Chapter 1. Introduction to Nutrient Management

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The impact of agriculture on water quality

Agricultural sources of water pollution in the Mid-Atlantic region

Despite the enormous progress that has been achieved in reducing water pollution, almost 40% of U.S. waters that have been assessed have not met water quality standards (Zygmunt, 2000). According to state water quality agency data submitted to the United States Environmental Protection Agency (U.S. EPA), about 15,000 water bodies are impaired from siltation, nutrients, bacteria and other pathogens, oxygen-depleting constituents, trace elements, pesticides, and other organic chemicals. Many of these pollutants do not come from a single point such as a sewage outfall or an industrial discharge pipe and are thus termed *non-point source* pollution.

Nutrients, particularly nitrogen (N) and phosphorus (P), are the major pollutants in lakes and estuaries and the second leading source of pollution in rivers (U.S. EPA, 1998). Life within rivers, streams, lakes, and bays could not exist without nutrients; however, an excess of nutrients (*eutrophication*) may cause ecological problems and can harm aquatic life.

Smith and Alexander (2000) estimated that nearly all of the N and P exported from watersheds in the Mid-Atlantic are from non-point sources, to which fertilizer and animal manures used in agriculture contribute significantly (Table 1.1). A six-year study by the U.S. EPA (1983) revealed that runoff from farmland was a major source of pollution contributing to water quality decline in the Chesapeake Bay. While these nutrient loading estimates continue to be the source of debate and further research, agricultural non-point source pollution must clearly be reduced in order to reverse the degradation that the Bay and other Mid-Atlantic regional waters have undergone.

Table 1.1. Point and non-point source contributions to total nitrogen and phosphorus export from Mid-Atlantic watersheds.

			Non-point source			
Nutrient	**Total export[a]**	**Point source**	Fertilizer	Animal agriculture	Atmosphere	Non-agricultural runoff
	kg/ha/yr	----------Median, as % of total export----------				
Nitrogen	9.0	4	14	16	32	22
Phosphorus	0.68	14	19	25	NA	22

[a] Total export is the median export from hydrologic cataloging.

Effect of agricultural non-point source pollution on water quality

Excess N and P can cause excessive growth of algae, a type of phytoplankton, whose eventual death and decomposition reduces the dissolved oxygen (DO) concentration in the water. Low DO reduces respiration, growth, and reproduction of aquatic organisms and can result in the death of fish and other aquatic organisms.

Another adverse effect associated with excessive nutrient concentrations in the Chesapeake Bay and some tributaries was the appearance of the toxic microorganism *Pfiesteria* in 1997, which caused both death of fish and adverse health effects in commercial and recreational fishermen. Foul tastes and odors often occur in drinking water populated by excessive algal blooms in surface water.

Excessive phytoplankton growth also reduces water clarity, which reduces light transmission available for the growth of submerged aquatic vegetation (SAV). Submerged aquatic vegetation serves as an important habitat for fish, crabs, and other species of economic and environmental importance. Due in large part to increased nutrient concentrations in the Bay, areas of SAV beds have been greatly reduced in recent years because of the shading effect of the phytoplankton growth. Vast areas of SAV were well documented from colonial times until the 1960s, during which time the Bay was one of the most productive estuaries in the world.

Phosphorus is generally the limiting nutrient for phytoplankton growth in the saltwater portions of the Bay during all seasons except summer. During the summer, however, N is the limiting nutrient. Since most phytoplankton growth in the Bay occurs during the summer months, N control strategies become very important.

Agricultural impacts such as sedimentation, eutrophication, and general water quality degradation due to presence of inorganic or organic constituents and pathogens in the water and sediments also occur in tributaries miles from the Bay. Phosphorus is usually the limiting nutrient in these upper tributaries of the Bay watershed and in other freshwater bodies. Other agricultural impacts may include contamination of groundwater, which is a source of drinking water for many rural communities, resulting from migration of pesticides, nitrates, and pathogens.

Eutrophication standards vary among major types of water bodies such as rivers, lakes, reservoirs, estuaries, and coastal systems. For example, critical concentrations of dissolved P recommended or established for lakes (0.01-0.05 mg/L) and streams (0.10 mg/L) can differ by an order of magnitude (Sharpley et al., 1996). Critical concentrations have been suggested for total N (2.2 mg/L) and P (0.15 mg/L) in rivers, but these values are well above the average total dissolved nutrient concentrations expected for unpolluted major

rivers (~0.375 mg N/L and ~0.025 mg P/L), respectively (Meybeck, 1982). The nitrate N groundwater standard of 10 mg/L established to protect human health has been demonstrated to be too low; however, such a concentration may be too high as an ecological standard (L'Hirondel, 2005).

