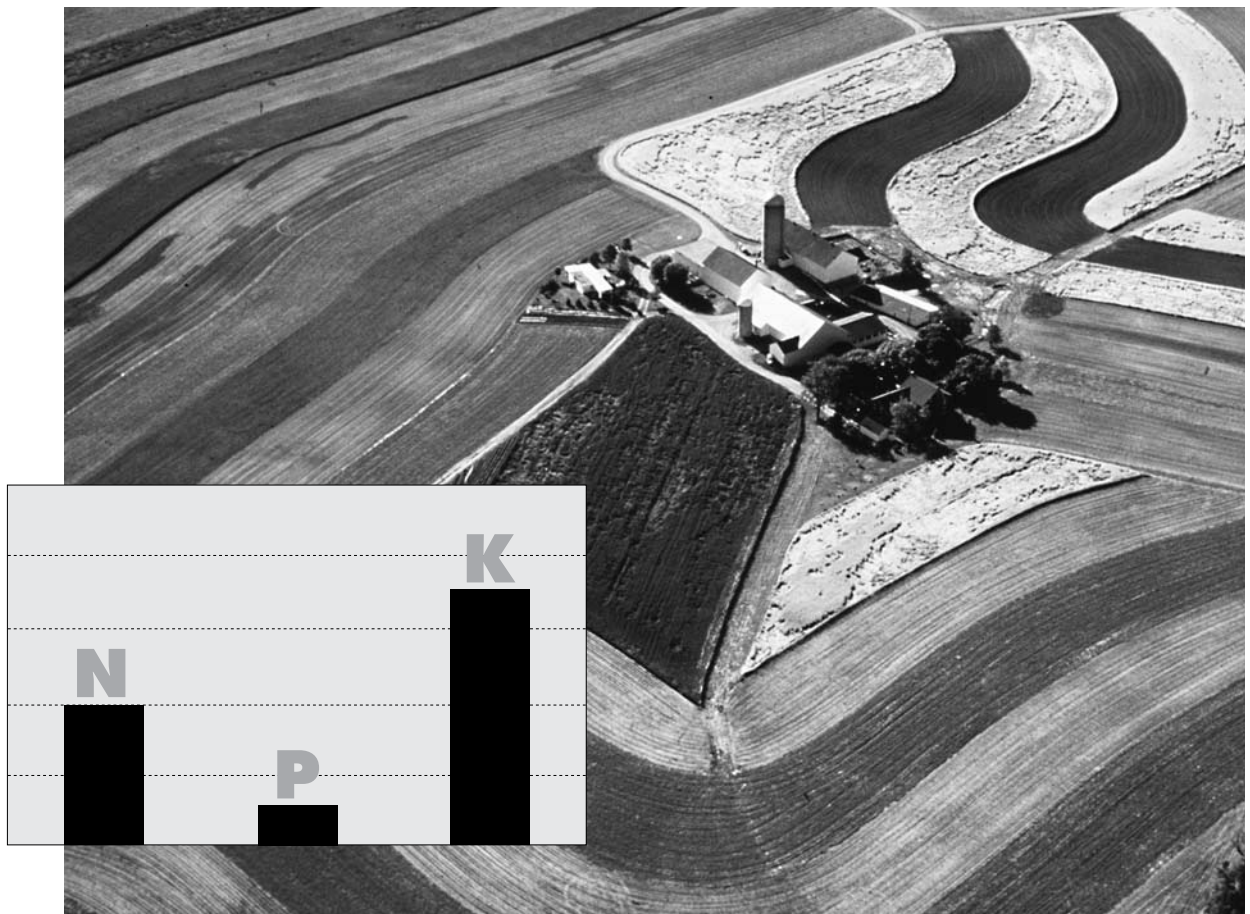




NUTRIENT BUDGETS FOR PENNSYLVANIA CROPLAND

WHAT DO THEY REVEAL AND
HOW CAN THEY BE USED?



Introduction

Every year in a number of areas in Pennsylvania, farmers are faced with the challenge of managing manure on their operations. In today's agricultural system, feed and fertilizer are often transported across state and regional boundaries to the farms where they are used. As a result, nutrients in locally produced manure may exceed local crop requirements in some areas. The challenge of managing manure in these areas is to recover manure's valuable nutrients while minimizing adverse environmental impacts. Nutrients that are not used by crops or stored in the soil can degrade the quality of groundwater, local lakes and streams, and regional water resources such as the Chesapeake Bay.

To address the environmental impacts of excess nutrients, significant long-term changes need to be made to our current agricultural system. Some alternatives may include reducing the nutrient content of manure, transporting manure to where it can be used most efficiently, and redirecting future growth in animal agriculture through land-use planning. Diverse interest groups need to devise new and creative solutions to this problem.

