Nutrient Cycling and Attempts to Reduce Nutrient Losses from Farms in Maryland

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Take Home Messages

- Nutrient management regulations are increasingly focused on mandating nutrient management plans and preventing runoff from manure storage and animal holding areas.
- Although most regulations have focused on manure management and fertilizer application, the most cost effective means to reduce nutrient pollution and comply with regulations is to improve production per cow and feed closer to requirements.
- Phosphorus-based nutrient management, as mandated in Maryland and on large farms in the USA, will require a greater land base for manure application, exportation of manure, a reduction in herd size, and/or reduced feeding of phosphorus.
- Water and air quality regulations will get more and more strident until agriculture no longer contributes substantially to water and air pollution. Ineffective regulations will only lead to more strident, but not necessarily more effective, regulations.

Introduction

The Chesapeake Bay is one of Maryland's most treasured natural resources. It has long been recognized that the Bay is suffering from over-fertilization with nitrogen (N) and phosphorus (P), or eutrophication, which results in excessive growth of algae. The algae block sunlight from getting to underwater grasses that protect small aquatic creatures, and decaying algae use oxygen and produce carbon dioxide reducing water oxygen concentrations. Thus, excessive nutrients degrade the environment for growth and reproduction of a number of aquatic organisms including the fish that support Maryland's seafood and tourism industries.

There are many contributing sources of nutrients that flow into the Chesapeake Bay. These include sewage treatment facilities, septic systems and agricultural losses. Attention has been focused on all of these sources of nutrients, but with increasing housing development on our shorelines, and an increasing demand for agricultural production, little progress has been made with regard to reducing nutrient losses to water. The programs directed toward agriculture had been voluntary, and focused on nitrogen management. Farmers were encouraged to participate by using cost-sharing incentives sponsored by the State and Federal governments. But, after the summer of 1997, the voluntary nature of nutrient management was about to change.

▪ The Mysterious Microbe

Environmentalists and an increasing number of Maryland residents were frustrated with the lack of progress on improving the Bay's water quality. Then in the summer of 1997, an outbreak of a toxic microbe appeared in one of the main tributaries to the Chesapeake Bay (Hughes et al. 1997). The microscopic organism was called Pfiesteria. It had several different life forms and some of them were toxic to fish and humans. Dead fish with lesions began to appear in the Pocomoke River. The toxin produced by Pfiesteria was known to cause short-term memory loss and irritability in humans so the Governor closed access to the river.

A debate ensued as to whether the lesions were caused by Pfiesteria or something else, whether the fish became ill in the Pocomoke River or had swum there after becoming ill, and if the fish kills were caused by Pfiesteria, what caused the common organism to become toxic. Some also questioned whether this would ever happen again. It was a summer with unusual weather patterns. An early drought severely damaged crops, then hard rains washed the nutrients into the rivers, so nutrient levels were high. The water was warm and slow moving, two other factors that could have contributed to Pfiesteria becoming toxic.

Irrespective of the answers to these questions, the event highlighted the fact that there are real problems with the health of the Chesapeake Bay, and there are a lot of people concerned about it. The drainage basin for the Pokomoke River was a rural area occupied mostly by large poultry growers and processors. Therefore, agriculture received a lot of the blame for the health of the Bay. As a result, the Maryland Water Quality Improvement Act (State of Maryland, 1998) was passed by the legislature and signed by the Governor the next January. The bill contained many requirements, programs and budget initiatives, but the most difficult aspect for farmers was that nitrogen and phosphorus-based nutrient management plans were mandated. A review of the regulations is available on request or online (Simpson, 1998).

Maryland Nutrient Management Regulations

A nitrogen-based nutrient management plan is a simple idea. Farmers must consider the need for nitrogen application to crops and only apply as much fertilizer as is needed. It is no longer be legal to just spread manure on the most convenient hay field next to the barn every time. Now farmers need to estimate realistic crop yields, measure nitrogen content in manure, calibrate their manure spreaders to be sure they are spreading the amount intended, and only apply manure in amounts needed to provide nitrogen for crops. Of course, all of this needs to be documented so the record keeping is the part farmers dislike the most. How much manure did you spread? When did you spread it? When was the spreader last calibrated? Where are those manure analysis records? All farmers have been required to have an N-based plan since January.

The truly difficult part of the law goes into effect in the year 2005. By then, farmers may need a phosphorus-based nutrient management plan. In this case, farmers must only apply as much phosphorus as is needed for crop production. Since manure contains more phosphorus than nitrogen relative to crop needs, applying to meet the crop's phosphorus needs severely limits manure application. Farmers might even need to apply inorganic nitrogen fertilizer with their manure because the manure application will be so restricted. Furthermore, since phosphorus doesn't leach or runoff as easily from the soils, it builds up in the field. A soil test may indicate that more than enough phosphorus is already available for crop production. Considering the high concentration of poultry farms in Maryland, many of the soils are already high in phosphorus, leaving no place to put manure.