Fate and transport of nutrients

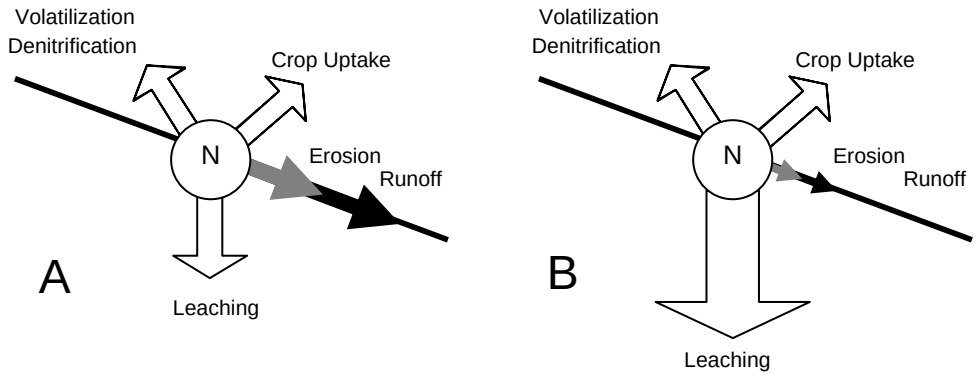
Nitrogen

Nitrogen, an essential element for plant growth and animal nutrition, is the nutrient taken up in the largest amount by crops. Nitrate (NO_3^-) is the major inorganic form of N in most soils. This anion is not attracted by the predominately negatively charged soil colloids and is, therefore, quite mobile and moves freely with soil water. Nitrogen application to soils beyond that required for plant uptake and maintenance of the soil microbial biomass will generally result in NO_3^- leaching and possible high NO_3^- levels in groundwater. Elevated concentrations of NO_3^- in drinking water may lead to methemoglobinemia in infants, the formation of carcinogenic nitrosamines in the human stomach, and hypertension. A national survey of drinking water wells (U.S. EPA, 1990) found that NO_3^- was the most common contaminant, with 52% of the 94,600 community water systems tested containing detectable concentrations and 1.2% of those water sources exceeding the drinking water standard of 10 mg NO_3-N per liter (10 ppm). Localized contamination has been measured beneath cropped, well-drained soils that received excessive applications of manure and commercial fertilizer in the Mid-Atlantic states and the Delmarva Peninsula (Spalding and Exner, 1993).

While leaching losses are generally considered the major environmental threat from N, runoff losses are also possible. The potential of each system to contribute N to surface waters will depend upon its transport (i.e., erosion and runoff) capability and the surface soil N concentration (Figure 1.1A). Nitrogen is lost to surface water as NO_3^- from recently applied inorganic fertilizers or in particulate organically-bound forms. Movement of excessive amounts of N to surface waters can result in a number of undesirable effects, such as eutrophication, associated algal blooms, and subsequent oxygen depletion.

Managing N to minimize NO_3^- losses is very difficult because of the many possible loss pathways. For example, increased water infiltration may increase leaching of nitrate if practices to reduce runoff and erosion, such as no-till, are adopted (see Figure 1.1B). Similarly, incorporating manure to reduce N volatilization losses increases the risk of N loss through runoff, erosion, and leaching. Consequently, one of the primary emphases of nutrient management is minimizing the potential source of N in the system because any excess N will likely be lost to the environment in some manner.

Figure 1.1. (A) General fate of N and (B) how adopting processes to reduce erosion and runoff increases N leaching losses.



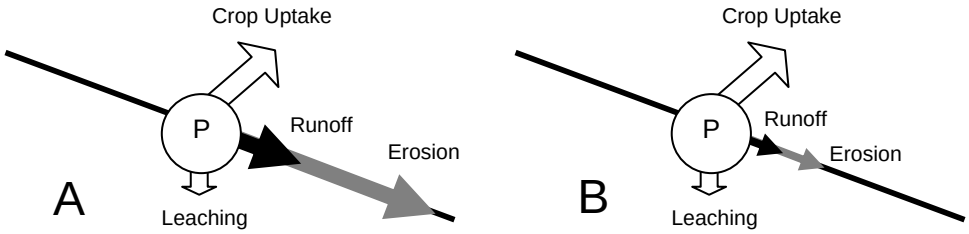
Phosphorus

Phosphorus is another element required by plants and animals whose accumulation in water bodies may result in nutrient pollution. Increased public and regulatory concern over the use and application of P to agricultural lands is due to the eutrophication that can result from increased P loadings to surface waters (Daniel et al., 1998). Algal and aquatic weed growth in most inland surface water systems is P-limited, and elevated P levels result in algal blooms, oxygen depletion, and occasional problems with drinking water taste and odor.

