A nutrient management approach for Pennsylvania:
Plant nutrient stocks and flows

Almost all decision-making in agriculture, in the boardrooms of industry or on the tractor seats of farms, affects the distribution of materials such as crops and manure within farms, and the movement of materials such as feeds and farm products to and from farms. Most common farm materials contain important plant nutrients, such as nitrogen, phosphorus, and potassium, and are moved as part of the everyday activities of farming and agriculture. As a result, the many factors considered in *each* management decision affect plant nutrient distribution and have implications for nutrient management to meet the many expectations.

The balance of nutrients in the material flows at any one place on a farm influences the status of the nutrient inventories, or stock of nutrients at that place. The balances can also affect the status of the entire farm. Since farms are also part of larger geographic regions such as watersheds, or jurisdictional units such as townships and counties, the nutrient inventories at these levels of organization can be affected.

Significant features for the physical dimension of nutrient management are:

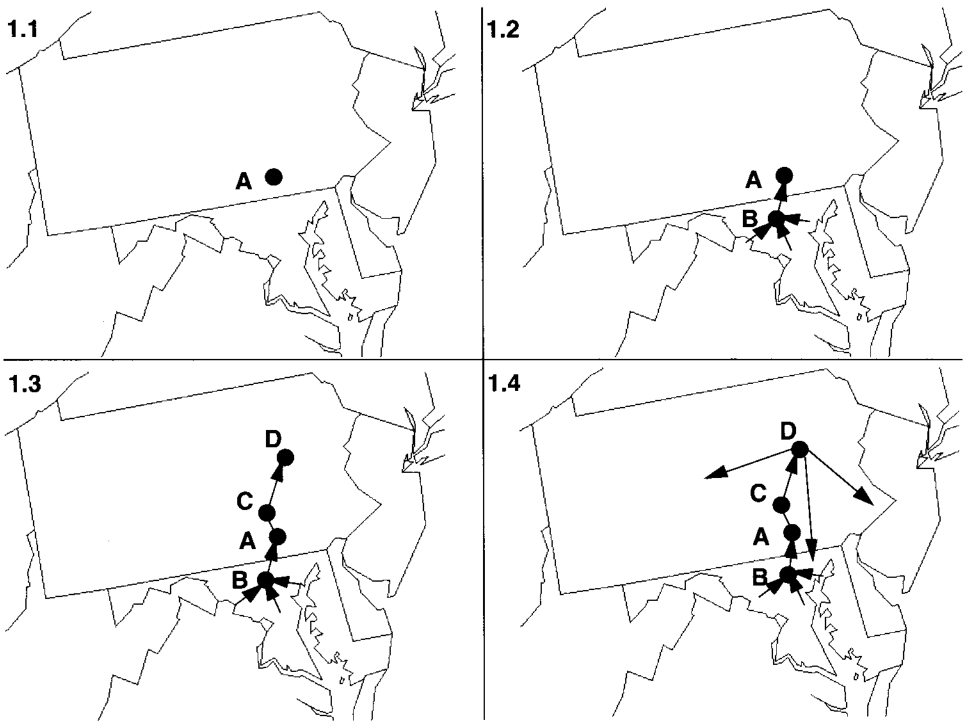
flow – the movement of nutrients to, from, and within farms or within geographic and jurisdictional units; the nutrient inputs and outputs, and

stock – the inventory of nutrients in fields, on farms, and in the associated geographic areas such as watersheds and jurisdictional units; changes in stock depend upon the balance of nutrients in the flows.

Understanding the pattern of material flow to, from, and within farms can help define possible trends in the changing stock of nutrients over time on farms, in geographic regions, or in jurisdictional units.

