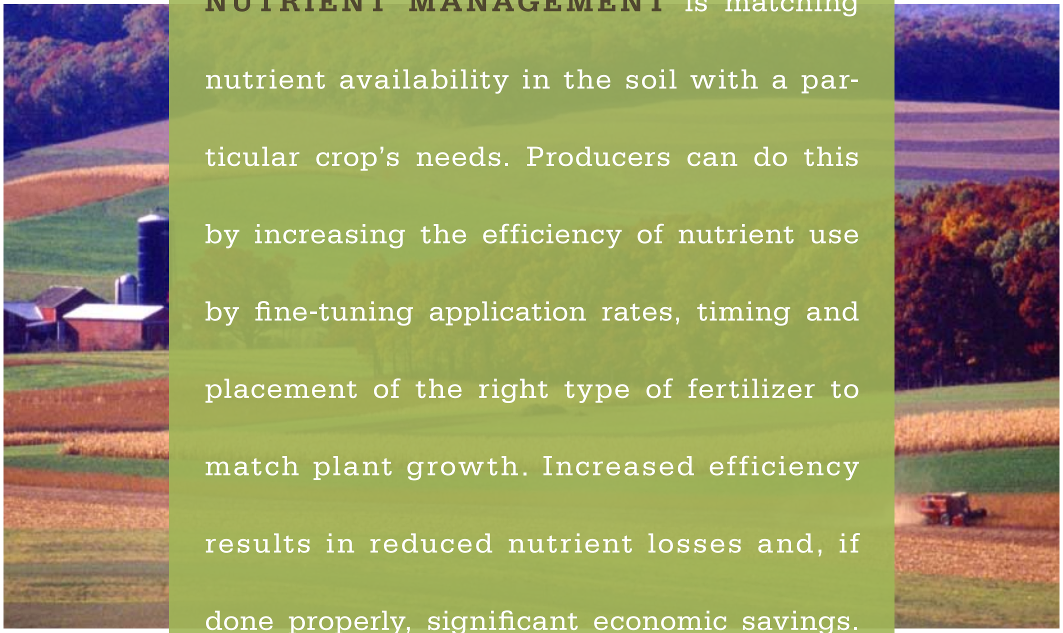
CTIC
1220 Potter Drive
West Lafayette, Indiana 47906-1383
Phone (765) 494-9555
FAX: (765) 494-5969
E-mail: ctic@conservationinformation.org

CTIC is supported by a partnership of individuals, corporations, governmental agencies, associations, foundations, universities and media.

AN INTRODUCTION TO

NUTRIENT MANAGEMENT

Table of Contents



NUTRIENT MANAGEMENT is matching nutrient availability in the soil with a particular crop's needs. Producers can do this by increasing the efficiency of nutrient use by fine-tuning application rates, timing and placement of the right type of fertilizer to match plant growth. Increased efficiency results in reduced nutrient losses and, if done properly, significant economic savings.

THIS DOCUMENT IS AN INTRODUCTION TO TWO IMPORTANT NUTRIENTS, NITROGEN AND PHOSPHORUS, and a look at some of the options for best management practices (BMPs) associated with them. The following information should be helpful to ag producers, agricultural professionals advising farmers on nutrient management practices and those writing farm-specific nutrient management plans. Included at the conclusion of this paper is a summary of BMPs for each nutrient. For more information about these management practices you can read the companion paper titled "A Review of BMPs for Managing Crop Nutrients and Conservation Tillage to Improve Water Quality" which can be found at: http://www.conservationinformation.org/?action=learningcenter_publications.

Every farm is different—soil types, topography, climate and the availability of water can change dramatically within a county, to say nothing of the differences between the conditions of a Deep South cotton farm and corn-bean rotation in the Midwest. Specific nutrient tests, application methods and other practices must be calibrated to local conditions. There may be programs offered through county or state agencies to assist with financing conservation efforts and location-specific regulations may apply. **Always consult with Extension, Soil and Water Conservation Districts, NRCS and other state and local resources to find specific regulations and opportunities.**

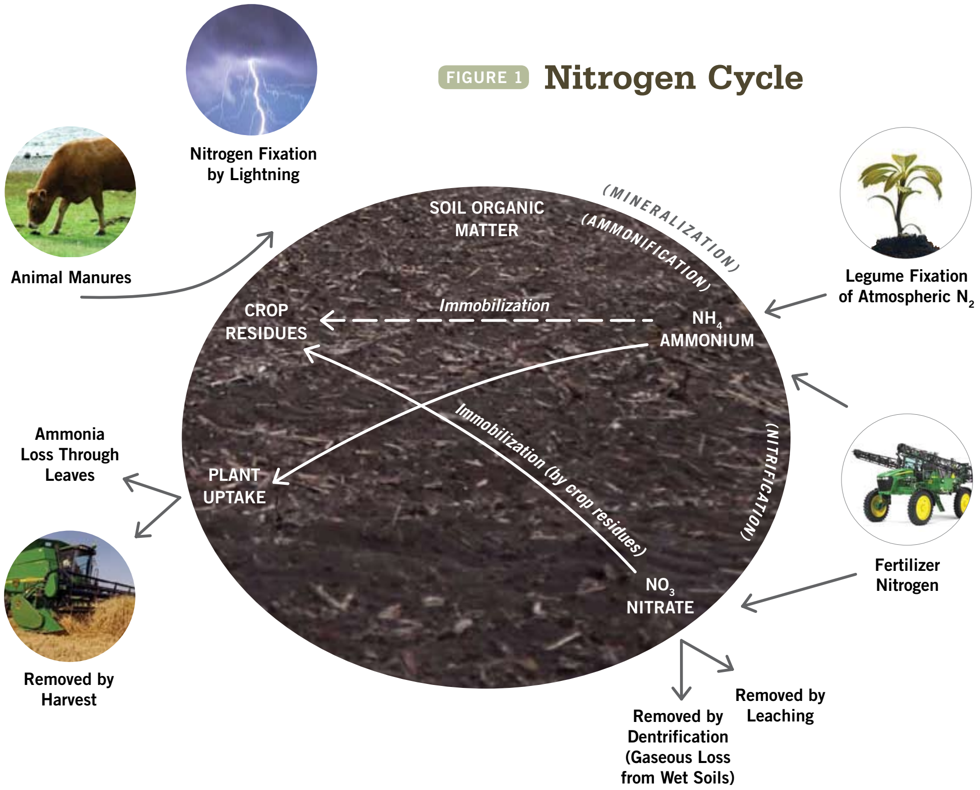
> Today there are plenty of on-farm reasons to have an efficient nutrient management plan in place. Improving the financial position of your operation is the primary reason to consider developing a nutrient management plan.

WHY UTILIZE A NUTRIENT MANAGEMENT PLAN?

Nutrients are essential for the growth of all living organisms. Agriculture depends on nutrients supplied by many sources, including the mineralization of soil organic matter, animal manure, sewage sludge, commercial fertilizers, nitrogen fixed by legumes, nitrogen contained in irrigation water and atmospheric deposition. Research conducted over many decades has aided farmers in the efficient use of added nutrients through techniques such as soil testing and nutrient placement and timing. Until recently, most research and education was aimed at helping farmers determine economically optimal nutrient application amounts and methods.

