Site-Specific Nutrient Management

For Nutrient Management Planning To Improve Crop Production, Environmental Quality, and Economic Return

Economics and Environment: Chapter 10 of 10

Written By:

Agustin Pagani, Post-Doctoral Fellow
John E. Sawyer, Professor
Antonio P. Mallarino, Professor
Department of Agronomy, Iowa State University

Developed in cooperation with:
Lara Moody, The Fertilizer Institute (TFI)
John Davis, Natural Resources Conservation Service (USDA-NRCS)
Steve Phillips, International Plant Nutrition Institute (IPNI)

Funding provided by the USDA-NRCS and TFI.

Chapter 10:
Economics of Nutrient Management and Environmental Issues

Agustin Pagani, John E. Sawyer, and Antonio P. Mallarino / Department of Agronomy, Iowa State University
Developed in cooperation with Lara Moody, TFI; John Davis, NRCS; and Steve Phillips, IPNI.
Funding provided by the USDA Natural Resources Conservation Service (USDA-NRCS) and the Fertilizer Institute (TFI).

Introduction

The objective of nutrient management is to apply the proper nutrients and rates, and place them correctly and at the right time to best supply crop needs for profitable crop or animal production. Properly managed nutrients can also help protect the environment. Nitrogen (N), phosphorus (P) and potassium (K) are typically the largest fertilization expenses in crop production. The application of these nutrients is critical because it can significantly improve crop yield in many crop rotations. However, unneeded application or poor efficiency results in increased production cost and lost potential economic return. In addition, N and P management has environmental importance since their losses from agricultural systems have been identified as likely contributors to elevated surface or groundwater nitrate (NO_3^-) concentrations, impairment of freshwater bodies, and also hypoxia of coastal waters (such as the Chesapeake Bay and the Gulf of Mexico). Therefore, when choosing N and P applications, rate, timing, source and placement, producers need to carefully consider options to achieve the most profitable economic return while minimizing impacts on water quality.

Despite the progress that has been achieved in reducing water pollution from point and non-point sources, assessments indicate that almost 40% of U.S. waters have not met water quality standards. When N or P is present in lakes or rivers at a high concentration, a condition called "eutrophication" or biological enrichment can occur. High N and P from the Mississippi River has been blamed for a low oxygen hypoxic zone in the Gulf of Mexico. Excess algae growth occurs in response to the enriched nutrient concentrations. When the algae die, their decomposition consumes dissolved oxygen that suffocates fish, increases toxin-producing microorganisms, and reduces the aesthetic value of water. Also, excessive NO_3^- in drinking water systems can present a health hazard to very young infants (methemoglobinemia) and sometimes requires expensive treatment for nitrate removal. Sources of N and P contributing to environmental problems include agricultural surface runoff, soil erosion (mainly for P), leaching to subsurface drainage tile lines and groundwater (mainly for NO_3^--N), sewage treatment plants, atmospheric N and other sources.

Since N and P are very different in terms of their dynamic interactions in soil, fertilization practices and management influence on potential losses, the economic and environmental aspects related to management will be discussed separately.

Nitrogen Management Considerations for High Profitability and Low Environmental Risk

Proper N management for crop production involves the integration among adequate rate, source, timing and placement. When managing N, interactions among these four factors are perhaps more important than for any other nutrient. However, rate often has the greatest influence on leaching losses of NO_3^--N.

Nitrogen Rate

Crop response to applied N varies among crops. It is very important from the management point of view to have an approximate idea of the shape of the yield-N fertilization response curve for each crop and specific conditions affecting response to applied N before deciding an N rate to apply. Figure 1 shows the quadratic-plateau shaped N response curve for yield response in a crop like corn, where over applying N beyond the rate at which the maximum agronomic yield is reached (within a certain range) usually does not cause a yield decrease or quality issues. For small grain crops, like wheat, barley and others, however, over-application of N may cause yield decreases due to plant lodging and harvesting problems and in some cases too high grain N or poor grain quality for end uses. Not only is fertilization rate important, but also consideration of other N inputs that may result in too-high crop available N in the soil, such as carry-over NO_3^-, residual manure N, and previous legume crops.