The movement of farm materials for a poultry farm in southcentral Pennsylvania illustrates some of the flows (Figure 1) and provides insights to changes in nutrient stocks along the way. The poultry farm is located just across the Pennsylvania/Maryland state line (A, Figure 1.1). Feed is shipped from a dealer in Maryland (B, Figure 1.2) to the farm every other day. The feed is prepared from grain produced in the area surrounding the feed dealer plus very likely some from other farther away sources. The eggs produced on the farm are marketed through a wholesaler (C, Figure 1.3) to a retail grocery chain (D, Figure 1.3). The retail grocery chain markets the eggs throughout eastern Pennsylvania and parts of Maryland (Figure 1.4). Manure produced by the laying hens is spread on the cropland at the poultry farm and on other local farms within 5 miles of the poultry houses. It is

Figure 1. Movement of farm materials to and from a poultry farm in southcentral Pennsylvania.



obvious from this pattern of farm material flow, whether it is feed, eggs or manure, that the nutrient stocks on the farms in Maryland and in Pennsylvania are going to be affected differently.

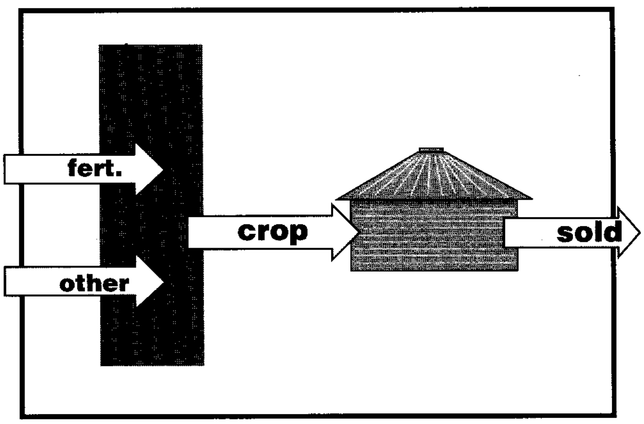
There are many stakeholders in this process. Some are concerned with the physical quantity of the production, whether it is the crop farmers looking for markets, the poultry producers marketing eggs, the retailers depending on an abundant and economical supply of eggs, or the consumers in the grocery stores watching food budgets. Other stakeholders are concerned about the consequences of the production process on environmental quality. These may be neighbors of the poultry farm who are concerned about the possible pollution of groundwater from the accumulation of nutrients in the on-farm nutrient stocks or they may be the environmentalists who are concerned about additions of nutrients to the Chesapeake Bay. The challenge is to balance the production quantity and environmental quality claims of the various stakeholders. This balance is not necessarily straight forward since those who benefit from the production process are not necessarily those who are affected by the environmental impact. Governmental officials may find themselves in the difficult position of reconciling the claims of the different stakeholders who are involved in the same process.

Understanding the pattern of material flow can be useful in identifying or developing approaches to nutrient management while meeting the farm production and/or environmental protection goals of farmers, community residents, and/or governmental officials. Different types of farms have distinctive patterns of material flow.

Cash-crop farm

A modern cash-crop farm is an easy beginning point to visualize patterns of farm material movement to, from, and within a farm and to understand the associated flow of nutrients in the managed pathways (Figure 2).

Figure 2. Movement of farm materials in the managed pathways of a cash-crop farm.



Nutrients come onto a cash-crop farm in the easily recognizable form of fertilizers and other materials that are applied directly to the fields. Harvested crops take a fraction of these nutrients plus nutrients from soil reserves with them when they are transported from the fields. When the crops are sold from the farm, the nutrients contained in the crop also leave the farm. The change in the nutrient stock on a cash-crop farm will be determined by the balance of the inputs of nutrients to the farm fields and the outputs from the fields. The change in stock for the farm will be closely related to the balance of the fertilizer and other nutrient inputs to the fields and the crops ultimately sold from the farm. Tallying the movements in the managed flows can be a starting point for understanding the farm operation. Additional flows such as biological nitrogen fixation or nitrate leaching can be evaluated in the same way if that information is available.

If inadequate nutrients are supplied to replace those removed in the crops, the soil nutrient stock will be depleted. If nutrient applications to the fields build soil reserves in excess of crop nutrient requirements at the field level or by the export of nutrients in products from the farm, the nutrient stocks of the fields *and* on the whole farm increase. But, there are limits to the depletion or accumulation of nutrient stocks. The limits to depletion occur when the soil reserves can no longer support satisfactory crop growth so crop removal of nutrients is reduced or eliminated. Or, the ability of the soil to retain nutrients may be exceeded and the nutrients will actually move through the soil and out of the root zone. These nutrients will be lost from the fields. Nitrogen is more readily lost through Pennsylvania soils than is potassium, and phosphorus is lost through the root zone much less easily than is potassium. Movement of unused nitrogen beyond the root zone is a concern for environmental quality protection.