Phosphorus is typically immobile in soil and seldom migrates downward with soil water to any great extent because it is strongly adsorbed by and/or precipitated as highly insoluble soil mineral phases (Figure 1.2A). Much of the P that is applied to soils in fertilizer, manure, and biosolids is retained in the near-surface layer in various inorganic precipitates and in adsorbed forms that prevent it from leaching.

The risk of groundwater contamination by P in crop production systems is usually not high, although leaching can be a significant loss pathway for P in coarse-textured (sandy) soils with shallow water tables. Runoff and erosion losses to surface waters are the major water quality risks from P (Figure 1.2B).

Figure 1.2. (A) General fate of P and (B) how adopting processes to reduce erosion and runoff does not usually increase P leaching losses.



Because P is strongly adsorbed by soil solids, P runoff from permanently vegetated areas such as perennial sods or forests is minimal, and largely occurs as traces of orthophosphate (PO_4^{-3}) ions in solution. In areas where erosion risk increases, such as where annual crops are grown using conventional tillage, the total P loss increases greatly as the P is moved in solid particulate form with the eroding soil. Although water-soluble P is immediately available for biological uptake, sediment-bound or particulate P forms (or *bioavailable particulate P*) are released over longer periods. The overall impact of a given production system on P runoff to local surface waters will, therefore, be primarily dependent upon relative rates of sediment loss and the P levels in these eroding soil surfaces.

Nutrient loss from organic wastes

Many crop production systems in the Chesapeake Bay region receive various organic wastes as fertilizer amendments. Organic amendments such as manure, municipal wastewater sewage sludge (biosolids), municipal solid waste compost, and other miscellaneous agricultural, municipal, and industrial by-products all have the potential to improve soil properties while increasing organic matter levels. Organic amendments are particularly effective at improving the productivity of marginal or degraded lands.

The major water quality concerns associated with the land application of organic by-products are the direct runoff or erosion of the organic material and any mobile constituents (such as N, P, or pathogens) into surface waters and the migration of NO_3^- and pathogens to groundwater. Application rates for these materials are generally based on the estimated amount of plant available N in the by-product, but P can be the limiting nutrient for application to soils whose P adsorption capacity is becoming saturated. Phosphorus runoff may occur in soils that have routinely received heavy annual applications of animal manure because the maximum P retention capability of such soils is being approached or exceeded.

Nutrient cycles and management on different types of farms

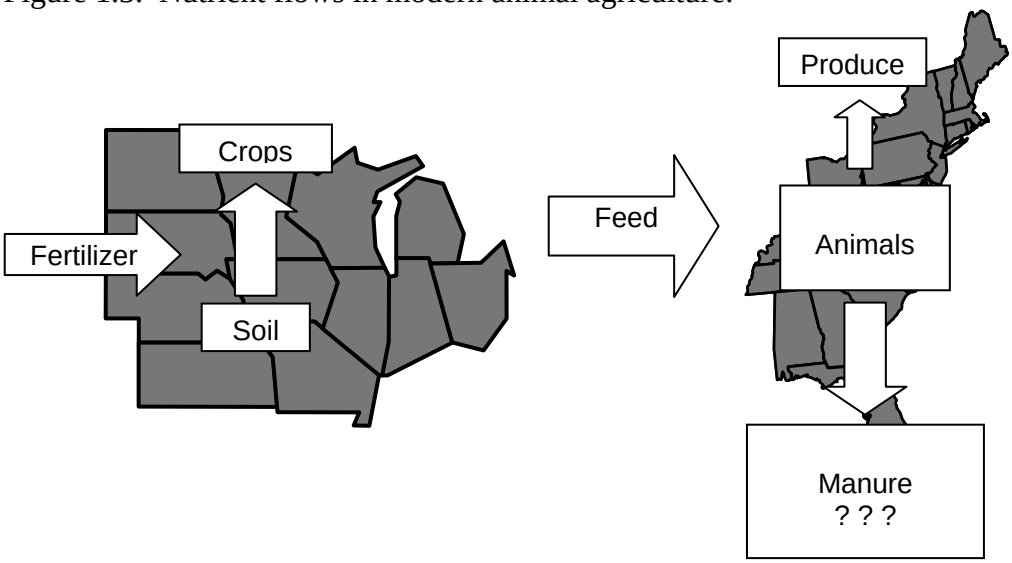
Introduction: why nutrient losses are a problem

A common misconception is that farmers, in general, are mismanaging nutrients on their farms. While there is usually room for improved management, the nutrient pollution problems from agriculture primarily result from the way modern agriculture has evolved.