Today, we are more aware of the potential off-site impacts that nutrients may have when they leave agricultural fields with surface runoff or leaching and enter surface or ground water in excessive amounts. Nutrient losses may cause impacts harmful to aquatic ecosystems, or harmful to human health. Increased knowledge and concern about the adverse impact of excessive nutrients on water quality has led to a reexamination of agricultural nutrient management practices and their impacts on water. New water quality standards and regulations may be developed that may force changes in nutrient management, especially in areas where waters have been determined to be impaired by excessive nutrients. As some proposed nutrient standards for surface water are far lower than current nutrient levels, agriculture faces a major challenge to reduce nutrient losses. While there are no regulations as of yet that hold farmers accountable for cropland nutrient loss, today there are plenty of on-farm reasons to have an efficient nutrient management plan in place. Improving the financial position of your operation is the primary reason to consider developing a nutrient management plan.

FIGURE 1 Nitrogen Cycle



BEHAVIOR OF NUTRIENTS IN SOIL AND WATER

The practices that control or change the way nutrients are used are a function of the nutrients' behavior. Before any discussion of how nutrients can be managed, it is important to understand how they behave in the soil and water. Although they are essential for plant growth, potassium and micronutrients will not be discussed, as they are not typically a part of a nutrient management plan.

Nitrogen

Nitrogen (N) is an essential nutrient for all plant and animal life. It can follow many chemical pathways in soil and water, making it complex to trace. Nitrogen is continually cycled among plants, soil organisms, soil organic matter and the atmosphere. Understanding the main processes in the nitrogen cycle-mineralization, immobilization, nitrification, denitrification, volatilization and leaching-can be helpful in recognizing how BMPs can work to improve water quality.

FIGURE 1 **Nitrogen Cycle** *(above) Adapted from the University of Minnesota*

At any given time, most of the N in the soil is contained in soil organic matter and the soil humus. N is slowly released as soil microbes decompose or mineralize the organic matter.

Organic N occurs as particulate matter, in living organisms, and as detritus (dissolved and particulate dead organic matter). It occurs in dissolved form in compounds such as amino acids, amines, purines and urea. Mineralization converts organic N into ammonium (NH_4^+), which can be taken up by plant roots. The ammonium ion is positively charged and thus is held by negatively charged clay particles and organic matter, preventing it from leaching with percolating water.

In converse to mineralization, immobilization includes processes by which ammonium (NH_4^+) and nitrate (NO_3^-) are converted to organic N,

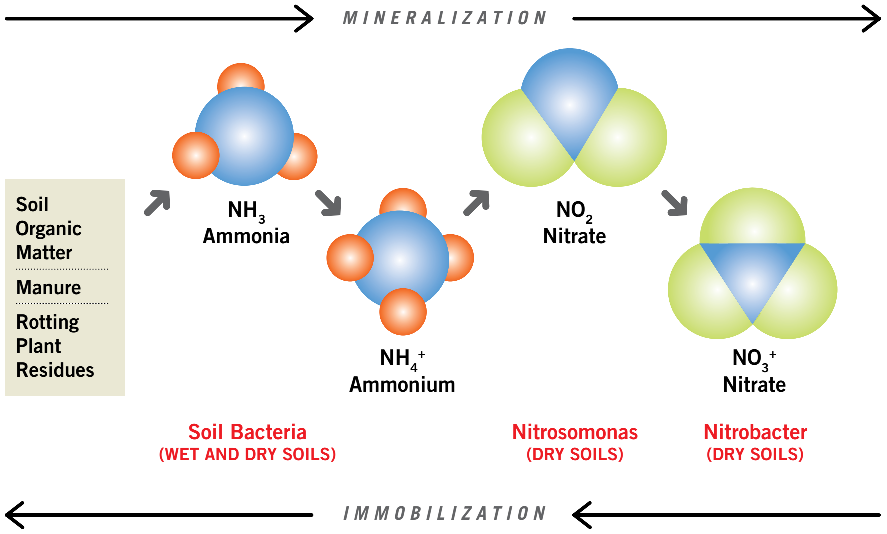


FIGURE 2 **Mineralization and Immobilization**

through uptake by plants and microorganisms, and bound up in the soil. Adding carbon rich crop residues to the soil causes temporary immobilization of N, when bacteria take up ammonium and nitrate as they decompose crop residues. As crop residues decompose, nitrogen is again released. The speed of release varies with climate, with higher soil temperatures speeding release.

FIGURE 2 **Mineralization and Immobilization** *(above) Adapted from the University of Minnesota*

An important part of the nitrogen cycle in relation to water quality is nitrification. Nitrification is the process by which two different bacteria convert ammonium (NH_4^+) in the soil to nitrate (NO_3^-). Nitrosomonas bacteria mediate the conversion of ammonium (NH_4^+) to nitrite (NO_2^-), which is then quickly converted to nitrate (NO_3^-) by Nitrobacter bacteria. Nitrate is readily taken up by plant roots and is often the major form of N utilized by crops.

FIGURE 3 **Nitrification** *(following page) Adapted from the University of Minnesota*

Nitrification rates depend upon soil temperature. Nitrification can occur rapidly in warm, moist, well-aerated soils, changing the ammonium form of N commonly found in many fertilizers to the nitrate form within one to two weeks after application. Because the ammonium form of N has a positive charge, it is relatively immobile in the soil. Nitrate, which results from nitrification, is negatively charged; it enters the soil solution and is subject to leaching. Nitrification significantly slows down at temperatures below about 50 F. Thus, application of ammonium fertilizers to soils below 50 F allows the ammonium to remain in its positively charged, immobile form until soil temperatures increase.

FIGURE 4 **Dentrification** *(following page) Adapted from the University of Minnesota*

There are two processes by which nitrogen from the soil can return to the atmosphere. They are denitrification and volatilization. Denitrification is the bacterial conversion of nitrate to elemental nitrogen (N_2) or nitrous oxide (N_2O) gasses, which are lost to the atmosphere. These forms of N are unavailable to plants. Denitrification reduces nitrogen availability to crops