It is important to remember that cash-crop farms could not be widely distributed before fertilizers were readily available following World War II. (Refer to Agronomy Facts 38-A.) Before that time, the nutrients available to farmers and agriculture were limited and nutrient cycling within agriculture and society was important to maintain the farm nutrient stocks. There are even some reports of declining crop yields early in this century due to the mining of soil nutrient stocks. So, before World War II, building nutrient stocks on a farm was not only uneconomical, it was physically difficult because the nutrients were generally not available to the farmers.

If a nutrient management performance criterion specifies that the flow of plant nutrients should be balanced on a cash-crop farm, the consequences for the farm will depend on the status of the nutrient stocks. If nutrient stocks are low, then for a period of time more inputs than outputs would add to the productivity of the farm by increasing deficient soil stocks and promoting additional plant growth in response. The probability of plant nutrient availability limiting plant growth will be reduced as the stocks are increased. If the nutrient stocks are high relative to the crop needs, then a more closely balanced flow will be more efficient (unit of yield/unit of nutrient supplied) and avoid building stocks beyond the capacity of the soil to retain the nutrients.

On a cash-crop farm, there is a direct connection between the movement of farm materials, the accompanying flow of nutrients, the status of the nutrient stocks on the farm, and the agronomic and economic performance of the farm. Crop output generates the gross returns to the farm and farm profits are determined after the costs of production (including fertilizer costs) are subtracted. As a result, traditional economic and agronomic incentives can be effective in guiding nutrient use on these farms.

Of course, the managed pathways do not illustrate the only paths that nutrients can take. If nutrients are overapplied when abundant nutrients already exist in the soil nutrient stocks, or if nutrients are allowed to be lost from the fields with runoff or leaching water, significant nutrient losses can occur in pathways other than the managed flows. These lost nutrients can cause pollution of ground and/or surface water. If nutrients in the managed flows are not maintaining the soil stocks or if crop growth is limited by nutrient availability, that may be evidence that nutrients are being lost in other ways.

Changes in nutrient management on cash-crop farms made to protect environmental quality will generally promote efficient use of nutrients and reduced additions in fertilizer after the nutrient stocks have been built up. Therefore, the cost of nutrient management to protect environmental quality can be at least partially offset by decreased costs in fertilizer on these farms.

Self-sufficient crop and livestock farm

Traditionally, crop and livestock farms have been seen as producing animals and/or their products from the almost exclusive use of on-farm resources (Figure 3). The pattern of material flow (and the associated plant nutrients) on such a farm clearly contrasts with the material movement on the modern cash-crop farm.

Manure applications returning plant nutrients to the farm fields establish a recycling of those nutrients in this idealized version of the traditional crop and livestock farm. The output of the farm is not crops, but animals and/or animals products.

The potential return of nutrients to the fields in the manure on a traditional crop and livestock farm is always less than the uptake of nutrients in the crops that were harvested and fed to the livestock. Nutrients from the crops are both retained by the animals and lost in the process of manure handling. The existing stock of nutrients in the fields and on the farm is gradually depleted under these conditions of nutrient flow, even with "efficient" recycling of manure nutrients. If the nutrients remaining on the farm in the manure are not efficiently returned to the fields, "mining" of nutrients occurs in the fields and on the farm. So, returning the ever decreasing amount of nutrients to the fields is critical to the productivity of the farm. Even when nutrients are recycled efficiently, the depleted nutrient stocks will be inadequate to maintain production.

Unfortunately the traditional farm has few additional sources of nutrients to replace those "lost" through the removal of animals and/or their products. Biological nitrogen fixation by legume crops is the only significant way to contribute to any of nutrient stocks on the farm using only farm resources. However, this process supplies only one of the nutrients that are essential for crop growth. As the stocks of the other nutrients become deficient for crop growth, even the potential for biological nitrogen fixation is likely to be reduced by the less vigorous growth of the legume plants.