To encourage and facilitate dialogue, nutrient budgets have been developed by Mid-Atlantic Regional Water Program—a partnership between land-grant universities in Delaware, Maryland, Pennsylvania, Virginia, and West Virginia and USDA's Cooperative State Research, Education, and Extension Service (CSREES)—to quantify the magnitude and sources of excess nutrients that are being generated and applied throughout Pennsylvania.

Excess Nutrients: How They Got Here

Prior to World War II, a balance of crops and animals was maintained on farms. Transportation and storage systems were less developed then, so the nutrients that crops and animals needed to grow had to be available from local sources. Locally grown crops were used for animal feed, and people consumed locally raised animals and animal products. Since fertilizer availability was limited, manure was a valuable resource to replenish nutrients that were removed when harvesting crops. Nutrients were cycled between crops and animals within a relatively small geographic area, such as a farm or county.

Technological advances that enabled the conversion of nitrogen (N) in the atmosphere to a form usable by plants initiated significant changes in our agricultural system. N, combined with phosphorus (P) and potassium (K) from geologic deposits, produces fertilizers that can supply the primary nutrient needs of crops. The increased availability of commercial fertilizers following World War II meant that farmers no longer had to rely solely on manure to supply nutrients to their crops. Fertilizer availability, along with changes in animal feeding, allowed some farmers to focus on animal production and others to focus on crop production. Specialization and trade that were occurring in other industries also encouraged specialization in agriculture, such as the development of the U.S. soybean oil industry. Changes in tariffs and regulations dramatically increased soybean oil production, which resulted in an increase in the production of soybeans and also created an alternative protein source (soybean oil meal) for animal feed. Crop and animal farms began to be geographically separated and, as a result, nutrients in feed and

fertilizer began being transported over greater distances.

Today, nutrients are often transported across state, regional, and even national boundaries. Fertilizers are transported to sustain farms specializing in crop production, which are common in the upper Midwest. In 2002, Illinois, Indiana, Iowa, and Minnesota accounted for more than one-quarter of total U.S. fertilizer consumption. Feed produced from farms in these areas is transported to regions of the country that specialize in animal production (the Northeast, Mid-Atlantic, Southeast, South-Central, and Great Plains regions).

Some of the feed nutrients imported to animal operations are, in turn, exported from the animal operations to other areas in the form of animal products. However, many of these imported nutrients are excreted in manure and remain near animal production facilities. Consequently, nutrients are moving over a larger area but are no longer cycling as they were prior to World War II. Instead, the nutrient cycle has become fragmented due to the geographic separation of crop and animal production. As a result, in areas with extensive animal production, such as southeastern and south-central Pennsylvania, manure nutrients can exceed local crops' needs.

Why Are Excess Nutrients a Problem?

Nutrients that are not used by crops or stored in the soil can travel in stormwater runoff to lakes and streams or through soil to groundwater. Excess nutrients, particularly P in lakes and streams and N in estuaries such as the Chesapeake Bay, can cause algae growth. The growth and decay of algae consumes oxygen, which degrades water quality for human use, aquatic plants, and animal life. Algae growth also blocks sunlight

from subaquatic vegetation, which is essential for both oxygen production and use as wildlife habitat. Excess N in groundwater can degrade drinking water quality, leading to health risks for certain population groups.

What Is a Nutrient Budget?

A nutrient budget is an accounting system for nutrients. It is similar to a financial budget, except a nutrient budget is calculated in pounds of nutrients rather than dollars and cents. In a financial budget, monetary inputs (income) and outputs (expenses) for an account are calculated. In an agricultural nutrient budget, nutrient inputs (such as land-applied manure and fertilizer) and outputs (such as harvested crops) are calculated for the cropland within a geographic region. The geographic region can be as small as a single field or as large as a multistate area, such as the Chesapeake Bay Watershed.

What Does “Nutrient Balance” Mean?

The balance of a bank account is the difference between monetary inputs and outputs. Similarly, a nutrient balance is the difference between annual nutrient inputs and outputs in a cropland (Figure 1). A negative nutrient balance (or deficit) occurs when more nutrients

are removed from a cropland than are supplied by land-applied nutrients each year. A positive nutrient balance (or surplus) occurs when more nutrients are added to a cropland than are removed each year. Unlike a positive bank account balance, a positive nutrient balance can be undesirable due to the potential loss of excess nutrients to the environment.

Continued nutrient surpluses or deficits indicate potential problems both on and off the farm. If surpluses occur year after year, nutrients accumulate in the soil and the potential for nutrient loss to the environment increases. Continued deficits deplete soil nutrients, and the remaining nutrients may no longer support potential crop production.

Why Do Farms Have Nutrient Surpluses?

Farmers specializing in crop production have an economic incentive to conserve nutrients (i.e., to closely match nutrient inputs and outputs and maintain a nutrient balance). A nutrient deficit will result in declining crop yields over time, while a nutrient surplus is likely to cause unnecessary fertilizer expenditures. In practice, however, overapplication of fertilizers can occur even when a farm has to purchase all of its nutrients. For example, a farmer typically applies fertilizer according to the crop requirements for a high-yield goal. The more common, undesirable growing season can result in lower yields and surplus nutrients.