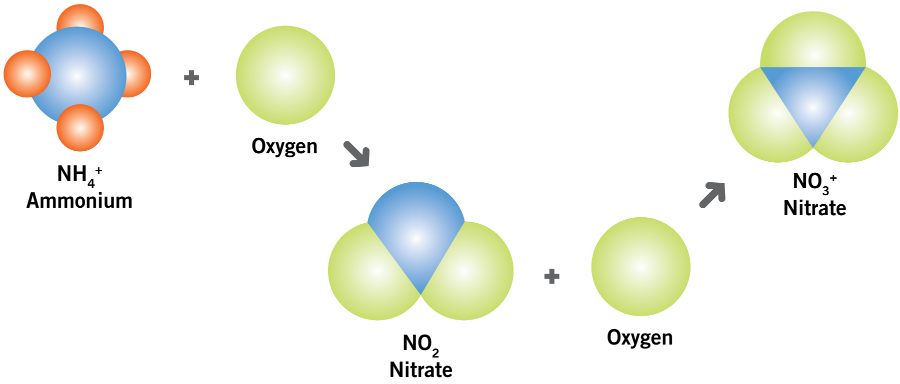


FIGURE 3 **Nitrification**

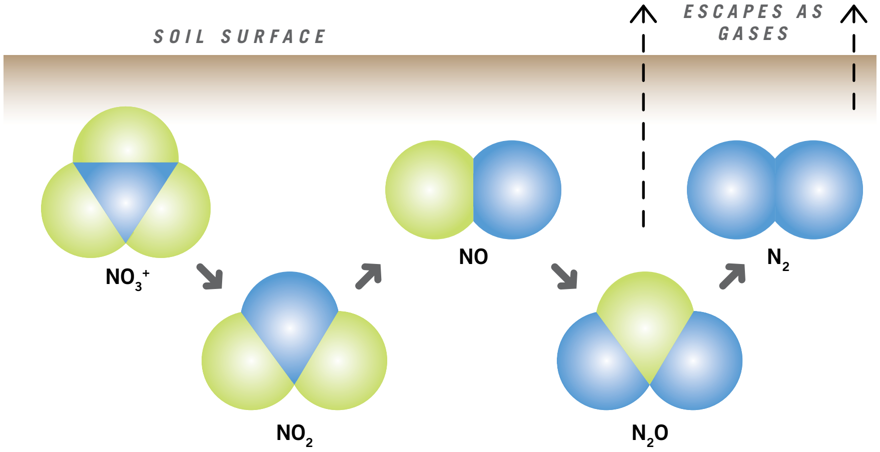


FIGURE 4 **Dentrification**

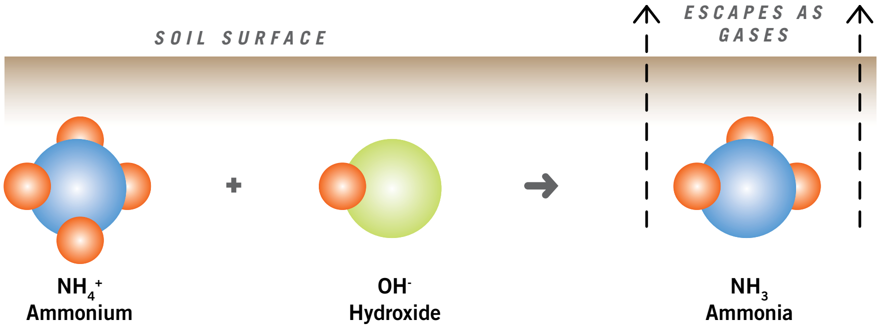


FIGURE 5 **Volatilization**

but does not threaten water quality. However, because nitrous oxide is a greenhouse gas, denitrification has climate change implications.

Denitrification occurs in poorly aerated, waterlogged soils. This process is rapid, so that if water stands on the soil for two to three days during the growing season, much of the nitrate will be lost by denitrification.

Volatilization losses of ammonia gas to the atmosphere can occur when manure, urea fertilizer or solutions containing urea are surface applied and not incorporated into the soil. Volatilization losses are greatest with high temperatures and lack of rain after application, and where surface crop residue is present. Injection of solutions containing ammonia and incorporation of manure and urea fertilizers greatly reduces volatilization losses. Some ammonia lost to the atmosphere returns to the soil through precipitation. Precipitation also carries N from industrial and automobile emissions and nitrate formed by oxidation of nitrogen gas by lightning.

FIGURE 5 **Volatilization** *(above) Adapted from the University of Minnesota*

Symbiotic N fixation converts atmospheric N into plant available N forms. Rhizobia bacteria living in the roots of legumes like soybeans, alfalfa and clovers make N available to their host plants. As these crops decompose, N is made available to succeeding crops. Small amounts of N are also fixed by free living organisms in the soil such as Azotobacter and blue-green algae.

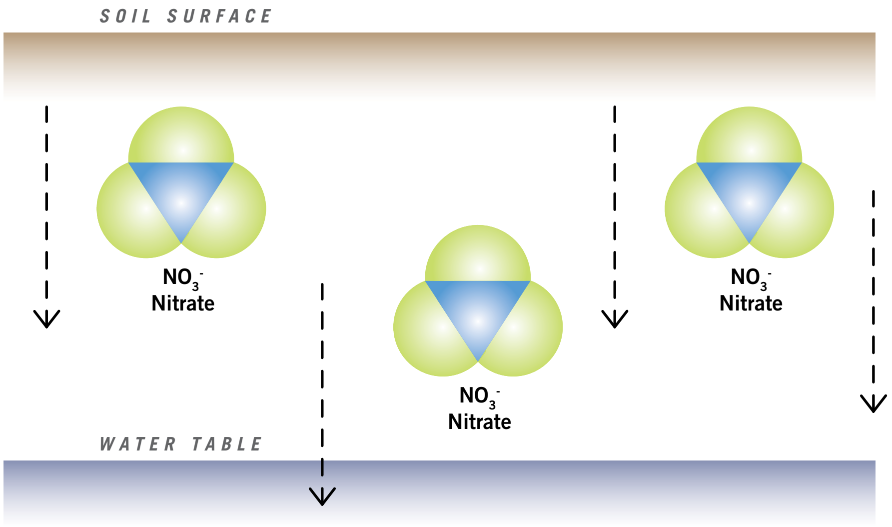


FIGURE 6 **Leaching**

Nitrogen and Water Quality

Most N reaching surface or ground water is in the nitrate form because of its mobility. Because ammonia is held by soil particles, little leaching occurs, but erosion can carry ammonia to surface water. Erosion and runoff can also carry organic forms of N to lakes and streams where later conversions can release plant available N.

Leaching of nitrate to groundwater can occur when nitrate in excess of crop needs is present in the soil solution and water percolates through the soil. Risk of leaching is greatest on coarse textured soils, with shallow aquifers being most vulnerable. High rainfall or irrigation in excess of crop needs increases leaching risk.

FIGURE 6 **Leaching** *(above) Adapted from the University of Minnesota*

Because nitrate is mobile, it readily moves into the soil with rainfall or irrigation, rather than running off the surface of fields. In many settings, surface runoff contains little nitrate. Exceptions can occur, such as when fertilizers or manures are applied to frozen soil, or heavy rains occur soon after application. The way nitrate usually enters streams and lakes is to first leach to shallow groundwater and then move laterally with natural subsurface flow or through drainage tiles. Areas that have been extensively tiled often have greater nitrate losses to surface water than untiled areas. A 1995 study by Fausey, et al. estimated that 37 percent of Corn Belt and Great Lakes cropland is artificially drained by surface channels, subterranean tiles or a combination of the two. It is important to be aware of the subsurface flow pathway