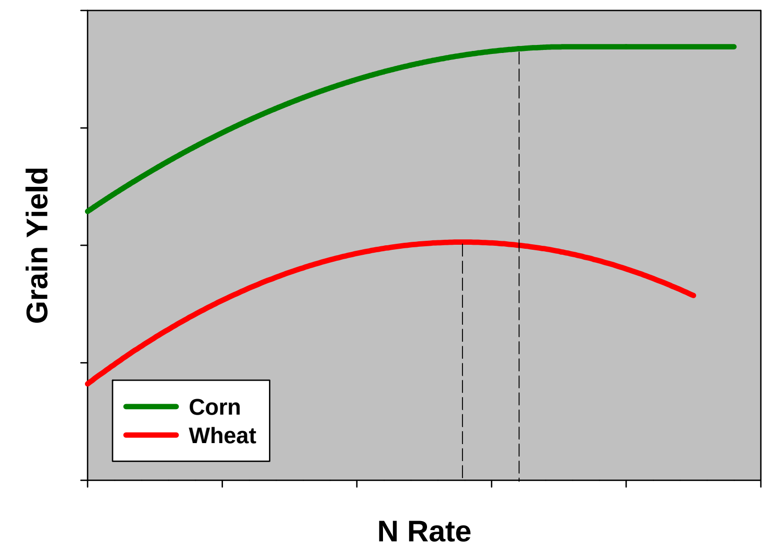

Figure 1. Schematic representation of typical N response curves for corn and wheat. The vertical dashed lines indicate the N rate at which the maximum agronomic crop yield is reached.

From an economical point of view, rather than applying N to produce maximum yield, producers should apply N rates that return the most profitable yield, where the yield gain from N application will more than pay for the invested N. Applying N at rates that produces maximum yield always causes lower net return, although the return loss can vary from small to large depending on crop/nutrient price ratios, crops and the shape of the response curve for specific conditions. From an environmental point of view, applying N to produce maximum yield will result in greater N loss (NO_3^--N) than application at the most profitable rate. Therefore, both economic and environmental perspectives need to be considered together when making N management decisions.

Applying more N than needed by crops to assure maximum yield is not considered an acceptable management practice. The current N fertilizer cost situation is neither cheap production insurance nor environmentally benign. High N fertilizer costs, uncertainty about crop prices and environmental effects should encourage growers to critically consider application rates. Figure 2 shows how NO_3^--N loss via tile lines increases rapidly as fertilizer N rate increases beyond the economic optimum N rate (EONR). This concept applies for all crops fertilized with N and most production scenarios, which highlights the importance of accurately determining the optimum N rate to maximize profitability and minimize environmental impacts within specific crops and production systems. In spite of much research, this is much easier to say than actually achieved in production fields due to the numerous and unpredictable factors that affect the optimum N rate and the crop response to applied N.

Since NO_3^--N in subsurface drainage increases with increasing N application rate, there is potential to affect NO_3^--N losses through change in N rate. However, the level of change will be related to the rate comparison and starting rate. In addition, and as mentioned above, the success relative to water quality goals is not likely to be achieved solely through rate adjustment. For instance, at EONR for corn production, NO_3^--N in tile flow typically exceeds the maximum contaminant level (MCL) of 10 mg N L^{-1} drinking water standard. Moreover, even if no N is applied, NO_3^--N will exceed the proposed EPA nutrient criteria for total N in surface waters. There are also questions regarding costs associated with reducing NO_3^- losses, and how those costs are to be paid. If N application rates being used are above the EONR, then producers can gain economically by reducing rates to those levels. They will achieve a net economic positive due to reduced N input and no associated loss in yield. However, if producers are already applying N at the EONR, then reduction below those rates will impose an economic penalty through yield loss.

Since yield response decreases with increasing N rate, the cost in yield penalty for reduced N input is less near the EONR than at lower N rates. Therefore, cost per unit of NO_3^--N reduction in drainage water becomes much larger as N rate declines below the EONR and approaches zero. This illustrates the significant risk and economic constraints that producers face if they are asked to reduce N application to rates below maximum net return.