To address this issue, the P index was introduced (Hughes, et al. 2000). In Maryland, if soils are high in phosphorus (above about 150 ppm), a P index will be performed to determine if there is a high potential for runoff of P from the fields (Simpson, 1998). Factors considered include field slope, soil drainage capacity, fertilizer type, and method of fertilizer application. When all the factors are crunched into the equation, the number that comes out indicates that the field has a low, medium, high or very high potential for P loss. If the potential for P runoff is medium, manure application is restricted to provide for the P requirements of crops. If the potential of P loss is high or very high, no manure can be applied. Remember that only fields that are high in phosphorus will even be evaluated with the P index. If the plant available P is lower than 150 ppm, an N-based nutrient management plan is still permitted. Even if the soil test indicates a high plant available P, if the potential from runoff is low, the N-based plan is still permitted. So in the end, the law is not as restrictive as it might have been. However, it will require a lot of record keeping and soil tests every three years, and farmers will pay at least part of the cost of writing nutrient management plans and determining the P index.

Similar laws will be put into effect for large farms in the whole of the United States, and the definition of a large farm may change from being more than 1000 cows to more than 350. However, in Maryland the law pertains to farms with as few as five cows.

▪ The Regulations Coming

Just before the Pfiesteria outbreak in Maryland, nitrogen was the primary concern among farmers and environmentalists. A short time later, phosphorus was the bigger, more difficult, issue. I'd like to say that if we can solve the phosphorus problem we are home free, but I know that would not be accurate. The N-based nutrient management plans are easier to implement because crops can use a lot of N, and it doesn't accumulate in soils. Therefore, having excess manure is not the issue. The reason N doesn't accumulate in soils is that it is readily leached through soils to ground water (much of which resurfaces to streams), and it volatilizes to the air where it contributes to various environmental problems. It isn't that N is not a problem. It is such a big problem that, for now, it is being ignored. N-based nutrient plans are being mandated, but to really reduce N losses from agriculture will require altering feeding, as well as manure handling, storage and application methods. In this paper, I bring the bad news that even the stringent regulations in effect in Maryland are not likely to improve environmental quality as much as society demands. But, there is some good news. There are measures, that are currently not being taken, that could do much more for the environment at less cost to farmers and food consumers than current regulations.

▪ Striving for Efficiency

Why has pollution from agriculture become a problem now? There have been a few changes in our agricultural practices in the past fifty years that have accelerated the process of environmental damage. In order to meet the increasing needs for global food production, agricultural production has become more efficient at using land resources and levels of production have increased. In particular, the use of inorganic fertilizer has allowed us to produce more food per acre of land. Animal enterprises have become intensive.

Production efficiency has been measured in many different ways over the past decades. When considering the viability and profitability of a farm, the efficiency of food production relative to financial costs is the primary concern. On a global scale, when considering the limited availability of land for food production, we have often thought of the need to increase the efficiency of production per unit of land. However, with today's technological advancements enabling more and more production per acre, it is the efficiency of production relative to environmental damage this is of particular interest. The question becomes: how do we maintain productivity while decreasing environmental damage -- and at the same time stay in business.

Fortunately, we have already conducted a vast amount of research related to answering this question. Research has focused on improving the nutritional efficiency of animal production. For example because protein is an expensive nutrient to obtain, we have continually improved our methods of feed analysis and ration formulation. As a result, we have discovered ways to reduce the amount of feed nitrogen (an element mainly found in protein), relative to the amount of milk or meat produced. This improved efficiency translates into producing more animal product with lower levels of manure nutrients. At the same time, we have selected crops and determined their nutrient requirements to improve their use of nutrients in soils, and we have developed manure management practices to use manure nutrients more efficiently. The main reason for this research was to reduce the costs of food production by decreasing feed and fertilizer costs while production the same or greater amount of product. Now, the goal is to also reduce the environmental costs of productions.

▪ A Whole-Farm Issue

Most agricultural scientists specialize in specific aspects of the production cycle rather than integrate the various sub-components of the system. Nevertheless, farmers are required to consider the whole system and how the sub-components add up. We have addressed these holistic concerns by developing mathematical models of the animal enterprise (Kohn et al. 1997). One of these models is represented in Figure 1.