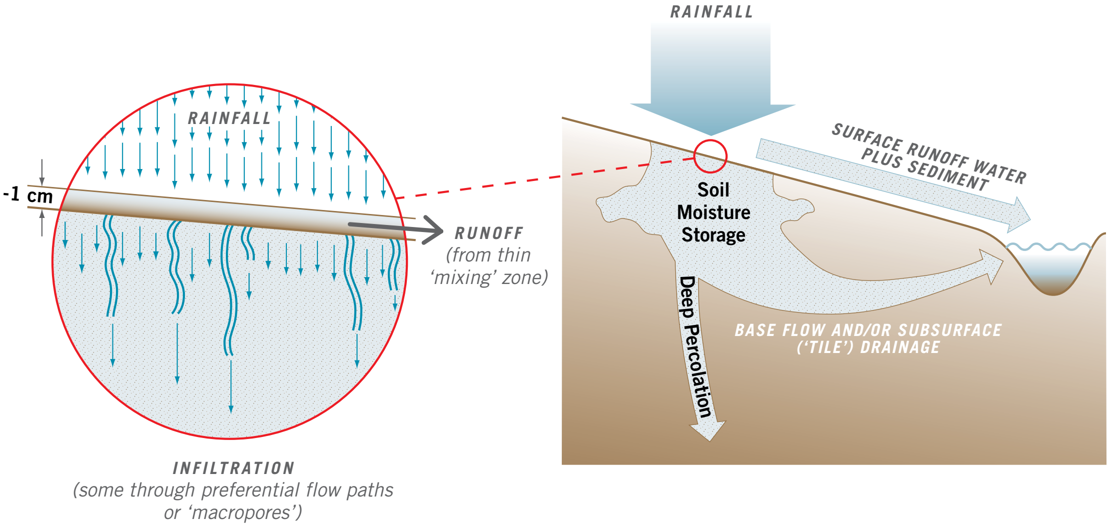


FIGURE 7 **Surface and Subsurface Flow**

of nitrate to surface water in selecting appropriate BMPs. BMPs directed at surface water, for example riparian buffer strips, would be ineffective if nitrates are coming primarily from subsurface pathways, such as through tile drainage.

FIGURE 7 **Surface and Subsurface Flow**
(above) Adapted from Jim Baker, Iowa State University

As previously discussed, the ammonium and nitrate forms of N are plant available. Which form is preferred depends upon the plant species. The primary N fertilizers used in the U.S. are anhydrous ammonia, urea, ammonium nitrate, and urea-ammonium nitrate (UAN) solutions. Before it can be utilized by plants, urea ($CO(NH_2)_2$) first must be hydrolyzed, or decomposed, by the enzyme urease to the ammonium (NH_4) form. Ammonium is strongly held by soil particles, while urea and nitrate are soluble and subject to leaching. Ammonia (NH_3) is volatile and can be lost to the atmosphere. Ammonia volatilization can be significant with surface application of fertilizers containing urea, especially when applied to large amounts of crop residue. Ammonia losses also may occur from surface manure applications, or when application slots fail to close properly behind anhydrous ammonia applicators.

FIGURE 8 **Side-Dress Applicator** *(following page)*
Provided by Case IH

FIGURE 8 **Side-Dress Applicator**

Phosphorus

Phosphorus (P) undergoes many transformations in the soil that affect its availability to crops and its potential to be lost to water. Phosphorus exists in both organic and inorganic forms. Organic P consists of undecomposed plant and animal residues, microbes and organic matter in the soil. Inorganic P is usually associated with aluminum (Al), iron (Fe) and calcium (Ca) compounds of varying solubility and availability to plants. Phosphorus is added to soils so that there are adequate levels for optimum crop growth. However, P can be rapidly converted in the soil to forms unavailable to plants. This “fixed” P can be slowly converted to “labile” or available forms, but this conversion is often too slow to meet crop needs. Agronomic soil tests have been developed to determine the amount of plant available P in the soil and how much fertilizer or manure should be added to meet desired crop yield goals.

There are over 200 forms of naturally occurring P minerals in the soil. The most common P minerals are: 1) apatite (calcium phosphate), which is found in unweathered and moderately weathered soils; and 2) iron and aluminum phosphates, which are found in highly weathered soils. Commercial P fertilizer is apatite (calcium phosphate) treated with sulfuric or phosphoric acids to increase the solubility of P.

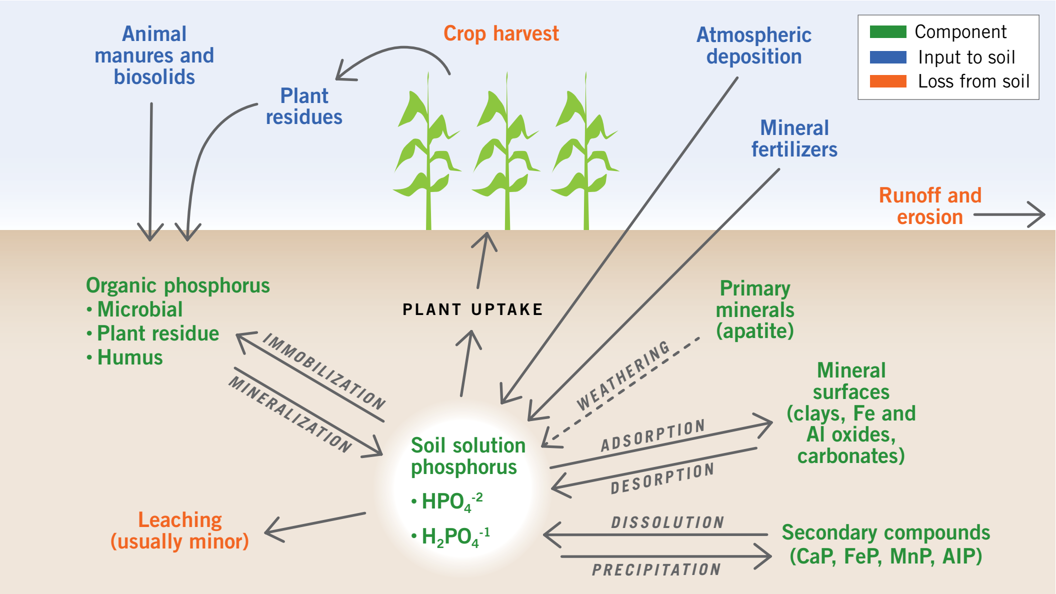


FIGURE 9 **The Phosphorus Cycle**

Figure 9 (above) shows the phosphorus cycle. In the soil solution, P is present as either $H_2PO_4^{-1}$ in acid soils (monovalent) or HPO_4^{-2} in alkaline soils (divalent). Phosphorus enters the soil solution by one of the following processes:

- Dissolution of primary minerals
- Dissolution of secondary minerals
- Desorption of P from clays, oxides and minerals
- Biological conversion of organic P to inorganic forms

FIGURE 9 **The Phosphorus Cycle** *(above) Adapted from the International Plant Nutrition Institute*

Phosphorus available for crop uptake (or available to aquatic organisms when P reaches water bodies) is called bioavailable P and consists of soluble P and a portion of P bound to soil particles that can subsequently be released into solution. Analyzing a soil for total P content is not very useful from an agronomic standpoint, as it does not determine how much P is available for crops. Agronomic soil tests have been developed over the years that extract all or a proportional amount of plant available P from soils. By correlating these soil tests with crop responses to P additions to various soils in the field, recommendations for needed amounts of P additions for optimum crop production on various soils have been developed. These agronomic P soil tests do not necessarily predict P losses to water.

FIGURE 10 **Soil Testing** *(following page) Provided by Dr. Harold Reetz, Foundation for Agronomic Research*

Phosphorus and Water Quality

Phosphorus losses are often measured as total P and soluble or dissolved P. Because soluble P is available to aquatic organisms, it has the most immediate impact on aquatic systems. Results of P loss studies sometimes refer to bioavailable P as algal available P.