Fertilizers and other inputs can offset the losses of plant nutrients in animal production and manure handling (Figure 4). The possibility of compensating for nutrient losses by the flow of fertilizers to farms has developed rapidly only since World War II. The industrial processes for fertilizer manufacturing and the capacity to transport fertilizers long distances accelerated the use of nutrients in fertilizers in the

Figure 3. Farm material movement in the managed pathways of a "traditional" crop and livestock farm.

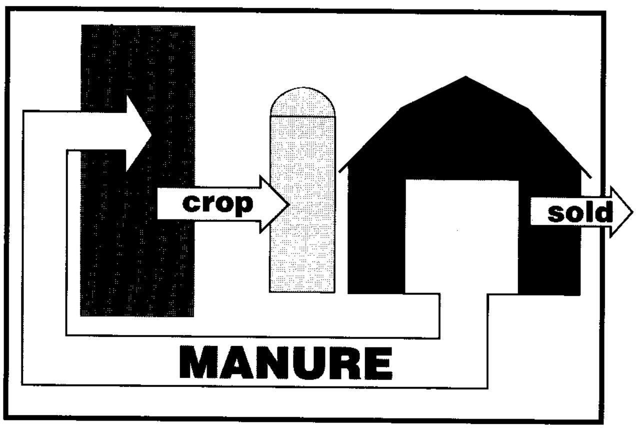
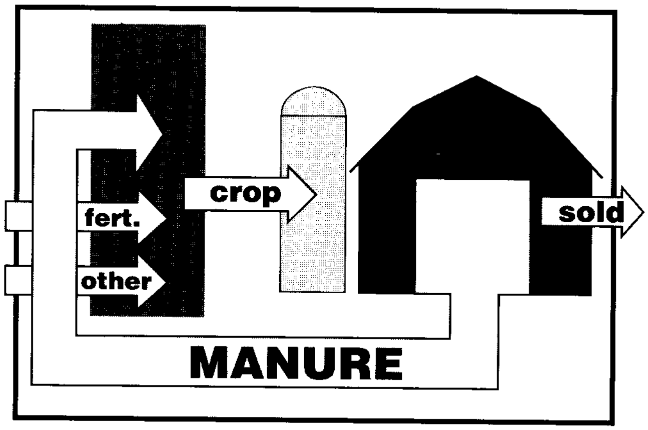


Figure 4. Flow of farm materials on a "traditional" crop and livestock farm that is supplemented by off-farm fertilizers.



United States from only a few hundred thousand tons/yr before 1940 to almost 25 million tons/yr in 1980. Stocks of nutrients in the geologic reserves of phosphorus and potassium and nitrogen in the atmosphere are being tapped in the process of making fertilizer. The nutrients from these previously inaccessible nutrient stocks are being transferred to the stocks of our fields, farms, geographic regions, and jurisdictional areas. They are becoming part of our contemporary landscape processes on a previously unknown scale.

Before the geologic and atmospheric sources of nutrients became available, the stocks of nutrients on many farms had been deficient either because of their origins or their management in the traditional way. Supplemental sources of fertilizer and other plant nutrient inputs to the fields made possible increased crop production under these conditions of deficient nutrient stocks.

Since a crop and livestock farm sells primarily animals and/or their products, neither crop production nor fertilizer use is directly connected to farm output. The production of a marketable farm output also depends on the animal husbandry skills of the farmer, not just success in crop production. On a farm organized this way, the decisions about plant nutrient use are not as sensitive to economic or agronomic criteria in field-level crop production as are decisions on the modern cash-crop farm where the flow of nutrients is directly connected to both the agronomic and the economic performance of the farm. The incentives to manage nutrients for environmental quality protection on these animal production farms may need to be different for managers than on cash-crop farms. Environmental protection incentives are likely to not be complemented by agronomic and economic incentives for crop production alone.