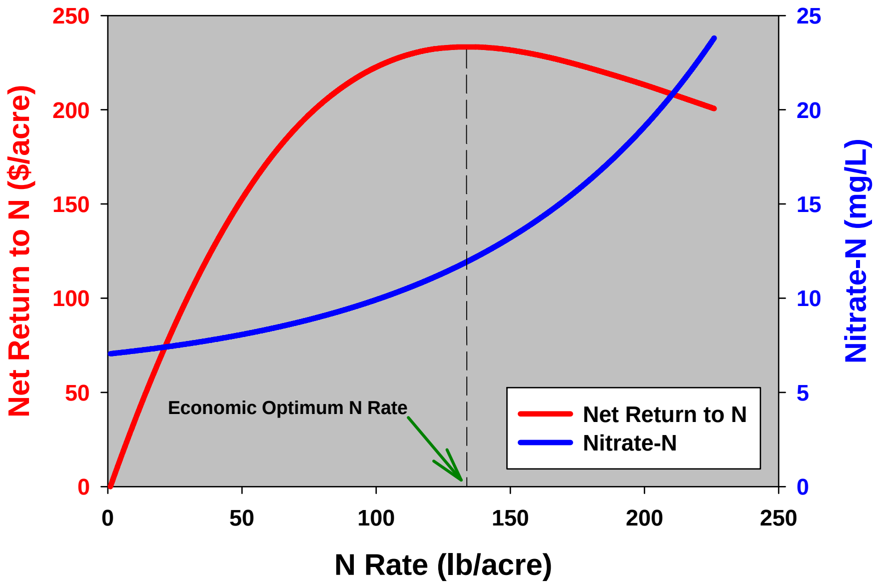

Figure 2. Importance of using economic optimum N rates for greatest profit and minimizing nitrate-N loss (via subsurface tile drainage).

Nitrogen Timing and Placement

Many corn producers in the U.S. Corn Belt apply N in the fall. Reduction in NO_3^--N concentration in tile drainage water can be observed with use of a nitrification inhibitor or when moving from fall to spring applied N fertilizer, considering the same application rate. Any additional fertilizer application in the fall to compensate for anticipated losses would further increase NO_3^--N loss, therefore moving from fall to spring in conjunction with a rate reduction would be an even larger benefit.

Sidedressing N in corn can potentially increase N use efficiency and reduce losses. This can be done in different ways and with different sources of N. However, the concept of applying fertilizer after crop emergence is consistent.

In small grain crops, N sufficiency during tiller initiation is very important because potential head number is determined by tillering success. However, the N requirement when stem elongation begins is only about one third of the total season uptake. Thus, split N applications often produce better results due to avoidance of potential N loss conditions such as volatilization, denitrification and leaching. The initial topdress of a split application should be applied before or at planting. The purpose of this application is to provide adequate N to promote adequate tillering and head number. In-season applications or final topdress should be applied by the time the first node appears at the beginning of stem elongation.

The thought behind this timing strategy includes applying N during plant uptake as well as timing to reduce the risk of loss from early spring rainfall/leaching events. Research in general shows a reduction in NO_3^--N concentration in tile drainage water when moving from fall to spring/split applied N fertilizer. In season N applications also allows the N rate to be adjusted through either soil sampling or crop canopy sensing.

Nitrogen Source

Research suggests there is little, if any, difference in NO_3^--N leaching or crop yield when using different traditional sources of fertilizer or manure, provided similar plant available N application rates are used and management is appropriate for the source. Using slow or controlled release fertilizer sources may have an impact on improved crop efficiency and NO_3^--N leaching, similar as with sidedressing N, but little water quality data is available to quantify this. Besides potential impact on NO_3^--N leaching, some manure sources high in solids content may have a positive impact on soil organic carbon, soil structure and surface runoff.