FIGURE 11 **Heavy Rain on Conventional Tillage** *(following page) Provided by NRCS*

Sediment-bound P constitutes 60 percent to 90 percent of P transported in runoff from cultivated land. Runoff from grass, forest and noncultivated land carries little sediment and is usually dominated by soluble P. While most sediment-bound P is not readily available to aquatic

FIGURE 10 **Soil Testing**

FIGURE 11 **Heavy Rain on Conventional Tillage**

organisms, sediment deposited in aquatic systems provides a long-term reservoir of P, as P is slowly released. Because of the ability of lake and stream sediments to provide a long-term source of P even after inputs have been reduced, beneficial impacts of P loss reductions are difficult to predict. Both total P and soluble P losses are important. The relative importance of each form may depend on local conditions.

Surface runoff and erosion are the primary mechanisms that carry P to surface water in most settings. Desorption of P from a thin layer of surface soil and vegetation releases soluble P carried in runoff water. Eroded sediment carries adsorbed P and mineral and organic P sources. Because of the rapid reactions by which P is immobilized in soil, P leaching has until recently been believed to be of minor importance. However, under some conditions soluble P and colloidal P can leach to natural subsurface flow or drainage tiles to reach surface water in significant amounts.

IMPACT OF CONSERVATION TILLAGE ON NUTRIENT LOSSES: OVERVIEW

Conservation tillage has unique interactions with N and P. Conservation tillage systems impact both soil erosion and water infiltration, which in turn can affect the runoff or leaching of N and P. The type of tillage system used also influences where nutrients are found within the soil profile and their vulnerability to loss. Conservation tillage systems, utilizing some form of incorporation, allow more of the applied fertilizers and manures to be removed from the soil surface, placing them away from overland drainage flow which could carry them to surface water. Fertilizers and liquid manures can be injected below the soil surface in any tillage system, including no-till, protecting them from runoff. Likewise, surface applied dry manure would require incorporation to protect nutrients from surface water flow.

Conservation tillage systems impact both soil erosion and water infiltration, which in turn can affect the runoff or leaching of N and P. The type of tillage system used also influences where nutrients are found within the soil profile and their vulnerability to loss. Conservation tillage systems, utilizing some form of incorporation, allow more of the applied fertilizers and manures to be removed from the soil surface, placing them away from overland drainage flow, which could carry them to surface water.

Surface application of fertilizer or manure in no-till systems results in a stratification of non-mobile nutrients like P. Higher P concentrations at the soil surface increase the availability of P for runoff. The organic matter content of surface soils also increases with no-till. This increased organic matter could reduce runoff losses of some potential pollutants, like pesticides and P, by providing more adsorption capacity and causing increased infiltration, due to improved soil structure.

The ability of conservation tillage to reduce erosion is well documented. Crop residue left on the soil surface protects the soil from the erosive impacts of rainfall and wind. Residue also slows runoff and prevents sealing of the soil surface, increasing infiltration of water. Reductions in erosion are usually proportional to the percent of the soil surface covered by crop residue.

Conservation tillage also often increases water infiltration. Surface roughness and surface residue are responsible for infiltration increases in conservation tillage systems utilizing some form of tillage. In no-till systems, improved soil structure and the presence of macropores consisting of worm holes, cracks and root channels, allows water to infiltrate rather than run off when rainfall exceeds the capillary flow capacity of the soil.

Nitrogen

Conservation tillage can reduce overall nitrogen loss by reducing ammonium nitrogen loss and organic nitrogen loss with sediment; however it may not reduce nitrogen leaching in the nitrate form. Nitrate is soluble and quickly moves down into the soil with rainfall or irrigation. Typically, little nitrate is present in surface runoff. In contrast, ammonium, which is held on soil particles, and soil organic nitrogen can move off fields with soil loss. Conservation tillage reduces runoff of these forms of nitrogen. Baker and Laflen (1983) found a 97 percent reduction of soil loss in no-till compared to a moldboard plow system resulted in a 75 percent to 90 percent reduction in total N loss for soybeans following corn and 50 percent to 73 percent reduction in total N loss for corn following soybeans. Several other studies have documented reductions in N losses with conservation tillage.

FIGURE 12 **Stream in Cropland** *(following page)*
Provided by NRCS

FIGURE 12 **Stream in Cropland**

FIGURE 13 **Tile Effluent from Soybean Field**

In most settings, nitrate reaches streams by first infiltrating and then moving with subsurface flow. Many researchers have investigated the impact of no-till and other conservation tillage systems on nitrate leaching. Most studies have found little impact, with a few studies finding a reduction or slight increase in nitrate leaching with no-till.

FIGURE 13 **Tile Effluent from Soybean Field**
(above) Provided by University of Michigan

Monitoring of drainage tile effluent has proven useful in measuring tillage impacts on nitrate leaching. A 1988 study by Kanwar et al. monitored tile effluent from continuous corn plots managed with no-till and conventional tillage in Iowa. Nitrate concentrations were similar between tillage systems in the first two years. By the third year of the study, nitrate concentrations were significantly lower in no-till plots. Kanwar and Baker (1993) monitored these plots over the next eight years and determined that nitrate concentrations in tile effluent were consistently lower with no-till than with conventional tillage. Monitoring of soil water at five depths from 3.9 feet to 11.8 feet (1.2 meters to 3.6 meters) also showed that nitrate concentrations were lower at all depths with no-till.

Nitrate concentrations in groundwater and in drainage tile effluent have been consistently lower under no-till management than with conventional tillage. However, increased infiltration from no-till may at least partially offset lower concentrations of nitrates by increasing total drainage through the soil. This increased infiltration of lower nitrate concentrations may result in a total quantity of nitrate loss similar to conventional tillage, leaching below fields to where it may reach ground water or be carried by subsurface flow to surface water. To enhance the effect of conservation tillage practices to reduce nitrate losses to water, other BMPs will need to be included in the management system.

FIGURE 14 **Algae from Excess Phosphorus**

Phosphorus

Phospohorus is lost from fields in two main ways: attached to eroded sediment particles that end up in streams and lakes and in the soluble P form that is lost from fields when water flowing from fields picks up P that is not adsorbed to soil particles.

FIGURE 14 **Algae from Excess Phosphorus**
(above) Provided by NRCS

Because total P losses in runoff consist primarily of insoluble P carried by eroded sediment particles, conservation tillage usually reduces total P losses. As stated earlier, sediment-bound P often represents 60 percent to 90 percent of the total P load of row crop runoff. Conservation tillage has been an important BMP recommended to farmers to reduce P losses in specific watershed projects. For example, following wide-scale promotion of conservation tillage to reduce P loading to the Great Lakes, Baker (1993) concluded that the downward trends in total and soluble P loads from Lake Erie tributaries for the period from the late 1970s to 1993 indicated that agricultural BMPs, including conservation tillage, were effective in reducing total and soluble P export.