Prior to World War II, most farms included both animals and crops. Nutrient use on those farms was interdependent because manure nutrients were used to produce crops which were fed to animals that generated manure. Fertilizer nutrients became more economical after the war, which resulted in the separation of crop and animal agriculture. With the loss of the on-farm relationship between feed crops and animals came a significant increase in animal agriculture in some areas that was supported by concentrated crop agriculture in other areas, often far away. Currently, nutrients from imported feed often accumulate to very high levels on the farms where the animals are located because of manure applications on those farms (Figure 1.3).

While farmers collectively have been making sound economic management decisions, the unexpected consequence of these decisions has resulted in the increased potential for nutrient pollution in the areas where nutrients are accumulating. Significant long term strategic changes in the structure of animal agriculture, rather than simple management changes, will be required to develop solutions to the problems inherent in this system. The following sections describe nutrient cycles and management on different farm types. Understanding these cycles can increase the adoption of strategies to enhance nutrient use efficiency and reduce potential environmental impacts.

Figure 1.3. Nutrient flows in modern animal agriculture.



Cash crop farm

Nutrients come to a modern cash crop farm in fertilizers and other materials applied directly to the fields (Figure 1.4). Crops harvested from the fields remove a fraction of the applied nutrients, which leave the farm when the crops are sold. On a cash crop farm, there is a direct connection between the flow of nutrients and the agronomic or economic performance of the farm.

Traditional economic and agronomic incentives can be effective in guiding nutrient use on cash crop farms to optimize both crop production and environmental protection. Improper management can result in significant nutrient losses other than those removed in crops and negative economic consequences for the farmer. The cost of practices that reduce nutrient losses on a cash crop farm can at least be partially offset by decreased costs in purchased fertilizer. The nutrient balance on a well-managed farm is usually very close to zero (Table 1.2).

Figure 1.4. Nutrient cycles on cash crop farms.

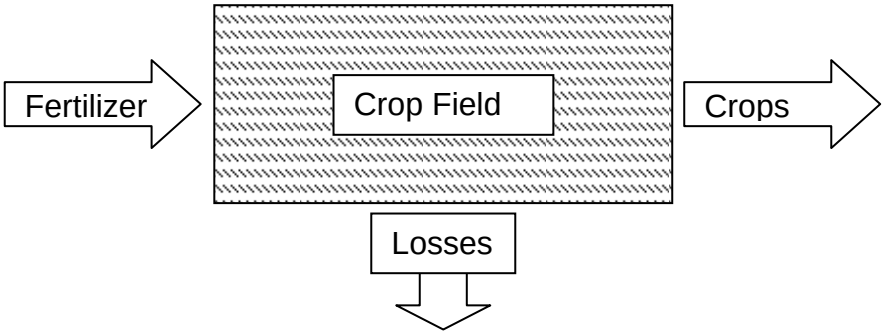


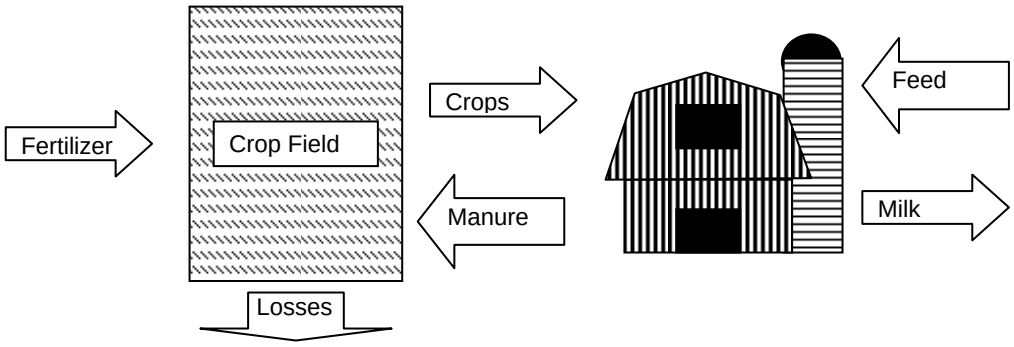
Table 1.2. Example of nutrient balance (P_2O_5) on a cash-crop farm in Pennsylvania.

Input:	**lb P_2O_5/A/yr**
Fertilizer	36
Output:	
Crop removal	32
Balance	+4

Crop and livestock farm

On farms with livestock (e.g., a dairy), a large proportion of the plant nutrients from crops produced as feed for the animals are traditionally returned to the farm fields in manure (Figure 1.5). This pattern of nutrient use and cycling varies significantly from a modern cash crop farm. The plant nutrients in the feed inputs can offset the nutrients removed from the farm as sold animal products.