Other Practices

Several in-field and edge-of-field practices besides direct N management (rate, time, placement and source) can significantly reduce NO_3^--N losses from production fields. These practices will likely need to be utilized in addition to traditional in-field N management in order to meet NO_3^--N reduction and water quality goals.

Cover crops have the potential to reduce NO_3^--N leaching in corn-soybean rotation by taking up water and NO_3^--N during the time between corn and soybean maturity and planting the next crop. However, effect on NO_3^--N leaching is greater in areas with potential for more fall and wintertime cover crop growth, and less in northern climates where the period for cover crop growth is more limited.

Crop rotation changes can help in reducing NO_3^--N losses by including perennial crops or crops that require minimal or no N fertilization. For example, perennial crops such as forage grasses, alfalfa, energy crops, or annual crops less N fertilization demanding would decrease the needed rotation N application and thus the amount of NO_3^--N loss. Even though this alternative does not seem possible at a large scale, it may be an option for specific areas where N contamination of water sources is severe. In extreme cases, land may need to be taken out of crop production, retired, or converted to permanent pastures in sensitive areas. The establishment of buffers at the edge of the fields, wetlands, or bioreactors to treat tile-flow water could also be complementary strategies to help reduce NO_3^--N loss to surface waters and help with Gulf hypoxia and local water quality concerns.

Phosphorus Management for High Profitability and Low Environmental Risk

Proper management of P applications is a key for optimizing yield, profitability and water quality. In most regions, key P management issues for crops involve knowing the optimum soil-test P level, applying fertilizer to avoid deficiencies and achieving the optimum soil-test level over time by using various strategies considering fertilization rates and the frequency of application. Therefore, in the vast majority of fields, the fertilizer P application rates being used are the rates that maintain desirable soil-test P values based on removal or empirical information. In practice then, the historical P application rates and current soil-test P level a farmer maintains is the most important and widespread issue for the economics of P management and water quality. Nevertheless, in some conditions, the P rate, source, time of application and placement method should be considered to maximize P use efficiency and profitability while minimizing the risk of water quality impairment. The rate of P application is of great concern with excessive application that often occurs mainly when manure is applied as a waste, when any manure is applied at N-based rate to continuous grain crops and even when poultry manure (which often has a lower N/P ratio) is applied at N-based rates for corn in rotation with soybean. Subsurface banding or injecting of P could be a best management practice in soils with very high retention capacity that transforms applied P to forms of low availability to crops or with high risk of erosion and surface runoff.

Soil-Test Phosphorus Level, Crop Yield, and Profitability

Figure 3 shows the general relationship between soil-test P level and crop yield. Soil test levels are generally distributed into interpretation categories referred to as very low, low, medium (or optimum), high and very high (or excessive). The critical level or range separates soil-test values for which there is a high probability of large to moderate crop response to fertilization (very low and low) from values for which there are small and infrequent responses (high and very high). The critical level will vary with the test method, crop, soils, climate, and fertilizer/grain price ratio; and sometimes even with the philosophy of researchers that establish interpretations and recommendations. For example, the Bray-1 P level considered adequate for crops, and at which no fertilization is recommended, vary from about 12 to 30 ppm for forages or grain crops across the U.S.

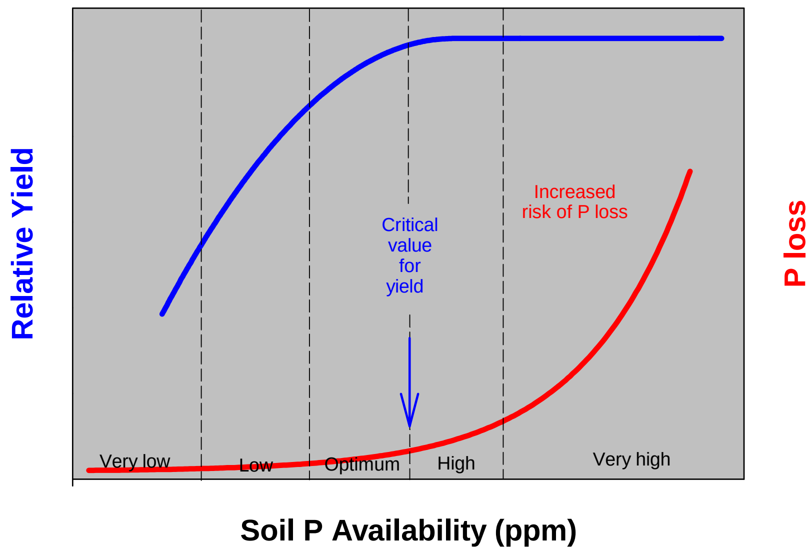

Figure 3. Schematic representation of the general relationship between relative crop yield and P loss with runoff.