Controlled studies have documented the ability of various conservation tillage systems to reduce P losses. For example, Baker and Laflen found that when total P runoff losses were compared between no-till and conventional tillage in Iowa, the 97 percent reduction in erosion with no-till resulted in an 80 percent to 91 percent reduction in total P loss for soybeans following corn. For corn following soybeans, the 86 percent reduction in erosion led to a 66 percent to 77 percent reduction in P loss.

Barisas et al. (1978) compared runoff losses of P in six tillage systems on three Iowa soils using rainfall simulation techniques. They found that as surface crop residue increased, soluble P losses increased, but because erosion was reduced by crop residue, total P losses decreased as residue increased.

Seta et al. (1993) compared nutrient losses with the moldboard plow, chisel plow and no-till

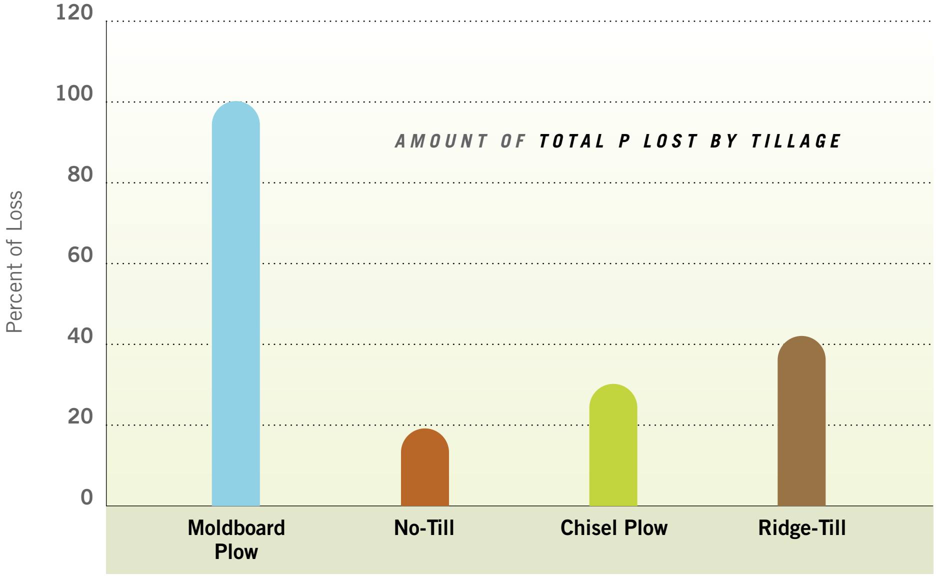


FIGURE 15 **Nutrient Loss Comparison When Fertilizer was Applied Before Tillage**

in Kentucky when fertilizer was applied before tillage. Total losses of nitrate, ammonia and phosphate were in the order: moldboard plow > chisel plow > no-till. However, nutrient concentrations were higher with no-till.

FIGURE 15 **Nutrient Loss Comparison** *(above)*
Adapted from Andraski et al. (1985)

The surface placement of fertilizer in no-till systems may explain much of the tendency for no-till systems to produce higher soluble P concentrations in runoff in controlled studies where P is surface applied (versus full width tillage systems in which P is incorporated into the soil). Application of P in a subsurface band in no-till has prevented any increase in soluble P loss compared to conventional tillage. Andraski et al. (1985) compared runoff losses of P from four tillage systems when fertilizer was subsurface banded in all systems. No-till, chisel plow and ridge-till systems reduced total P losses by 81 percent, 70 percent, and 59 percent, respectively, compared to the moldboard plow. Soluble P losses also were reduced by no-till and the chisel plow.

FIGURE 16 **Ridge Till** *(following page)*
Provided by NRCS

FIGURE 16 **Ridge Till**

Kimmel et al. (2001) measured P runoff losses as effected by tillage system and fertilizer placement in Kansas. A chisel plow-field cultivator-disk system was compared to no-till and ridge-till, with P fertilizer either broadcast surface applied or knifed in prior to planting sorghum. Losses of total P, soluble P and bioavailable P were measured. When the data are averaged over two years of study, knifing in fertilizer reduced losses of total P, bioavailable P and soluble P for all three tillage systems. Reductions in P losses with knifing were most evident for soluble P. Knifing reduced soluble P losses by about 75 percent in no-till and ridge-till.

FIGURE 17 **Tillage and P Placement Effects**

(following page) Adapted from Kimmell, R.J., G.M. Pierzynski, K.A. Janssen, and P.L. Barnes. 2001. J. Environ. Qual. 30:1324-1330.

THINKING ABOUT LIVESTOCK

High livestock concentrations in some areas have led to applications of manure as a source of nutrients in excess of crop nutrient needs. If manure applications are solely based on N content and crop N needs, excessive amounts of P may be applied. In the past, high P soil test levels were not considered to cause environmental problems, so manure was commonly applied based on N needs without regard to the level of soil test P. Such an application to a soil testing low in P could be viewed as appropriate, as it would build soil P toward optimum levels. But when excess P applications are continued for many years, soil tests reveal a rise to excessive levels of P and the risk of water contamination is increased.

FIGURE 17 Tillage and P Placement Effects on Soluble, Bioavailable and Total P Loss in Runoff Water from Sorghum Grown on a Silt Loam Soil with 1.0 to 1.5 Percent Slopes

TILLAGE SYSTEM	FERTILIZER PLACEMENT	*ANNUAL P RUNOFF LOSS AVERAGE OF 2 YEARS DATA*		
		Soluble P	Bioavailable P (g/ha)	Total P
Chisel-disk	Surface	16.0	49.5	605.0
Chisel-disk	Knifed-in	12.3	33.0	354.0
No-Till	Surface	329.0	398.5	832.5
No-Till	Knifed-in	73.5	123.5	479.5
Ridge-Till	Surface	320.5	426.0	1122.5
Ridge-Till	Knifed-in	77.5	121.5	675.5

Conservation tillage can be expected to consistently reduce runoff losses of total P. Losses of soluble P may be higher with no-till if P fertilizers are surface applied to no-till compared to incorporated in other tillage systems. However, subsurface banding of P fertilizer in no-till systems reduces losses of soluble P below loss levels for conventionally tilled soils with the same fertilizer application method.

FIGURE 18 **Consider N and P content of Manure** *(following page) Adapted from NRCS*

Manure utilization has become a dilemma for farmers in some areas, as more than twice as many acres may be needed to apply manure based on P levels as N levels. Transporting manure long distances to land testing lower in P can be costly.

Once P soil test levels reach excessive levels, it may take many years for P concentrations to decrease, depending on the cropping system, yield levels and soil characteristics. McCollum (1991) estimated that without further P additions, 16 to 18 years of corn and soybean production would be needed to deplete a soil test P (Mehlich—3) in a Portsmouth fine sandy loam from 100 ppm to the agronomic threshold of 20 ppm. It is important to manage current manure and fertilizer applications to minimize both current and future P loss risks.

The presence of soils testing high in P may simply mean a crop farmer can forgo P fertilizer applications for some period of time. However, forgoing P applications just compounds the problem for livestock farmers in need of land to apply manure. Regulations or required manure management plans could limit manure applications to such land.