Modern crop and ruminant livestock farm

Since World War II, it has been possible to maintain productive cash-crop farms because the nutrient stocks could be replenished with the flow of nutrients transferred from geologic and atmospheric stocks through fertilizers. The crops produced on these farms are available to livestock producers at other locations where there may not be adequate resources to produce feed for the livestock raised. Under these conditions, farm material movement on a modern crop and livestock farm with ruminant animals such as dairy cows (Figure 5) is more likely to be supplemented with off-farm feeds than is either of the "traditional" crop and livestock farms (Figure 3 or 4). The plant nutrients delivered *to* the farm in feed can offset nutrient losses *from* the farm in the removal of animal products or in the manure handling losses.

Since the additional feed is more closely related to animal management than crop production, more nutrients can be available in the manure produced than can be effectively utilized by the on-farm crop production. Consequently, protecting environmental quality will require explicit management of the additions to the farm nutrient stocks.

The key feature differentiating this type of farm from the traditional farm is that the manure produced by the animals is usually spread on a much smaller fraction of acres than where the crops were produced. Forage crops provide the basic component of the animal ration on these farms, and these are difficult and costly to transport long distances. Therefore, the number of animals supported at any one location is generally related to the ability of the land to produce only forage crops (and use nutrients), instead of producing all of the feed requirements for the animals.

Modern crop and nonruminant livestock farm

Trends in animal housing and in cash-crop farming that produces primarily grain crops have made it possible to concentrate large numbers of nonruminant animals, such as swine and poultry, on small land areas. Since these animals consume rations that are based almost completely on grains, most, if not all, of the feed necessary for these animals can be conveniently and economically transported to the farm where the animals are housed. Even if these modern farms produce crops for sale off-farm (Figure 6),

Figure 5. The potential pathways for farm material movement on a modern crop and livestock farm with primarily ruminant animals.

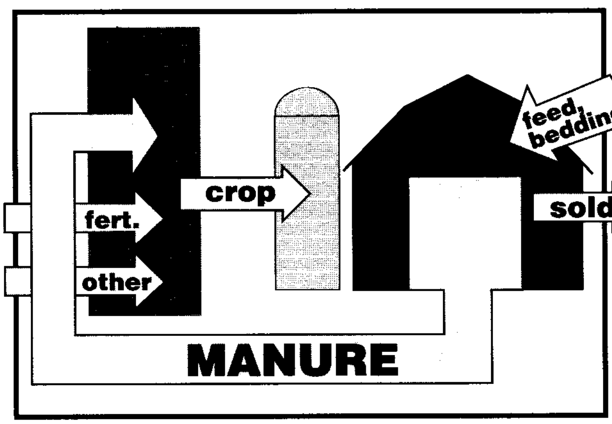
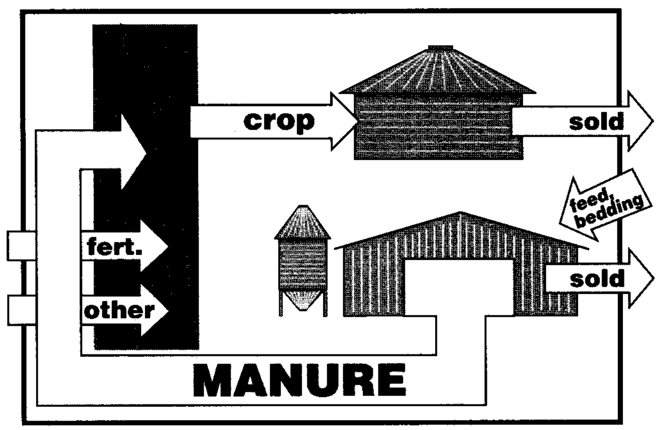


Figure 6. Material movement pathways on a modern crop and livestock farm with primarily nonruminant animals.



the land areas involved in crop production are often quite limited because the focus is on animal production, not crop production.

Nutrients are brought onto a cash-crop farm in proportion to the crop requirements. Feeds are brought onto a modern crop and livestock farm in proportion to the animal needs. A large fraction of the nutrients that animals consume does not remain in the bodies of the animals, nor end up in the products that leave the farm. When the nutrients in the off-farm feeds arrive at the farm, a substantial addition to the farm stock of nutrients can result. Also, the expected return from increased crop production based on nutrient applications to the fields is not closely related to the major production activity of the farm—selling animals or animal products. On the cash-crop farm, economic and agronomic incentives associated with nutrient management are directly related to the performance of the farm. These same incentives to use plant nutrients efficiently will also tend to minimize the potential nonpoint source nutrient pollution from the cash-crop farm.