In addition, because nutrient and crop prices influence the profitability of nutrient application and crop production, economic considerations together with producers' management and business philosophies further influence the optimum soil-test levels for crops. The optimal soil-test P level from an economic perspective will depend largely on the nutrient and fertilizer price ratios, producer management and other enterprise decisions. Figure 4 shows, as an example, how different crop/fertilizer price ratios influence the corn and soybean response to P fertilization and how prices may influence the optimum soil test level to maintain.

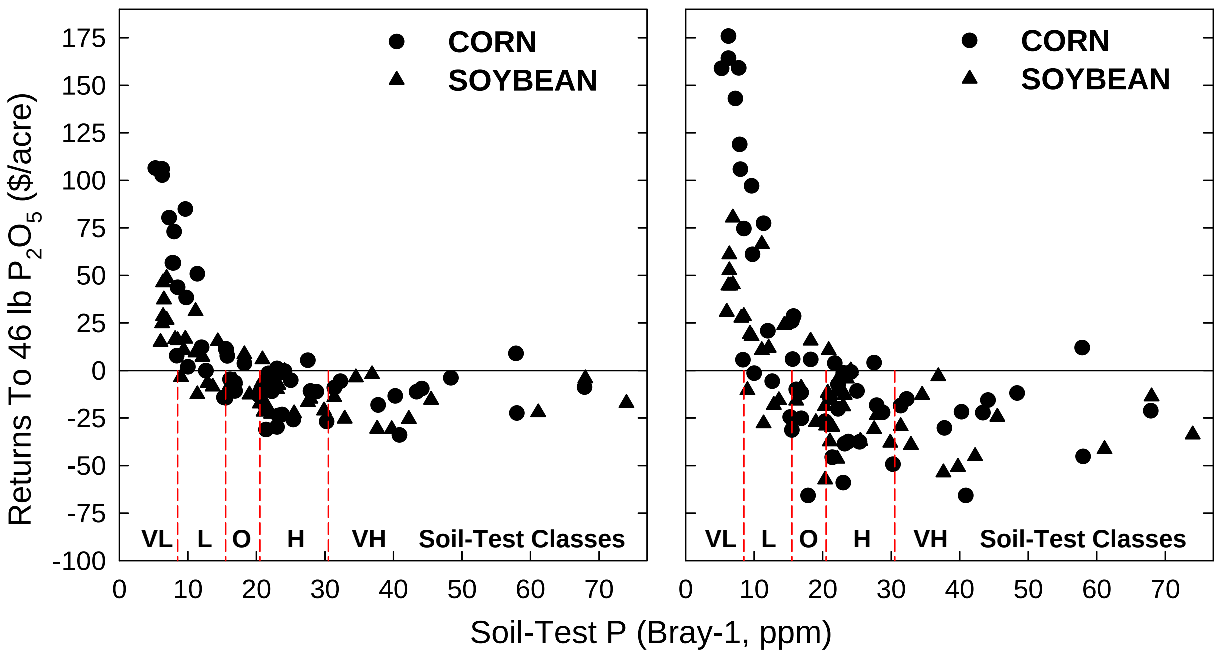

Figure 4. Net returns to P for different soil-test P levels and crop/fertilizer prices. Left graph: Corn and soybean grain at $2.00/bu and $5.50/bu, and P at $0.32/lb P_2O_5. Right graph: Corn and soybean at $4.00/bu and $10.00/bu, and P at $0.40/lb. VL, very low; L, low, O, optimum; H, high; VH, very high (from Mallarino, A.P. 2009. Long term phosphorus studies and how they affect recommendation philosophies. p. 6-12. North-Central Extension-Industry Soil Fertility Conf. Proceedings. Nov. 14-15. Vol. 25. Des Moines, IA).