For farmers who specialize in animal production, it may be more economical to purchase feed produced elsewhere and maintain a smaller area of land than would be needed to grow feed for their animals. While this approach is likely to create farm-level nutrient surpluses, the consequences of

these surpluses may only appear as off-farm impacts such as water-quality problems. Thus, the farmer may have no direct economic incentive, except those imposed by environmental regulations, to prevent farm-level nutrient surpluses from occurring. The land and community stewardship mindset of the majority of the farm community also provides an incentive to manage this nutrient surplus, even though addressing this issue may cost farmers financially.

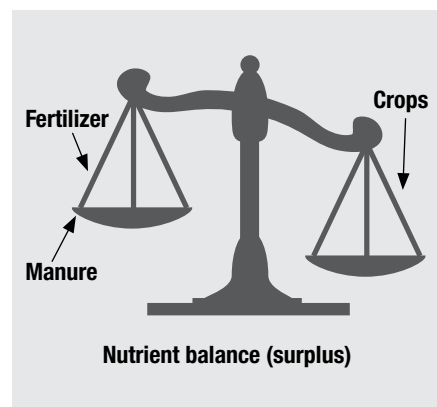
Why Develop Regional Nutrient Budgets?

When large regions (multicounty or multistate areas) specialize in high-density animal production, regional nutrient surpluses are likely to occur. Regional nutrient surpluses are problematic because they are indicators of potential negative environmental impacts, such as the degradation of surface and groundwater. Farm-level efforts to prevent nutrient losses to the environment are important. However, to solve long-term nutrient surplus problems, efforts to balance the nutrient inputs and outputs to a cropland area are needed. Nutrient budgets reveal the magnitude and sources of nutrient surpluses and can be used to devise strategies to reduce them. Over time, regional nutrient budgets can also be used to monitor the effectiveness of strategies that have been implemented.

How Were These Budgets Developed?

As part of the Mid-Atlantic Regional Water Program, nutrient budgets are being developed for Pennsylvania croplands at the state and county levels (see P Budget Assumptions and Limitations, p. 8). These budgets cover a period of rapid agricultural transformation from pre-World War II to the present. They are based on readily available data primarily from the U.S. Census

FIGURE 1. NUTRIENT BALANCE FOR CROPLAND.



of Agriculture and fertilizer sales reports.

P budgets were developed first because of the simplicity of the P cycle compared to the N cycle. These budgets include the major P inputs (manure and fertilizer) and outputs (crop removal). The Census of Agriculture and fertilizer sales information could also be used to develop N budgets for Pennsylvania and its counties, which will likely be done in the future. A first estimate of an N budget would be to consider the same cropland flows as for P. While the numbers would be different, trends are likely to be similar since both manure N and P production and crop N and P removal would be proportional to the number of animals and crop yields. However, due to the complexity of the N cycle, such N budgets would have more limitations than P budgets based on the same flows.

What Do the P Budgets Reveal?

Fertilizer P use in Pennsylvania generally increased from 1939 to 1978 but has decreased over the last 25 years (Figure 2). Historically, an agronomic approach to soil P management encouraged applications in excess of crop removal to reduce yield-limiting soil P deficiencies. Recent soil-test results from the Penn State Agricultural Analytical Services Laboratory indicate that, on average, the agronomic threshold for the soil stock of P (30–50 ppm) has been achieved in Pennsylvania (Figure 3). On average, fertilizer P applications in excess of crop removal are no longer necessary in most areas, especially in southeastern and south-central Pennsylvania. In addition, educational programs focusing on soil fertility issues, fertilizer costs, energy prices, and concerns about water quality may have contributed to reductions in

FIGURE 2. PHOSPHORUS INPUT TO PENNSYLVANIA CROPLAND.