Figure 1.5. Nutrient cycles on a modern crop and livestock farm.



Off-farm feed inputs enable crop and livestock farms to have more animals on fewer acres. Thus, on modern crop-livestock farms, the manure produced by the animals is often not spread on the fields where the crops were produced. Off-farm feed nutrients can exceed what is needed for the crops and result in excess manure nutrients that can be potential sources of water contamination. Accounting for all sources of plant nutrients being applied to fields is an important management practice for protecting the environment from negative impacts caused by the over-application of nutrients to crop fields.

Neither crop production nor fertilizer use is directly connected to the output of such farms because farms with this structure primarily sell animal products. Farm performance depends more on the animal husbandry skills of the farmer than successful crop production. The economic viability of the farm is not as sensitive to the decisions about plant nutrient use in the fields

as it is on the cash crop farm. The dairy farm given as an example in Table 1.3 demonstrates the nutrient excess that can occur as imported feed becomes significant.

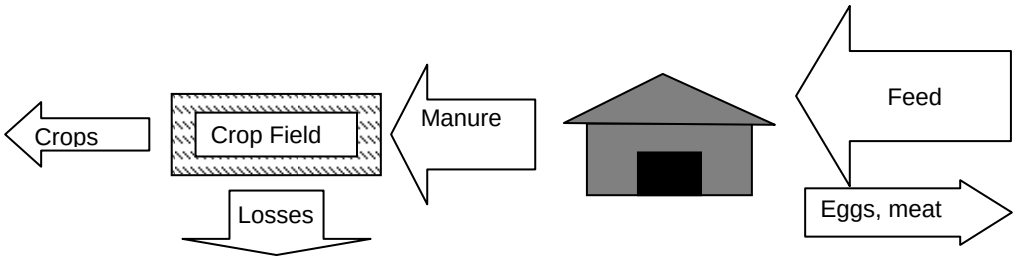
Table 1.3. Example of nutrient balance on a dairy farm in Pennsylvania.

Inputs:	**lb P_2O_5/A/yr**
Fertilizer	22
Feed	60
Output:	
Milk	24
Balance	+58

Intensive animal production farm

Trends in animal housing and the success of crop production on cash crop farms in specialized geographic regions have made it possible to concentrate large numbers of animals, such as poultry and swine, on small land areas. Most, if not all, of the feed necessary for these animals can be economically transported to the farm where the animals are housed (Figure 1.6).

Figure 1.6. Intensive animal production farm with limited crop production.



Although intensive poultry and swine farms may produce crops for off-farm sale, the land areas involved can be quite limited because management is focused on animal production. The cash crop farm and the intensive livestock farm are connected by the flow of feed, but nutrients typically do not cycle back to their original locations. This will usually result in an excess of nutrients on the farm where the animals are located and a high potential for environmental problems there.

For example the poultry layer farm illustrated in Table 1.4 has an excess of 2350 lb P_2O_5/A/year. The field-based economic and agronomic incentives that can be effective in motivating farmers to manage nutrients on a cash crop farm (and that will also minimize potential environmental impacts) are not as critical on the intensive livestock production-oriented farm. It is unlikely that

environmental quality can be protected on poultry and swine farms solely by recycling nutrients for crop production because of the small land area of the farm. Successful management of nutrients to protect the environment will depend on transportation of manure nutrients from the farm.

Note: Animal concentration areas
The number of animals in barnyards and holding areas can be greater on intensive livestock farms because ruminant animals often spend part of their time out of buildings. The result is that the areas around farmyard facilities can become sources of nutrient losses from the farm. Animal concentration areas are such locations where the animals gather and deposit manure nutrients in quantities that exceed removal in growing vegetation. These areas often have little or no vegetation and may be located in environmentally sensitive areas, such as stream bottomland. These areas require special attention in nutrient management plans and usually require BMP (*Best Management Practices*) to protect water quality.

Table 1.4. Example of nutrient balance on a poultry layer farm in Pennsylvania.