The future of manure management will be finding ways to use it as a beneficial byproduct, not a waste product. (Note: *Partners* magazine, the quarterly e-publication of CTIC, includes articles about manure management in its 2007 issues. Partners: **www.conservationinformation.org/partners**)

FIGURE 18 **Consider N and P content of Manure**

ROLE OF NUTRIENT MANAGEMENT IN LARGER CONSERVATION SYSTEMS

Nutrient management by way of conservation tillage is just one practice of conservation farming, and is most effective when done in tandem with other practices to create a whole farm conservation system. For example, conservation tillage may reduce P runoff, but won't necessarily reduce N leaching, so a producer would benefit from precision application of N or growing cover crops. A constructed wetland can dramatically reduce N that has already reached a field's tile system, but does little to keep phosphorus in place. It pays to come up with a farm-wide plan. Always consult with state and local resources, such as Extension, SWCD or NRCS offices, to find out specific regulations and opportunities. Some counties, especially those with impaired waterways, may have cost-share opportunities to help implement a nutrient management plan.

A SUMMARY OF NUTRIENT BMPs

THE FOLLOWING IS A LIMITED COLLECTION OF BEST MANAGEMENT PRACTICES, DIVIDED INTO SECTIONS ON N AND P, THAT RUNS THE BREADTH OF NUTRIENT MANAGEMENT. Farmers can consider these BMPs as they develop the most appropriate system of conservation practices for their operations. A brief overview of manure, pasture and hayland management is included. Remember that a whole-farm plan must be specific to the conditions of the area in which the plan will be applied. What is best *here* is not necessarily best *there*—talk to an expert about what practices are appropriate for your area.

NITROGEN

ALTERED DRAINAGE TILE DESIGN

- Controlled drainage-subirrigation systems recycle nitrate leaching from the soil profile and reduce nitrate lost in tile drainage.
- Research is underway to alter tile installation to favor denitrification before tiles intercept drainage water.

APPLICATION PRECISION

- New designs of manifolds may increase the uniformity of anhydrous ammonia distribution across applicators.
- Experimental applicators, such as injectors that form a compacted soil layer and surface ridge, may reduce N losses in the future.
- Variable rate applicators, combined with intensive soil or crop sampling, can allow correct N rates where fields vary in available N.

BREEDING CROPS FOR EFFICIENT N UPTAKE

- Certain crop varieties may be able to more efficiently extract N from the soil.
- Seed companies are developing varieties that have improved nutrient uptake.

CONSERVATION BUFFERS

- Install buffers to trap sediment containing ammonia and organic N.
- Nitrate in subsurface flow is reduced through denitrification enhanced by organic sources placed in the subsoil by buffer plants.
- Buffer plants take up nitrate and other nutrients, preventing N loss to water.
- Other conservation practices, such as terraces and contouring, reduce total N losses due to erosion reduction.

NITROGEN, *continued*

CONSERVATION TILLAGE

- Conservation tillage reduces total N losses because it reduces sediment loss.
- Leaching losses of nitrate are not consistently affected by conservation tillage.

CONSTRUCTED WETLANDS

- Constructed wetlands placed to process tile effluent reduce nitrate loads to surface water through denitrification.
- Constructed wetlands may be more effective in reducing nitrate when coupled with buffer strips.

COVER CROPS

- Cover crops grown between the time annual crops are harvested and when successive crops are planted can scavenge N and other nutrients and prevent leaching.
- Cover crops can prevent soil erosion and improve water infiltration where N is surface applied.

CROP ROTATION

- Legumes and other crops not needing supplemental N can utilize N remaining in the soil from previous N-fertilized crops, reducing nitrate leaching risk.
- Alfalfa can remove nitrate from the soil below the rooting depth of most annual crops.

CROP TESTING

- Leaf tissue tests can identify N deficiencies.
- Variations in chlorophyll content are being evaluated as a potential tool to facilitate variable rate N applications in-season.
- Post-black-layer corn stalk nitrate tests help to determine if N rates were low, optimal or excessive, so that management changes can be made in following years.

FERTILIZER APPLICATION METHOD AND PLACEMENT

- Injection or incorporation of urea or N solutions reduces volatility losses.
- In ridged crops, placing N fertilizers in a band in ridges makes N less susceptible to leaching.
- Controlled release N fertilizers can help improve crop uptake.

INHIBITORS

- Nitrification inhibitors maintain applied anhydrous ammonia in the ammonium form longer, reducing leaching and denitrification losses.
- Where fall N applications are appropriate, nitrification inhibitors reduce risk of leaching loss.
- Urease inhibitors temporarily block the function of the urease enzyme, maintaining urea-based fertilizers in the non-volatile urea form, and reduce losses when these fertilizers are surface applied in high residue, conservation tillage systems.

NITROGEN APPLICATION RATES

- Include N applied as manure, in irrigation water and fixed by legumes as part of the total N application rate.
- Use appropriate soil tests to determine residual N.
- Increase plant populations in soils with greater potential to release mineralized N.
- Nitrogen credits for legumes, such as alfalfa, can provide significant amounts of N to crops grown in rotation and need to be subtracted from total N required.
- Manure credits should be taken into account when determining crop N needs.
- Use a reasonable method to determine expected yields if N rates are based on yield.

NITROGEN, *continued*

PEST MANAGEMENT

- Proper pest management allows crops to attain their potential yields, utilizing applied N and reducing the amount of excess N available to loss.
- Bt corn prevents European corn borer feeding and associated stalk rots, which can cause corn to die early and leave excess N in the soil.
- Rootworm resistant corn may allow better root growth and improved N uptake from the soil.

TIMING OF N APPLICATIONS

- Applying N sources close to when crops can utilize N reduces N loss risk.
- Side-dress application, usually made four to six weeks after planting crops, provides N just prior to the time of most rapid N uptake, and reduces risk of leaching and denitrification losses.
- Split applications, involving preplant and side-dress applications, allow efficient use of applied N and reduce risk of yield reductions, should side-dress applications be delayed.
- Fall application of N may be discouraged in some areas. In regions where anhydrous ammonia can be suitably applied in the fall, soil temperatures should be below 50 F before applying.

SOIL TESTING

- Preplant soil tests are useful in drier climates.
- In areas where significant spring nitrate losses may occur due to leaching and/or denitrification, late spring or pre-side-dress N tests can determine if and how much additional N is needed.
- New soil test procedures, such as amino sugar tests, may be useful in determining potential N release from the soil.

PHOSPHORUS

APPLICATION RATES FOR PHOSPHORUS

- Use soil tests to determine agronomic rates.
- P rates may need to be reduced for environmental reasons in high-risk areas.
- Environmental P thresholds are being developed by states to determine P rates protective of water resources.
- Consider P content of manure rather than solely N content.

APPLICATION TIMING FOR PHOSPHORUS

- Avoid fertilizer and manure application to frozen soil.
- Incorporate fall-applied P fertilizers and manure to reduce runoff.
- Avoid fertilizer and manure applications to wet soils.

CONSERVATION BUFFERS

- Buffers trap sediment and adsorbed P.
- Construct and maintain buffers to encourage sheet flow of runoff over the buffer.
- As sediment accumulates in buffers, changing their profile, sediment should be removed, or buffers reshaped.
- Select buffer species based on adaptation to local conditions and other desired benefits of buffers, such as wildlife habitat.
- Other soil conservation practices, such as terraces and contour planting, reduce total P losses due to reduced erosion.