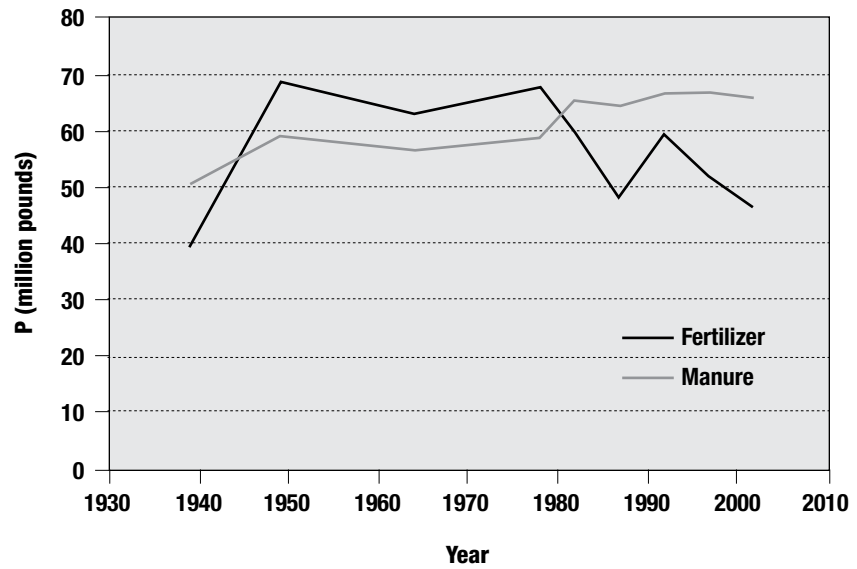
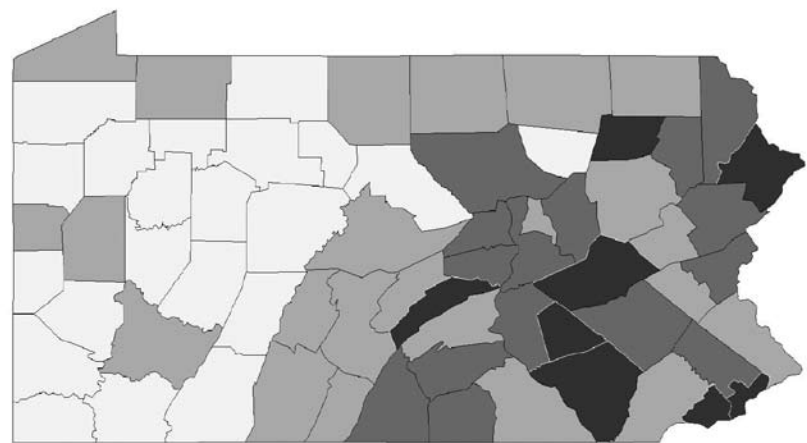


FIGURE 3. AVERAGE SOIL TEST P FOR PENNSYLVANIA COUNTIES BASED ON SAMPLES ANALYZED IN 2002.



Average Soil Test P (ppm)

- < 50
- 50–75
- 75–100
- > 100

State Average = 79 ppm

Based on agronomic samples test in 2002 using the Mehlich 3 test. Optimum level for crop production is 30–50 ppm.

Source: Penn State Agricultural Analytical Services Laboratory

fertilizer P use over the last 25 years.

Overall, P inputs to croplands have been declining slightly since peaking in the 1950s (Figure 4). Manure P in Pennsylvania increased an average of 124 tons per year since 1939 (see Figure 2). These increases were mostly due to increases in poultry and hog production. However, these changes were outweighed by the larger decrease in fertilizer application throughout the state, resulting in a net decrease in P inputs since 1949 (see input line, Figure 4).

The P removed annually by harvested crops increased from 1939 to 1982, then remained relatively stable (see output line, Figure 4). These changes were primarily due to yield increases and shifts in the crops grown in the census years measured. Since 1939, the number of harvested corn and soybean acres increased, while the number of harvested small grain acres decreased. In 2002, yields were very low due to drought, so the apparent larger decrease in crop P removal probably does not represent a true trend.

Nearly twice as much P is applied to Pennsylvania croplands in manure and fertilizer than is removed in harvested crops. In 1992, 1997, and 2002, P inputs to Pennsylvania croplands were between 1.7 and 1.8 times more than P removed in harvested crops. In Figure 4, the difference between the inputs (P applied) and outputs (P removed) trend lines represents the state-level P surplus.

Annual P surpluses for Pennsylvania croplands peaked in 1949, decreased until 1978, and have generally stabilized over the last 25 years (Figure 5). Decreases in P surpluses from 1949 to 1978 were due to the combination of decreases in fertilizer sales and increases in crop P removal. Relatively stable P surpluses over the last 25 years resulted from decreases in

FIGURE 4. P INPUTS AND OUTPUTS TO PENNSYLVANIA CROPLAND.