Inputs:	**lb P_2O_5/A/yr**
Fertilizer	0
Feed	3380
Output:	
Eggs	1030
Balance	+2350

Nutrient management planning

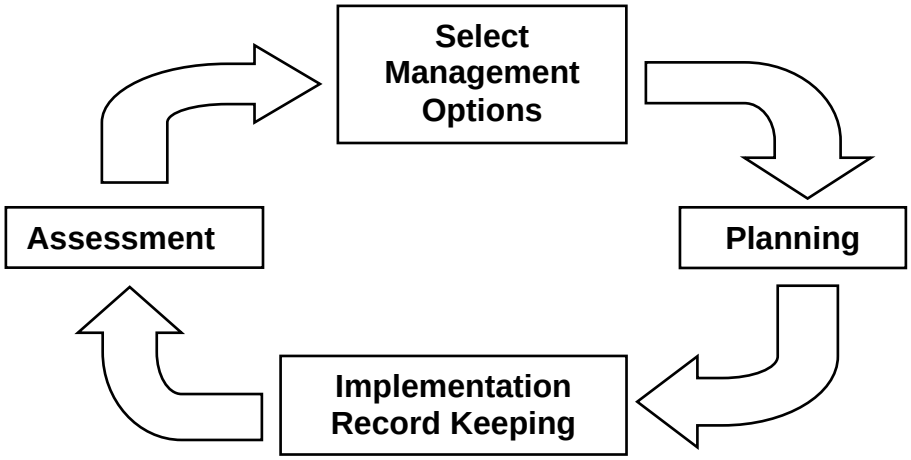
Purpose of nutrient management

Nutrient management is the implementation of practices that permit efficient crop production while protecting water quality from nutrient pollution. A *nutrient management plan* is a site-specific plan whose recommendations permit efficient nutrient use by crops and minimize nutrient losses to the environment (primarily water and air). 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.

The nutrient management process

Nutrient management should be planned as a multi-step, constantly evolving process. The key components of the process are: **assessment, management option selection, planning, implementation**, and **record keeping** (Figure 1.7).

Figure 1.7. The nutrient management process.



Nutrient management assessment I: nutrient status and balance

A thorough assessment of the nutrient status of the farm and the potential for environmental impacts from nutrients should be conducted. Key criteria should include:

- farm management goals and constraints.
- available farm resources (land, equipment, and financial resources.)
- potential critical problem areas on the farm (sensitive water bodies, neighbor concerns, existing problems such as barnyards, severe erosion, manure storage, etc.)
- nutrient balance.

Nutrient balance can be estimated from easily determinable farm characteristics. Table 1.5 provides some simple criteria that can be used to assess farm nutrient balance. These are estimates only, and actual nutrient balance will vary depending on specific farm characteristics.

Table 1.5. On-farm criteria that can be used to estimate nitrogen[1] balance.

Criteria	**Farm is deficient in N**	**Farm has balanced N**	**Farm has excess N**
Feed Source (% off farm feed)	On farm (<50%)	Combination (50 – 80%)	Off-farm (>80%)
Animal Density (AU/A[2])	Low (<1.25 AU/A)	Medium (1.25-2.25 AU/A)	High (>2.25 AU/A)
Pollution Potential[3]	Low	Medium	High

[1] To estimate P balance, these numbers can be cut in half
[2] AU = Animal unit = 1000 lb live weight; A = Acres available for manure application
[3] Assuming good management

Nutrient management assessment II: sites which may have accelerated nutrient loss

The potential for plant nutrients (particularly N and P) to migrate to surface water and groundwater is largely dependent upon soil and site conditions. Any combination of soil and site conditions that will lead to either rapid rainfall runoff or rapid movement of dissolved ions through the soil will lead to water quality risks from almost any land use practice. Thus, an important part of nutrient management planning for agriculture is recognizing and delineating these sites for development of specific management practices to avoid the anticipated effects.

The following soil/landscape features and properties are particularly vulnerable to the loss of nutrients from agricultural practices:

- **Soils with high leaching potentials:**
  This includes soils with very coarse textures and those where the water table is at or near the surface during the winter. The combination of these factors poses a high risk for nutrient loss to groundwater and associated surface waters. If accurate soil survey information is available, the leaching index for a given soil can be obtained by following the procedures outlined in the U.S. Department of Agriculture National Resources Conservation Service (USDA-NRCS) Field Office Technical Guide (available at http://www.nrcs.usda.gov/technical/efotg/).

  Such soils should not receive nutrient applications during times of the year when nutrients are least likely to be assimilated by crops (i.e., late fall, winter). Nutrient management practices in fields containing significant areas of these soils should include such practices as split application of N on crops and the use of winter cover crops to scavenge residual soil N.

- **Karst lands (landscapes underlain by limestone bedrock or other highly soluble carbonate-bearing parent materials):**
  Sinkholes are formed by the long-term dissolution of carbonates underlying the surface, which eventually leaves a cavity that collapses over time. These areas mainly occur in the Valley and Ridge Physiographic Province (see Chapter 2), but may also occur in the lower Coastal Plain.

  Sinkholes may form a direct connection between surface water and groundwater, and dye tracer tests have shown that water entering a sinkhole can contaminate nearby drinking wells within hours. If muddy or cloudy water appears in a well after a significant rain, surface water is likely entering the water bearing zones in the rock by direct flow down channels and rock fractures.