Phosphorus Management and Water Quality

Phosphorus is lost from fields as dissolved forms in surface runoff or subsurface drainage and as P bound to soil particles, which is usually referred to as particulate P. The dissolved P runoff fraction is readily available to algae growth, while the particulate P fraction becomes available over time at a rate that depends mainly on the chemistry and depth of the receiving waters. With few exceptions, such as in areas with sandy soil or subsoil and level landscape, the particulate P loss is several times greater than the dissolved P loss. Therefore, soil and water conservation practices are as important, and often more important, than P management practices concerning P loss from fields. This is the reason that in most states P risk assessment tools or P indices have been developed that consider all these factors to classify fields or field areas according to risk of P loss. The P index or related risk assessment tools are being required as part of the nutrient management planning process by regulatory federal or state agencies when manure is applied or when any P source is applied within watersheds with impaired water quality.

Different types of P indices have been developed regionally or by the states. No P index is a complete P source and transport model, although some have been validated with water quality data. It is a practical quantitative tool that provides reasonable estimates of P loss risk while they can be used by advanced farmers, crop consultants and nutrient management planners. It uses an integrated approach to consider soil and landscape features as well as soil conservation and P management practices in individual fields or different areas within fields. These characteristics include P source factors such as soil test P, total soil P and the rate, method and timing of P application using commercial fertilizer, manure and other organic sources. Transport factors include precipitation, erosion and sediment delivery, surface runoff, distance from the field to the nearest stream, a variety of soil conservation practices and subsurface drainage. Components of all current P indices are erosion (particulate P lost with sediment loss) and surface runoff (dissolved P loss). A subsurface drainage component (dissolved P loss) also is included in regions where leaching through the soil profile or subsurface tile drainage are important. Most states have publications in which each state P index is explained with detail. Understanding how the different factors influence the risk of P loss helps agricultural producers, conservation planners and others by determining the causes of high risk loss. This allows for the identification of the most effective P management practices and soil or water conservation practices to reduce the P loss for different fields and conditions.

Phosphorus Management Practices

There are considerations regarding P source, timing, placement and rate that producers that are included in P indices and should be considered in order to maximize P use efficiency and minimize P loss from fields.

Phosphorus soil-test level: Interpretation of soil-test P values for water quality issues must be different than for crop production. There is general agreement that soil-test levels higher than adequate for crops may significantly increase the risk of P loss and water quality impairment, which was indicated in Figure 3. The concept of soil-test calibration used for crop production also applies to interpretations for risk of water quality impairment. The meaning of a certain soil-test value in terms of nutrient loss and impact on algae growth may vary greatly across sampling depths, soil-test methods, soil properties, soil and water transport to water resources and the properties of the receiving water body. Although the hypothetical example in Figure 3 indicates an exponential relationship between soil-test P level and P loss, the relationship found can be linear when values are not extremely low or high. Sampling a shallow soil depth, which seldom improves the value of soil testing for crops, greatly improves the relationship between soil-test P and P loss compared with the common 6 or 8-inch sampling depth for all fields but mainly for no-till, hay, or pastures. In general, the increasing risk of P loss becomes consistent for soil-test values higher than about 30 to 50 ppm (Bray-1 or Mehlich-3 tests, 6 to 8 inch sampling depth), which is at the optimum or slightly higher levels for most crops. Therefore, the economics of crop production and environmental concerns should discourage management strategies that increase soil-test P to levels much higher than optimum levels for crops. Scientists agree that the soil-test P level is only one of several factors that affect P loss and transport from agricultural fields, so the risk of loss from elevated soil-test P levels should be considered in a comprehensive P risk assessment tool, such as a P index.