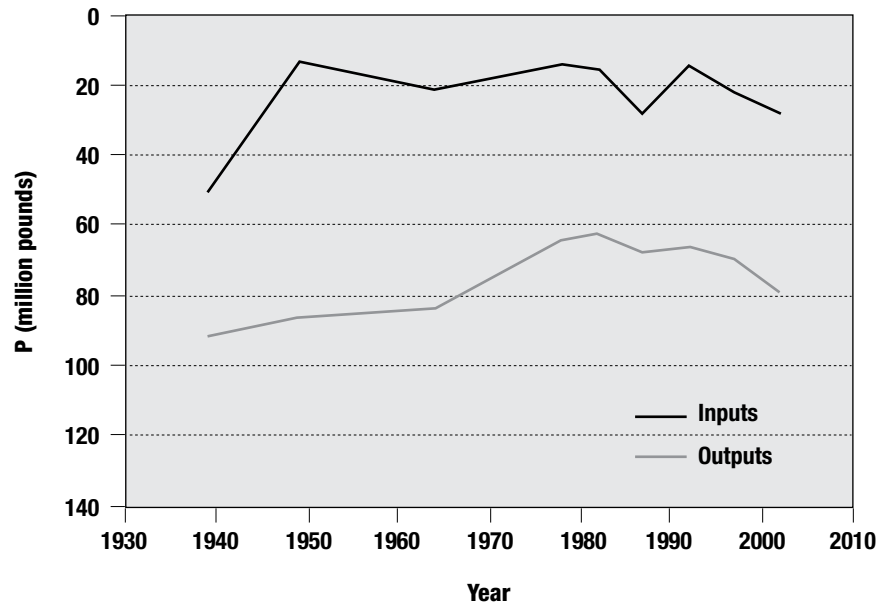
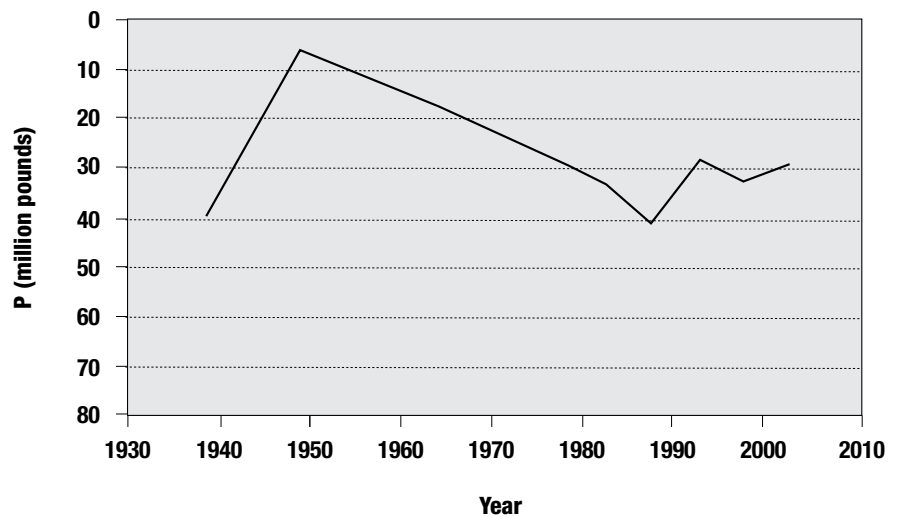


FIGURE 5. P BALANCES FOR PENNSYLVANIA CROPLAND.



fertilizer use being partially offset by increases in manure production. Since cropland area declined by approximately 33 percent in this period from a high in 1939, P excesses per area of cropland increased from 7.3 pounds per acre (16.8 pounds P_2O_5/A) in 1939 to 12.6 pounds per acre (29.0 pounds P_2O_5/A) in 2002.

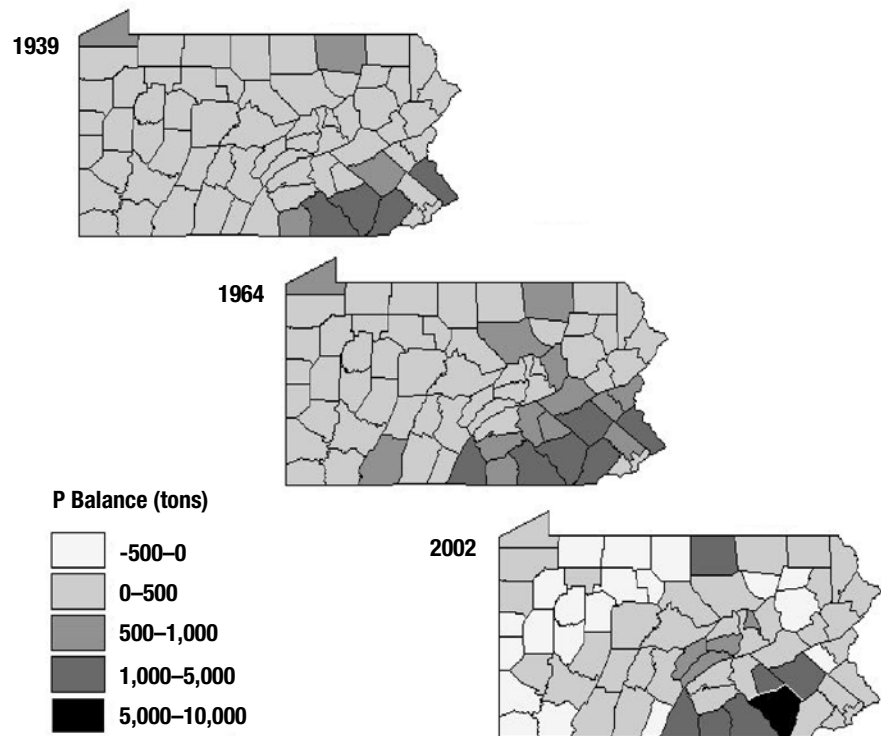
Although the state-level annual P surplus has been decreasing since 1949, the remaining surplus is concentrated in a smaller area. Annual surpluses have been decreasing in some counties since 1964, similar to state-level trends (Figure 6). However, in several counties in southeastern Pennsylvania where poultry and livestock production have intensified since 1939, annual surpluses have generally increased over this period. In 2002, only five counties accounted for over 50 percent of the surplus P for the state. By comparison, fourteen counties accounted for over 50 percent of the surplus P for the state in 1939.