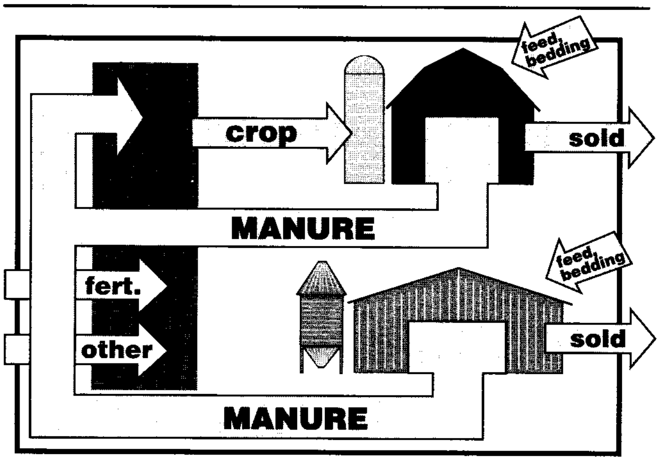
There are likely to be few nutrient management practices that will adequately manage the nutrient stocks on intensive crop and livestock farms to reduce the potential for nutrient pollution. Using nutrients efficiently on a farm that relies heavily on feed inputs can result in increasing nutrient stocks and increasing likelihood of nutrient losses into the environment. The most successful management to meet environmental protection performance criteria will be to transport nutrients from such farms. These requirements for exporting animal manure can conflict with the economic incentives for animal production.

Modern crop and mixed livestock farm

Another modern farm type combines both ruminant and intensive nonruminant livestock production (Figure 7).

Although this farm has some of the characteristics of both modern crop and livestock farms with ruminant or nonruminant animals, the relative balance between the crop and livestock activities will influence the potential nutrient utilization on the farm. The addition of a nonruminant animal enterprise to a primarily ruminant animal-based farm can further reduce the significance of economic and agronomic incentives associated with nutrient utilization in crop production.

Figure 7. Farm material movement in the pathways on a modern crop and livestock farm with both ruminant and nonruminant animals.



Farms with this pattern of organization will usually have adequate land resources for the production of feed for the ruminant animals. In contrast, the feed for the nonruminant animals is most likely to come from off-farm. Plant nutrients in the manure from both animal groups can be applied to the fields that produced the feed for the ruminant animals. These additions can compensate for the losses of nutrients in marketed animals and/or their products and manure handling for both animal groups. The nutrients in the feed purchased for the nonruminant animals can replace nutrient losses as fertilizer might do otherwise. The field and farm stocks of nutrients can be maintained by this flow of nutrients in the animal feed.

These farms are most likely to require substantial off-farm technical support to satisfactorily balance field and farm nutrient flows. This nutrient management support will involve not only planning to balance the manure nutrients with crop utilization potential, but ensuring that crop yields are actually attained (expected yields are the basis for the nutrient applications). The entire range of agronomic factors affecting crop production, plus substantial logistical management effort, will be necessary to maintain crop production while protecting the environment. Fertilizer purchases on these farms will only supplement the other nutrients that are available for crop production on the farm. Agronomic and economic incentives for crop production will have limited effect on the management required to meet environmental protection performance criteria.

CLASSIFICATION OF FARMS FOR NUTRIENT MANAGEMENT ASSISTANCE

A variety of characteristics can be used to classify farms according to the nutrient management considerations and the possible extent of field-based assistance needed to ensure environmental protection while maintaining farm production. Farm size or animal density are two commonly suggested characteristics. The assessment method demonstrated here emphasizes projected changes in the stock of nutrients on farms based on the flow of farm materials for both crop and livestock activities (Figure 8, farm category). The classification scheme assumes that nitrogen is the significant nutrient to be balanced.