<u>Phosphorus timing</u>: In general, the P application timing does not have a significant effect on crop yield where the soil properties do not result in extensive conversion of applied P to crop unavailable forms. This means that in most soils of the U.S., P application can be made at varying times before planting of crops However, the time of P application during the year and also the time between the application and a runoff event can significantly influence P loss with surface runoff. For example, research in Iowa and other states has indicated that total and dissolved P concentrations were over 60% less when a runoff event occurred after 10 to 15 days compared with events immediately after surface application. As added P reacts with the soil, it enters the labile soil P pool and is less prone to losses in runoff. Therefore, the risk of P runoff can be substantially reduced by applying P when runoff events are unlikely for one to three weeks after P application. The probability of runoff P loss in the Midwest is typically greatest in late winter and spring due to increased frequency and intensity of rainfall for already wet soils, and in northern areas also due to snowmelt runoff events.

<u>Phosphorus source</u>: Research has shown reduced P losses with runoff with manure compared to fertilizer, especially with runoff events soon after application. Manure P typically is less soluble in water than fertilizer P due to organic P fractions, and that results in less dissolved P in runoff occurring immediately after surface application. Also, manure application can result in reduced erosion and surface runoff due to increased water infiltration when manure contains considerable bedding, with reductions in sediment and runoff volume that can be greater than 2.5% per ton of surface applied manure (dry matter basis) per acre. The effect of such manure application on runoff and erosion can extend for multiple years after manure application.

<u>Phosphorus placement:</u> Research has shown little to no differential response to P placement methods for most crops in soils with low P-fixing capacity and where initial soil-test P levels are not very low. In severe P-deficient conditions, high clay soils and high fixing soils such as those with high content of aluminum and iron oxides or reactive calcium carbonate, P banding is generally recommended over broadcast application to increase plant availability of applied P and to obtain higher P use efficiency and economic return. From a water quality perspective, however, P banding or injection always reduces particulate or dissolved P loss with erosion or surface runoff compared to surface application unless the operation increases soil erosion significantly. This is because surface application of P increases soil P levels at the soil surface (in the soil-runoff water mixing zone). Runoff P loss may or may not be reduced with incorporation of manure or fertilizer with tillage because of usually increased soil erosion rates. Precipitation, slope, infiltration rate, application rate, distance to stream and many other factors influence the benefit of incorporating P with tillage at reducing P loss with runoff. Dissolved P in runoff is generally higher with surface application if a runoff event occurs shortly after application. The risk decreases with time after application before a runoff event occurs and can decrease further when rainfall that do not cause runoff occurs before a runoff event.

Variable rate phosphorus application: Dense within-field soil sampling has shown very large spatial variability of soil test P. Precision agriculture technologies available to producers or custom applicators facilitate application of fertilizer and manure at rates adequate for different parts of a field. Research has shown that grid or zone soil sampling methods combined with variable rate application based on soil-test P may not increase crop yield compared with traditional methods but always reduces spatial variability by minimizing P application to high-testing areas within fields. Variable rate application of fertilizer P is common, and some custom applicators are beginning to apply manure using variable-rate technology. Therefore, dense soil sampling and this technology can be implemented to addressing environmental as well as economic concerns.

Soil and Water Conservation Practices

The risk of runoff P loss is affected by many soil and water conservation practices that in spite of their potential importance and effectiveness to reduce P loss form fields can only briefly addressed here. These practices are especially effective in fields with grain crops, since soil and water losses are much less with well managed permanent hay or pastures. The different practices typically reduce total P loss by affecting differently the loss of particulate P and dissolved P.

Tillage and phosphorus incorporation into the soil: Tillage practices generally have an impact on soil erosion, which is the primary source of P delivery with sloping ground. Although the results of P loss with different tillage systems is site specific, research suggests less P loss generally occurs with minimum tillage than conventional tillage systems. Systems such as no-till, for example, decrease significantly the particulate P loss but usually increase the proportion of dissolved P lost.