How Can Nutrient Surpluses Be Reduced?

Nutrient budgets do not reveal how to reduce nutrient surpluses. They are tools that can facilitate the discussion of possible solutions by helping to frame the problem in an historical and spatial context. Nutrient budgets can be used to quantify the potential impact of any proposed strategy and to track the impact of strategies that are implemented.

Below are examples of strategies that could be used to reduce nutrient surpluses. The first two strategies—diet modification and manure transportation—are already applied in Pennsylvania. However, as noted below, the P budgets suggest that the degree of implementation of these strategies has not yet been sufficient to reduce

FIGURE 6. P BALANCES FOR CROPLAND IN PENNSYLVANIA COUNTIES, 1939, 1964, AND 2002.



P surpluses significantly in recent years. Further implementation of these strategies, along with others, is needed to dramatically reduce P surpluses.

Discussion of the benefits and costs of these strategies is included only to illustrate the challenge at hand, not to advocate any particular solution. Reducing nutrient surpluses will require cooperation of a diverse group of stakeholders including farmers, fertilizer and feed industries, environmental organizations, and government agencies. These example strategies are meant to illustrate how nutrient budgets can be used to evaluate the potential impact of strategies in reducing nutrient surpluses. In addition, they are meant to stimulate thinking and discussion among these and other groups about new and creative ways to address this issue.

Manure P Reduction

Technology and experience can be used to modify animals' diets, making P in feed more digestible and better matched to an animal's nutrient requirements. Such dietary modifications allow for more efficient use of P in animal feed, which reduces the amount of nutrients wasted (excreted in manure). One example is phytase, an enzyme that makes P in feed more available to poultry and swine, which reduces P concentrations in manure. Because phytase is economical, it has already been widely adopted in the poultry and swine industry. According to the 2004 Chesapeake Bay Commission report *Cost-Effective Strategies for the Bay*, phytase use decreased P concentrations in poultry litter by 16 percent in recent years. The same report suggests that other dietary changes could result in a 30 to 40 percent total reduction

in P excreted by poultry (compared to prephytase levels).

Adjusting dairy rations is far more complex than hog and poultry diets. Hog and poultry diets are very close to their nutrient needs largely because these industries are highly concentrated. All hogs or poultry in a barn are typically at the same stage in the life cycle with virtually identical nutrient needs; their rations are precisely developed and adjusted to meet these needs. However, a dairy farm usually has calves, heifers, and cows in all stages of growth, lactation, and pregnancy, which causes wide fluctuations in their nutrient needs in order to maintain health and production. Also, a dairy farm often uses hay and silage grown on the farm, with large variations in quality and nutrient content due to differences in soil, weather when harvesting, and storage conditions. So, much more intensive technical assistance, including laboratory analyses of feeds, manure, and milk, is needed to help reduce excess nutrients in dairy cows' diets.

Nutrient budgets can be used to estimate the impact of dietary modifications. For example, reducing poultry manure P excreted in 2002 by 40 percent would have reduced Pennsylvania's P surplus from 61.6 to 55 million pounds. Therefore, even if the potential for dietary strategies in the poultry industry were completely accomplished, this change alone would only reduce Pennsylvania's P surplus by about 10 percent. However, the P budgets also indicate that in 2002 more than 50 percent of manure P in Pennsylvania was produced by cattle and calves. Thus, although more challenging to implement, dietary modifications for these livestock may offer significant opportunities to further reduce P surpluses.

Manure Transportation

Phosphorus surpluses could be reduced by transporting manure to areas where it is needed as fertilizer. It is critical to ensure that manure application at the receiving site does not create an environmental threat. Raw manure can be transported and applied to croplands directly. Manure can also be converted to a more manageable form, such as through composting, digesting, or burning for energy production. P may be altered through manure treatment processes but is generally conserved, so the initial amount still needs to be managed, typically by applying it to croplands. Thus, manure treatment is a way to make manure easier to transport and apply appropriately; however, it is not a strategy for reducing the total amount of P that must be managed. Unlike P, N is more active, and changes and losses of N to the environment (particularly when it's in its gaseous form) can occur during storage, treatment, and application. Significant losses of gaseous N can be a potential threat to air quality.