  If a sinkhole is located in an isolated high area of a field, a grassed buffer should be placed around it. If the sinkhole occurs on a sideslope or below a cropped field, significant runoff may drain into the sinkhole. The field area draining into the sinkhole would be best used for hay crops, pasture, or trees, in order to reduce runoff.

- **Shallow soils over fractured bedrock:**
  Soils that are shallow (less than 41 inches) to fractured bedrock are environmentally sensitive and should be managed like soils with a high leaching index. Although many of these soils do not have high leaching potential, once the soil water percolates to the fractured rock, the water and any dissolved nutrients can move rapidly to groundwater.

  Lists of shallow soils in each state can be obtained from the NRCS and by reviewing county soil survey reports. Nutrient management practices in fields containing significant areas of these soils should include such practices as split application of N on crops and the use of winter cover crops to scavenge residual soil N.

- **Tile-drained lands:**
  Artificially drained fields should be treated as environmentally sensitive because of the direct connection of the tile outlets to surface watersheds. These lands are typically drained because they have a high seasonal water table and, therefore, have the potential to pollute both the surface water with their drainage discharge and the local water table if nutrients are over-applied relative to crop uptake. These soils should be treated like coarse-textured soils with high water tables. Nutrient management practices in fields containing significant areas of tile-drained soils should include split application of N on crops and the use of winter cover crops to scavenge residual soil N.

- **Irrigated lands:**
  Fields receiving irrigation, because of the increased water input, are prone to runoff and leaching of water and nutrients. The leaching index approach cannot be used on these areas since it would underestimate the actual leaching potential. To maximize water use efficiency and minimize leaching and runoff, irrigation scheduling methods should be used. These include the use of gypsum blocks, tensiometers, or computerized systems. When these indicators show the need for irrigation, rates and amounts of water should be based upon the soil type and water-holding capacity to further reduce water and nutrient losses.

- **Excessively sloping lands:**
  Lands with steep and long slopes pose a high risk for the surface loss of applied nutrients. Slopes greater than 12% to 15% are prone to runoff losses of surface-applied N and P. Significant amounts of sediment can be lost if a heavy rainfall event occurs following tillage to move these surface-applied nutrients below the flow of runoff. Applications of manure or biosolids may be limited to P soil test needs or crop uptake estimates, unless injection is used, if these organic by-products are applied to such slopes. Soil conservation measures should be practiced on highly erodible lands.

- **Flood plains and other lands near surface waters:**
  Runoff and leaching from agricultural lands that are close to surface waters can have a direct impact on surface water quality. If channelized flow develops, surface flow of runoff water from these areas has little chance to be filtered before discharge into adjacent waters. Subsurface flow in groundwater can also directly seep into the adjacent surface water body. If water containing NO_3^- flows into a wetland, however, significant amounts of N can be denitrified and lost to the atmosphere, with a subsequent reduction in the N levels that reach the adjacent surface waters.

  Using manure or biosolids on flood plains is not a recommended practice. If manure or biosolids must be applied to a flood plain, incorporation or injection application methods should be used to minimize losses if flooding occurs.

The list of environmentally sensitive sites given above is not all-inclusive but does include the major types of land with these concerns in the region. Appropriate setback or buffer areas should be established between these areas and any field receiving nutrient applications, and intensive nutrient management practices should be employed on any lands adjacent to sensitive areas. Each state has its own guidelines for these buffer areas as well as regional guidelines such as those associated with the various Chesapeake Bay initiatives.

Selecting management options

After the nutrient management assessment of the farm, appropriate management options can then be selected for inclusion in the nutrient management plan. Each farm will have unique qualities, resources, and problems that must be addressed in the nutrient management plan.

Management options that maximize nutrient use efficiency by the crops and reduce the need to purchase nutrients would be emphasized on a farm that is nutrient deficient. On a farm with excess nutrients, practices that maximize safe utilization and off-farm distribution of nutrients would be emphasized. For example, spreading manure onto alfalfa would not be a recommended practice on a farm with a deficit of nitrogen because this would be an inefficient use of the manure N; however, spreading manure on alfalfa may be recommended to safely utilize the manure on a farm with excess nitrogen.

Table 1.6 summarizes important considerations in selecting appropriate management options depending on the assessment outcome. Notice that the economics of improved nutrient management are not always positive. In fact, on farms that have excessive nutrients, improving the nutrient management usually results in a negative economic return. This is a common misunderstanding by people who think that improved nutrient management will always give a positive economic return. Farmers would likely have already adopted the practices if the economics were positive.