Category 1 – The manure available on these farms will generally not be adequate to meet total crop nutrient needs and the purchased nutrients will not maintain the nutrient stocks. These are the traditional, self-sufficient farms or those modern crop and livestock farms with ruminant animals and low levels of purchased fertilizers and feed. An initial assessment of the existing plant nutrient management strategies can be adequate to confirm that environmental protection criteria are being met. A well planned nutrient management program on these farms emphasizing economic and agronomic criteria could be to the farmer's advantage. Nutrient management changes may improve farm profitability.

Category 2 – The manure available on these farms could meet a significant part, if not all, of the nutrient requirements for crop production. These modern crop and livestock farms have ruminant animals and purchase substantial quantities of feed or fertilizer inputs, or they have both ruminant animals and nonruminant animals. Nutrient management changes on these farms may offer potential environmental benefits. It is very likely that intensive management assistance will be needed on these farms to adequately implement the nutrient management plan for crop production and environmental protection.

Category 3 – The manure on these farms generally exceeds the nutrient requirements for crop production. These modern, nonruminant animal farms rely heavily on off-farm inputs for the animals. Nutrient management programming on these farms most likely results in environmental benefits. Only part of the nutrient management program is field-based. A significant component of nutrient management involves off-farm cooperation for acceptable off-farm uses of the excess manure.

Since this is a simplified classification scheme, questions about the classification should be resolved with more comprehensive, specific information. This assessment is not intended as the basis for regulatory action, but as a guide for nutrient management assistance. The classification boundaries based on purchased feeds or animal densities are not the only ones that can be used. Values of the criteria used in the classification are flexible and depend on the intended use of the classification. Individual farms in each category will not necessarily fit all the characteristics listed for the category.

Figure 8. A farm classification scheme for potential nutrient management assistance when environmental quality protection is based on the potential for available soil nitrogen balance.

		FARM CATEGORY		
Nitrogen fertilizer on corn (lb/A)	>150	2	3	3
	50 to 150	1	2	3
	<50	1	2	3
External feed (% total)		<50	50 to 80	>80
Animal density (AU/A manured)		<1.25	1.25 to 2.25	>2.25

The characteristics of each category are summarized in more detail in Table 1. The characteristics reflect the conditions of nutrient flow based on the farm organizational pattern and the amount of land commonly involved in Pennsylvania farm operations of these types. Estimates of nonpoint source pollution potential are based on interpretations of the fertilizer use and manure nutrients that would be available. However, these descriptions are made to suggest the importance of considering the implications of farm management for environmental protection, not to assign responsibility for pollution to these farms.

Possible management considerations for the various categories of farms are listed in Table 2. These considerations can be included in the nutrient management decision-making process in order to adapt the decisions to specific nutrient management conditions on particular farms. The differences between the category 1 and 3 farms (the amount of assistance and the sources of options in order to implement nutrient management for environmental protection), illustrate the connections of off-farm interests to the success of farm nutrient management.

Table 1. Characteristics of farms based on the potential for available soil nitrogen balance.

	FARM CATEGORY		
ASSESSMENT	1	2	3
Feed source (% off-farm)*	On-farm (<50%)	Combination (50-80%)	Off-farm (>80%)
Animal density (Animal units/ acre routinely manured)	Low (<1.25/A)	Medium to high (1.25-2.25/A)	Very high (>2.25/A)
Nitrogen fertilizer use (lb/A on corn)	Low to moderate (<50 to 150)	Low to high (<50 to >150)	Low to high (<50 to >150)

*Feed purchased or grown on land that is not routinely manured.