Taxes are a potential tool for increasing manure transportation. For example, a fertilizer tax could be used to make manure a more competitive nutrient source, which would make manure transportation more economical. A sales tax on animal products could also be used to provide resources for manure transportation.

All variations of manure transportation strategies to reduce P surpluses are likely to have significant costs; thus, they will require a significant financial commitment by Pennsylvanians. There may be a limit beyond which the benefits of transporting additional manure do not justify its costs. Nutrient budgets will assist in economic analyses of manure transportation strategies by quantifying potential P surplus reductions of a proposed strategy

and the associated benefits and costs associated with it.

Some manure transport is already occurring, including manure imports from Maryland and Delaware, due to transportation subsidies in these states (Maryland Department of Agriculture). These nutrient flows were not accounted for in these budgets because data to document such transportation is not readily available. At a state level, though, Pennsylvania alone produces almost enough P in manure to supply its crops' nutrient requirements, yet nearly as much P is still sold in fertilizer. These data suggest that increasing manure transportation could reduce the need for commercial fertilizer applications, thereby reducing P surpluses.

Redirecting Growth

Another option is to consider gradual changes to the modern agricultural system that is driving P surpluses. Animal agriculture has become increasingly concentrated in southeastern Pennsylvania over the last 60 years. If this trend continues without added nutrient reduction technologies, it may become more and more difficult to manage manure so that it does not negatively impact water quality in this area of the state. While the location of animal agriculture in Pennsylvania is not going to change over night, agricultural policies and planning could consider changing the locations of animal production facilities over a longer term.

Nutrient budgets indicate the areas of the state where P has been accumulating in the soil for decades and other areas where P accumulation is much less of a problem. This information could be used to discourage new animal operations from locating in areas with the greatest surpluses. Likewise, new animal production facilities could

be encouraged to locate in areas where croplands exist that could use manure nutrients to replace chemical fertilizers.

There are a variety of ways to redirect growth in animal production facilities in Pennsylvania. Taxes on feed based on the distance it has to be transported would encourage new production facilities to locate in areas where both locally produced feed and livestock manure for crop fertilization are available. Another option is to increase the responsibility of integrators (financially and legally) for managing the manure produced in their animal production facilities. This would encourage integrators to locate new production facilities in areas where there are sufficient croplands to utilize additional manure.

While relocating animals could ultimately lower costs of manure treatment and transportation, it may incur other types of costs. Concentrating animals in one region of the state may be more economically efficient because supporting activities (such as feed delivery and veterinary services) are more accessible to producers. Changing to a system where agriculture is more evenly distributed throughout the state may increase production and transportation costs, which would ultimately increase the market prices of these products. If other states do not enact similar policies, this could make it difficult for Pennsylvania's agricultural products to compete with those produced elsewhere. Such a strategy may be very challenging for one state to implement without a regional or national commitment for redistributing animal agriculture to reduce P surpluses. As part of the Mid-Atlantic Regional Water Quality Program (<http://www.mawaterquality.org/>), similar methods are being used to develop nutrient

P Budget Assumptions and Limitations

The P balance for the state or a county is calculated as follows:

$$P \text{ balance} = \text{Manure P} + \text{Fertilizer P} - \text{Crop P}$$

Manure P is calculated from census animal numbers (U.S. Department of Commerce, various years; U.S. Department of Agriculture, 1999 and 2004) for each major livestock and poultry species and standard rates of P excretion reported in *The Penn State Agronomy Guide* (1997, 1998, 2004). P excretion totals for each species were then multiplied by a recoverable fraction that represents P losses in storage and handling (Lander et al., 1998; Van Dyne and Gilbertson, 1978). This report assumes that manure is not imported or exported from the area being assessed, as there is no data available to allow us to determine the movement of manure into and out of these areas.

Fertilizer P is primarily calculated from reports published by the Pennsylvania Department of Agriculture (Pennsylvania Department of Agriculture, various years). For 1939 and 1949, other sources were used (Mehring et al., 1940; USDA, 1966; National Fertilizer Association, 1942; and U.S. Department of Commerce, 1956). These numbers represent the amounts of fertilizer sold in each of Pennsylvania's county. Unfortunately, using the available data, there is no easy way to determine how much is sold in one county but used in another county. Also, estimates of farm versus non-farm fertilizer use are not available at the county level.