Table 1.6. Selecting management options depending on nutrient balance from the nutrient balance assessment.

	Nutrient Balance Assessment		
Option	**Deficient in Nutrients**	**Balanced Nutrients**	**Excess Nutrients**
Management emphasis	Maximize nutrient use efficiency	Maximize safe nutrient utilization	Maximize safe nutrient utilization and move excess nutrients off farm
Land available for spreading manure	Adequate	Adequate but limited	Inadequate
Basis for manure application	Optimum crop response	Balance nutrient inputs and outputs	Balance nutrient inputs and outputs by exporting nutrients
Economics	Positive	Neutral	Negative

Nutrient management planning

Nutrient management planning involves integrating the management options based on the assessment into a comprehensive tactical and operational plan. The nutrient management planning process is dependent upon the synthesis of information and data on the soils, cropping systems, nutrient amendments, management practices, and climate; therefore, care should be taken to ensure that the information used to develop the nutrient management plan is current and accurate.

Nutrient management plans must be tailored to specific soils and crop production systems. While each state in our region may have differing approaches to this process, the following steps will generally be essential.

	Nutrient Management Planning
Step	**Action**
1	Obtain accurate soil information for each field or management unit by analyzing representative soil samples from each management unit. This may require a new farm soil map or a revision of existing USDA-NRCS mapping coverage.

2	Determine the crop yield potential for each field based on the known productivity of the soils present coupled with the intended management practices.
3	Identify the total plant nutrient needs to achieve the expected yield potential. Usually this is based on the soil test recommendation.
4	Estimate the nutrient contribution that can be expected from residual effects or carryover from previous fertilizer, manure, or biosolids applications. Include credit for N supplied to a row crop following a previous legume.
5	Determine if any nutrients will be applied regardless of the manure application. Examples here might be starter fertilizers or fertilizers used as pesticide carriers.
6	Calculate the rate of manure, composts or biosolids that would match or balance the **net crop nutrient requirements**. **Net Nutrient Requirement =** Total nutrient needs minus residuals from manure and legumes minus fertilizer to be applied regardless of manure. Usually this rate is calculated based on the net N or P requirement. If the rate is based on N, the availability of the manure N to crops must be considered in the calculation. The potential environmental risk from P applied at the N-based rate should be evaluated with the use of a tool such as the P Index if the rate is based on N. The calculated rate is often adjusted to make it more practical for the farmer. The practical rate should not exceed the calculated balanced rate.
7	Recommend application timing and methods for manure, other organic nutrients, and/or commercial fertilizers to supply the needed nutrients at the appropriate time for optimal crop production.
8	Recommend appropriate management practices (e.g., tillage, irrigation, cropping system, buffer zones) to enhance the protection of surface water and groundwater.
9	Identify and plan treatment for sensitive areas whose characteristics may increase the risk of nutrient loss.

Implementation

The nutrient management plan will not protect the environment unless it is implemented. **Thus, it is essential to work with the farmer to assure that the plan is practical.**

Keeping records

Keeping records is often required by law, but recordkeeping is a critical process regardless of any legal requirement. The record provides accountability to the public and is the foundation for an assessment that will start the next nutrient management planning cycle. In the end, nutrient management planning should be a continuous process of assessing the implementation successes and failures, selecting new management options as appropriate, revising the plan, and implementing this revised plan. With time, the implementation should more closely match the plan.

Recordkeeping should be part of the plan to facilitate the process. For example, it is easy for the farmer to acknowledge that a component of the plan was completed as planned, or to note that something was done differently, if space for records is included in the operational summary of the plan that the farmer will follow.

Table 1.7 is an excerpt from a nutrient management plan manure application summary which includes the records of what was done. In this example, manure to be applied for corn should be incorporated within 4-7 days after application, but the record shows that it was not incorporated. If this continues to be a common occurrence, incorporation may be omitted in future plans.

Table 1.7. Excerpt from an example nutrient management plan manure application summary illustrating how the record can be integrated into the plan summary.

Field	Acres	Crop	Fertilizer	Actual	Type	Rate	Time	Method	Actual
1	10	Corn	10-20-10 Starter	**Done 4/29.**	Dair y	5000 gal/ A	Spring	Surface incorporate within 4-7 days	**Done 4/10. Not incorporated.**
2	10	Hay	0-50-150	**Applied 150 lb 0-0-60/A plus manure.**					**Applied 3000 gal dairy manure after first cutting 6/7.**
3	10	Corn	10-20-10 Starter	**Done 5/2.**	Dair y	5000 gal/ A	Spring	Surface incorporate within 4-7 days	**Done 4/17. Not incorporated.**

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