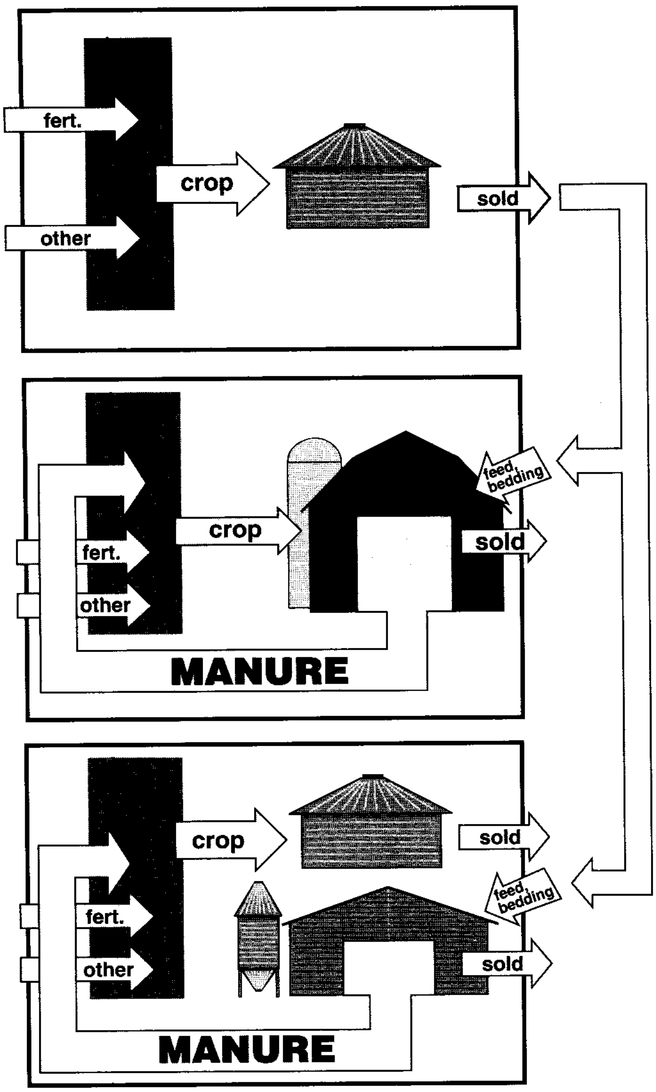
Table 2. Management considerations for environmental quality protection for farms when management is based on the potential for available soil nitrogen balance.

	FARM CATEGORY		
MANAGEMENT CONSIDERATION	1	2	3
Land for manure spreading	Adequate	Limited	Inadequate
Manure nutrient balance	Deficit	Balanced	Excess
Nonpoint source pollution potential	Low	Low to High	Very high
Assistance required for:			
Field-by-field nutrient management planning	Low to moderate	Moderate to high	Low
Nutrient management implementation	Low to moderate	Moderate to high	High
Source of nutrient management options	On-farm	On-farm	Off-farm
Manure management strategy	On-farm efficiency	On-farm high utilization	Off-farm excess distribution
Economics of manure management	+	+ or –	–

FARM EVOLUTION

Assessing the pattern of farm material movement on a farm is a first step in understanding the prevailing nutrient management conditions. But, Pennsylvania farms are not static and unchanging. Many of the decisions that determine the changes on a particular farm are influenced by the changes occurring on farms in other locations and in the boardrooms of industry. Specialization of agricultural production in areas of cash-crop production and areas of animal production have evolved together. The farms in these two quite different production regions are actually connected by the flow of crops as feed from one to the other (Figure 9). As conditions change to make both of these farms technically feasible and economically competitive and the transportation of commodities long distances practical, the farms will continue to change. Nutrient management for crop production and environmental protection must be flexible enough to adapt to the changes that are prompted by other incentives for farm performance.

Figure 9. Farms that produce cash crops are often connected with livestock-based farms through the transfer of crops as feed.



If nutrient management to protect environmental quality is to become a significant issue in the operation of Pennsylvania farms, the evolution of farms must be understood. Not only is this necessary to manage the expansion of existing operations, it reflects a concern for the intensification of animal-based agriculture in all parts of the state.

SUMMARY

Managing farm material movement is not simply a question of balancing nutrients on a farm in the upcoming growing season. It requires a long-term planning horizon for farmers and for others who are affected by the economic vigor of Pennsylvania agriculture. These considerations must become part of the issue of nutrient management for crop production *and* environmental protection when performance criteria are developed.

This fact sheet is one of a set of three dealing with nutrient management. The other titles are: Agronomy Facts 38-A, *Introduction to the Concepts;* and Agronomy Facts 38-C, *Nutrient Management Decision-Making.* These fact sheets are available from the Publications Distribution Center, 112 Agricultural Administration Building, University Park, PA 16802-2602.

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