Crop P is calculated from yields reported for each of the major agronomic crops reported in the census (U.S. Department of Commerce, various years; U.S. Department of Agriculture, 1999 and 2004) and P removal rates reported in *The Penn State Agronomy Guide* (1998, 1999, 2004). Following is a list of the major limitations associated with these nutrient budgets:

- Nutrient flows for nonagricultural areas and pastureland were not considered.
- Manure and fertilizer transfers across state and county boundaries were not considered. (Such transfers have not been historically well documented, but that may change.)
- Fertilizer data include fertilizer sold for both farm and nonfarm use.
- Applications of biosolids to croplands were not considered. Biosolids are nutrient-rich organic wastes derived from sewage sludge or residential septage that have been processed so they are suitable for land application (Department of Environmental Protection, 2006). Adding biosolid applications to the budgets could increase P surpluses, particularly in counties surrounding metropolitan areas.
- In some cases, animal or crop data were not published in the *U.S. Census of Agriculture* to avoid disclosure of information about individual operators. Undisclosed data were counted as zeros in budget calculations, which may result in underestimations of manure P production or crop P removal.
- Manure and crop P coefficients were assumed to be uniform for all farms in Pennsylvania in all years.
- Each year's nutrient budget is a snapshot that is not necessarily representative of subsequent years. Weather-related variations of year-to-year crop yields (which affect nutrient budgets) were not considered because developing multiyear yield averages requires the use of additional data sources.

More information on methods (including data tables), assumptions, and limitations is available at <http://mawaterquality.agecon.vt.edu/>

budgets in Delaware, Maryland, West Virginia, and Virginia. These regional nutrient budgets can be used to facilitate discussions about regional strategies for addressing P surpluses.

Redirecting growth in animal agriculture will mitigate negative environmental impacts in areas with the greatest P surpluses. However, this strategy will only be effective if it results in feed produced within the state replacing feed imported from outside the state and manure applications replacing fertilizer applications. In other words, the overall impact of this strategy needs to be that more nutrients cycle between crops and animals within a relatively small geographic area. Otherwise, redirecting growth in animal agriculture will simply result in redistributing the state-level P surplus across Pennsylvania, and over time, the soil stock of P will build up in other areas.

How Are Nutrient Problems Currently Being Addressed?

Currently, in many states, including Pennsylvania, nutrient problems are first being addressed as management problems. Thus, approaches promoting changes in management, such as regulation, education, technical assistance, cost share, etc., are the main focus. However, these approaches do not address the problem of nutrient imbalance as documented by the nutrient budgets for the state. Pennsylvania is unique in that it is the only state that recognizes nutrient balance as an important issue by targeting high density, concentrated animal operations in its state nutrient management regulations. (For information on Act 38 of 2005, known as the Agricultural, Community, and Rural Environment ACRE program, see the Penn State Cooperative Extension fact sheet *Questions and Answers*

about the ACRE Program or Nutrient Management Legislation in Pennsylvania: A Summary of the New Regulations (see Further Reading, p. 10).

While strategically targeting operations that are most likely to have an excess of nutrients is a good start, many of the tactical approaches being used in Pennsylvania are still targeting management changes, not nutrient imbalances.

As an example, Pennsylvania has developed a P Index, which is a tool for estimating the risk of P loss in runoff from agricultural fields. Under the Pennsylvania Nutrient Management Act, P Index calculations are required as part of nutrient management plans. The P Index allows users to determine when manure can be applied—based on N levels—with minimal potential for P loss in runoff even though excess P will be applied with this approach. The P Index is a useful tool for managing the immediate environmental risk from excess P application on a field. However, it does not address the underlying nutrient imbalance and often allows the imbalance to increase as long as it does not result in an unacceptable risk of P loss to the environment. At some point in the future, though, because of the accumulated excess of nutrients, it will become more and more difficult to land-apply manure in ways that do not negatively impact water quality. This will increase the number of acres where manure application is either restricted or prohibited based on P Index management guidelines. Therefore, the P Index alone will not solve the nutrient problems. However, if this approach is coupled with an understanding of the root cause of the problem—nutrient imbalance—it can provide environmental protection during the time we will need to develop better solutions for and transition to a more sustainable nutrient balance on farms.

Conclusion

Nutrient budgets present a unique perspective on the nutrient management problems we face. These budgets do not in themselves provide a solution to the problems. However, nutrient budgets can help us understand the fundamental reasons for the problems we face. This should provide a better context for developing solutions that will effectively address the problem. To develop an effective strategy for this problem, dialogue among diverse interest groups is needed. These discussions will generate additional ideas and encourage participants to evaluate the benefits and costs of all proposed solutions. Such analysis may reveal that the ideal strategy is composed of a combination of approaches including manure P reduction, manure transportation, redirecting growth, and others. For example, some dietary strategies may be cost effective yet only result in moderate reductions in nutrient surpluses. But, in sequence with other strategies, dietary strategies may result in significant nutrient surplus reductions.

Nutrient budgets add value to existing data on animal numbers and crop yields by converting these data to nutrient inputs and outputs to croplands. This makes quantifying the magnitude and sources of the nutrient surplus possible. Such information is essential to productive discussions of strategies for addressing this issue. When combined with other information, nutrient budgets can play a vital role in devising strategies for reducing nutrient surpluses. In addition, if the budgets are maintained over time, they can serve as an environmental indicator and a means for monitoring and measuring the impact of strategies that are adopted.

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