CONSERVATION TILLAGE

- Conservation tillage consistently reduces runoff losses of total P.
- Runoff losses of soluble P can be higher with no-till if fertilizers or manures are surface applied. Incorporating or injecting P sources below the soil surface reduces total and soluble P losses in all systems.

PHOSPHORUS, *continued*

CONSTRUCTED WETLANDS

- Wetlands have potential to reduce total P loads from surface runoff.
- Wetland results have been variable in removing soluble P.

COVER CROPS

- Plant cover crops to reduce erosion between when annual crops are harvested and the following crop covers the ground, thus reducing runoff of sediment-adsorbed P.
- Achieving phosphorus reduction depends on good cover crop stand management.

FERTILIZER AND MANURE PLACEMENT

- Incorporation or injection of P sources reduces runoff losses.
- Starter applications can usually supply all of the maintenance P requirements for row crops.
- Variable rate application, combined with intensive soil sampling, can reduce fertilizer inputs and avoid over-fertilizing high-testing areas of fields.
- Banded applications may increase yield when P is stratified and soil tests below 15 cm (6 in.) reveal low levels of P.

IRRIGATION MANAGEMENT

- Surface crop residue, in furrow irrigated crops, reduces sediment and P losses.
- Polyacrylamide (PAM) applied with furrow irrigation greatly reduces sediment, P and organic material losses.

LIVESTOCK FEED MANAGEMENT

- Carefully balance livestock rations so that supplemental P is not excessive.
- Feed low-phytate corn varieties, in nonruminant rations to reduce the P content of manure.
- Supplementing nonruminant feed rations with the phytase enzyme, reduces the need for supplemental P and reduces P content of manure.

PHOSPHORUS INDEX

- A coalition of U.S. scientists has developed a field-based planning tool that assesses the risk of P movement from soil to water. States are modifying the index to match local conditions.

MANURE, PASTURE AND HAYLAND MANAGEMENT

MANURE

- Determine nutrient content of manure to calculate appropriate application rates.
- Consider both P and N content of manure when determining rates.
- Fields testing low in P benefit most from manure applications.
- Consider risk factors such as nearness to streams and slopes, the presence of wells, sinkholes, surface tile inlets, and residences when selecting fields for manure applications.
- Inject manure or use limited incorporation to reduce runoff risk.
- Avoid manure application to frozen soil.
- Manure amendments such as alum may reduce soluble P losses in runoff.

PASTURE AND HAYLAND

- Use shallow tillage tools, such as harrows or “aerators” on pastures, that may increase infiltration and reduce runoff of manure or fertilizer.
- Rotational grazing reduces compaction, overgrazing and nutrient runoff.
- Exclude livestock from access to streams.
- Make maintenance P fertilizer applications to forage legumes after the first cutting, when runoff losses are lower.
- Cut hay higher to leave more stubble that may significantly reduces P runoff.

WORKS REFERENCED

Andraski, B.J., D.H. Mueller, and T.C. Daniel. 1985. Phosphorus losses in runoff as affected by tillage. *Soil Sci. Soc. Amer. J.* 49:1523-1527.

Baker, J.L. and J.M. Laflen. 1983. Water quality consequences of conservation tillage. *J. Soil and Water Cons.* 38:186-193.

Baker, D.B. 1993. The Lake Erie agroecosystem program: water quality assessments. *Agriculture, Ecosystems and Environment* 46:197-215.

Barisas, S.G., J.L. Baker, H.P. Johnson, and J.M. Laflen. 1978. Effect of tillage system on runoff losses of nutrients, a rainfall simulation study. *Trans. ASAE* 21:893-897.

Bouman, G.A., A.M. Blackmer, J.M. Bremner. 1980. Effects of different nitrogen and fertilizer on emission of nitrous oxide from soil. *Geophys. Res. Let.* 7:85-88.

Bundy, L.G. 1985. Understanding plant nutrients: soil and applied nitrogen. *Univ. WI Coop. Ext. Serv. Bull. No. A2519*.

Erbach, D.C. 1982. Tillage for continuous corn and corn-soybean rotation. *Trans ASAE* 25:906-922.

Fausey, N.R., L.C. Brown, H.W. Belcher, and R.S. Kanwar. 1995. Drainage and water quality in the Great Lakes and Cornbelt states. *J. Irrig. Drain. Eng.* 121:283-288.

Fawcett, R.S. and S. Caruana. 2002. Better soil better yields: a guidebook to improving soil organic matter and infiltration with continuous no-till. CTIC, West Lafayette, IN. 17 pp.

Gray, C.B.J. and R.A. Kirkland. 1986. Suspended sediment phosphorus composition in tributaries of the Okanagen Lakes, B.C. *Water Res.* 20:1193-1196.

Johnson, A.H.; Baker, J.L.; Shrader, W.D.; Laflen, J.M. 1979.Tillage system effect on sediment and nutrients in runoff from small watersheds. *Trans. ASEA* 22-1.110-1.114.

Kanwar, R.S., J.L. Baker, and D.G. Baker. 1988. Tillage and split N-fertilization effects on subsurface drainage water quality and crop yields. *Trans ASAE* 31:453-461.

Kanwar, R.S. and J.L. Baker. 1993. Tillage and chemical management effects on groundwater quality. In: Proceedings of the National Conference on Agricultural Research to Protect Water Quality. *SCS Ankena IA*, pp. 490-493.

Kimmell, R.J., G.M. Pierzynski, K.A. Janssen, and P.L. Barnes. 2001. Effects of tillage and phosphorus placement on phosphorus losses in a grain sorghum-soybean rotation. *J. Environ. Qual.* 30:1324-1330.

Logan, T.J. 1987. An assessment of Great Lakes tillage practices and their potential impact on water quality. In T.J. Logan, J.M. Davidson, J.L. Baker, and M.R. Overcash, eds. Effects of Conservation Tillage on Groundwater Quality. *Lewis Pub.*, Chelsea, MI. Pages 271-276.

McCollum, R.E. 1991. Buildup and decline in soil phosphorus: 30-year trends on a Typic Umprabuult. *Agron. J.* 83:77-85.

McDowell, R., A. Sharpley, and G. Folmar. 2001. Phosphorus export from an agricultural watershed: linking source and transport mechanisms. *J. Environ. Qual.* 30:1587-1595.

Randall, G.W., and T.K. Iragavarapu. 1995. Impact of long-term tillage systems for continuous corn on nitrate leaching to tile drainage. *J. Environ. Qual.* 24:360-366.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas, Jr., and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. *J. Soil and Water Cons.* 50:253-261.

Seta, A.K., R.L. Blevins, W.W. Frye, and B.J. Barfield. 1993. Reducing soil erosion and agricultural chemical losses with conservation tillage. *J. Environ. Qual.* 22:661-665.

Sharpley, A.N., S.S. Smith, O.R. Jones, 1992. The transport of bioavailable phosphorus in agricultural runoff. *J. Environ. Qual.* 21:30-35.

Young, T.C. and J.V. DePinto. 1982. Algal-availability of particulate phosphorus from diffuse and point sources in the lower Great Lakes basin. *Hydrobiologia* 91:111-119.