<u>Cover crops</u>: Cover crops reduce P loss mainly by reducing soil erosion, and the effect of P uptake varies widely with the amount of growth allowed and the cover species. A cover crop increases soil stability from root growth in addition to providing a physical barrier between rainfall and the soil surface. Cover crops can be seeded in the fall using a variety of methods including drilling the seed after crop harvest, broadcasting the seed after crop harvest, or aerially broadcasting the seed before harvest. In northern regions the efficacy of cover crops is diminished because there is no winter growth, and growth in the fall and early spring (before optimum crop planting dates) is limited. Research suggests that when using a cereal rye cover before corn, the cover should be terminated about 2 weeks before corn planting in order to limit negative impact on corn growth and yield. On the other hand, there is no effect on soybean yield, so rye growth can continue longer in the spring and potentially provide more benefit in reducing erosion and P loss during a period with high rainfall intensity.

<u>Sediment control structures, contour or strip cropping, buffers, and wetlands</u>: Terraces and ponds are well known practices that result in significant reduction of soil and P loss from fields, although their efficacy is highly dependent on the landscape and maintenance. Contour cropping and strip cropping that alternate summer and winter grain crops or grain crops with hay can significantly reduce soil erosion, surface runoff, and mainly particulate P loss. Buffers come in many sizes and shapes, and may involve diverse plant species. Buffers reduce sediment transport from fields and stabilize stream banks, and physically remove particulate P from runoff water. The impact on dissolved P loss usually is minor, and is more effective when will enters the soil under the buffer with infiltrating water. The performance of installed wetlands is very dependent on the wetland-to-watershed ratio (how large the wetland is compared to the watershed). The larger the wetland-to-watershed ratio, the greater will be the percentage of P removal. Many factors affect the efficacy of wetlands at reducing P loss, including how much land is available and the sediment influent concentration. Over the long term, wetlands may not effectively remove P due to P saturation of the system, and research has shown that some old wetlands are actually sources of dissolved P.

Summary

Adequate nutrient management permits efficient crop production while reducing water quality degradation from nutrient pollution. A nutrient management plan is a site-specific decision process that integrates appropriate rate, source, timing and placement. This permits efficient nutrient use by crops and helps reduce nutrient losses to the environment. The issues associated with development and implementation of nutrient management plans are many and complex. Some amount of nutrient loss will occur even when the best nutrient management practices are employed, but these losses should be lower than would occur without nutrient management.

For N management, of greatest importance is for crop producers to carefully consider the rate of application, and apply rates that provide maximum return to the N investment. Any N application will increase soil NO_3^--N and thus potential for greater NO_3^--N concentrations moving to water systems. However, applying economic optimal rates maximizes return and reduces N effects on water quality. Because N of most environmental concern is NO_3^-, other management practices need to focus on improving crop N use, that is high yield production, and limiting NO_3^- accumulation or keeping NO_3^- in the soil system. These practices, such as overall optimal crop production practices, time of application, nitrification inhibitors, slow-release products, cover crops and in-season tools such as soil NO_3^- testing and crop sensing, will help with improving use efficiency and lower chance of N loss.

Phosphorus management is somewhat simpler than for N in humid regions, due to differences in the type of chemical transformations, no gaseous phase or volatilization risk, and less influence of environmental factors on processes that control crop-available forms and losses. Also, although the vast majority of P in soils is unavailable to plants because it is bound in insoluble P minerals or sorbed strongly to soil particles, soil sampling and testing is more reliable and useful than testing for N in humid regions. The goal of sound P management in most regions of the U.S. should be to keep the soil-test P level at optimal ranges for maximum economic crop yield, and utilize application methods and timing that optimize P use efficiency and economic profitability, while minimizing the risk of excess P loss from fields that can impair water resources. Due to the strong dependence of P loss on soil and water losses from fields, crop, soil and P management systems should avoid or minimize practices that increase soil erosion and surface runoff. Therefore, P management planning must consider practices that influence erosion and water loss from fields, and cannot simply address soil-test P and P application. Use of the P index or similar P risk assessment tool that estimates in a comprehensive way impacts of the risk of P loss for P, soil, and water management practices the best way by which producers can evaluate how economically optimum P management practices interact with soil conservation practices so that they can minimize water quality impairment.