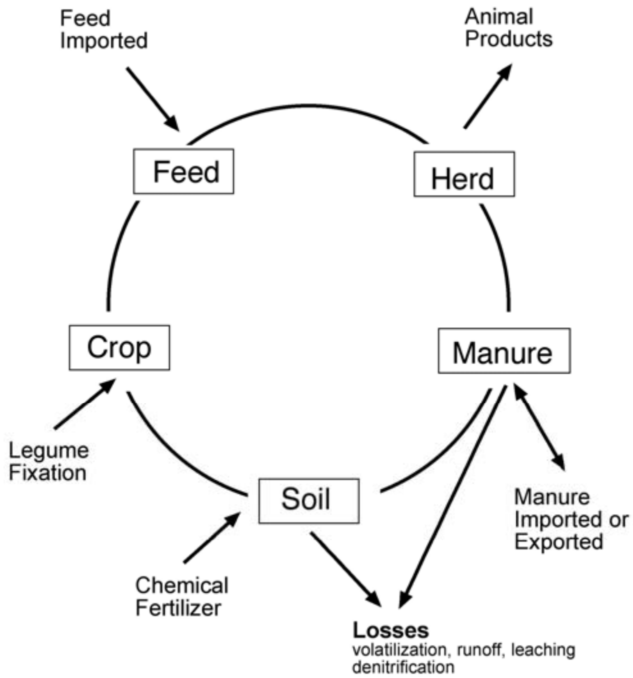

Figure 1. The nutrient cycle on a dairy farm

The model demonstrates that nutrients enter the farm as imported feed, legume N fixation from the atmosphere, fertilizer purchases, or imported manure. From here they are cycled through the system until they are lost. The ways that nutrients are lost from the farm include production and export of milk or meat, or losses from manure or soil from volatilization, runoff, leaching or denitrification.

The overall efficiency of nutrient utilization for the system is the amount of nutrient in product divided by the total nutrient inputs to the farm. And the inefficiency is the difference between nutrient inputs and useful productions. This inefficiency represents a potentially destructive loss of nutrients to the environment, and potentially a loss of income to the producer. The overall efficiency depends on the partial efficiencies of each subsystem. Improving the use of nutrients on the farm, and reducing potential of pollution, involves nutrient conversion in all subsystems. Feeding, herd management and cropping are important as well as manure management for reducing nutrient losses to the environment, and yet incentives and cost share has been almost completely focused on manure management. We used our mathematical model to figure out just how important these other subsystems are.

Nitrogen Management

The potential range in partial efficiencies for N utilization that might be expected in the field is shown in Table 1. For example, the efficiency of the herd would be the amount of product (milk and meat) N divided by the total amount of feed N used on the farm. The inefficiency of the herd is represented as manure production which includes feces, urine, and spilled feed. A 50% variation in herd efficiency is often observed from one farm to the next due to production level, feeding practices, and animal grouping strategies. The apparent uptake of crop nutrients also varies easily by 50%. Manure availability may range by 100% or more depending on manure collection, storage, and application methods.

Table 1. Typical range in nitrogen efficiencies of animal-crop production.

Subsystem Efficiency	Low	High
Animal Product N / Feed N	.16	.24
Feed N / Soil Available N	.50	.75
Soil Available N / Manure N	.25	.50

The predicted impacts on the environment of changing the efficiencies of sub-systems to a farm are shown in the Table 2. Improving the efficiency of animal production relative to feed N intake is the most important mechanism for reducing N losses from the farm. The 50% improvement in herd N utilization would reduce total N losses from the farm by nearly 40%. The second most important means to reduce N losses is to improve the efficiency of crop utilization of soil N. This may be accomplished by choosing crop species that are best suited for N uptake and high yields, and by applying the correct amount of fertilizer and available N from manure. As has been reported previously, the losses from the farm would be reduced substantially by improvement to both herd and cropping systems.

Table 2. N loss from the farm per product N, as affected by efficiency and source of N input to the farm.

Partial Efficiencies	N Input from Legumes	N Input from Fertilizer
All Low	4.9	10.2
Animal High	3.0	6.5
Crop High	4.5	6.0
Manure High	4.2	8.9
All High	2.1	3.0

The efficiency of manure conversion to soil available nutrients had the least impact on total farm losses. For example, an improvement in manure collection, storage and application, to reduce N volatilization from manure would have a lesser impact on the whole farm nutrient use efficiency than a proportionally similar improvement in herd or crop management. In fact, a doubling of the manure availability, which would be expensive to implement, would only reduce N loss to the environment by about 14%. None the less, gross losses in manure nutrients should be avoided. In contrast to improvements in animal nutrition which result in proportional or greater increases in whole farm efficiency, much of the conserved manure N is subsequently lost from the nutrient cycle before being translated into increased animal production. Improving N utilization in the animal reduces the amount of manure produced, and subsequently reduces the N loss to water from that manure, and at the same time, reduces the protein in the feed and the N losses associated with the production of protein supplements.

■ Phosphorus Management

The same sort of estimates of whole-farm nutrient cycling as were made for N can also be made for P. However, volatile P losses are minimal and there is little potential for leaching of P unless it is over-applied. The goal for P management is to prevent P build up in soils to levels that will make manure application risky to the environment and illegal.

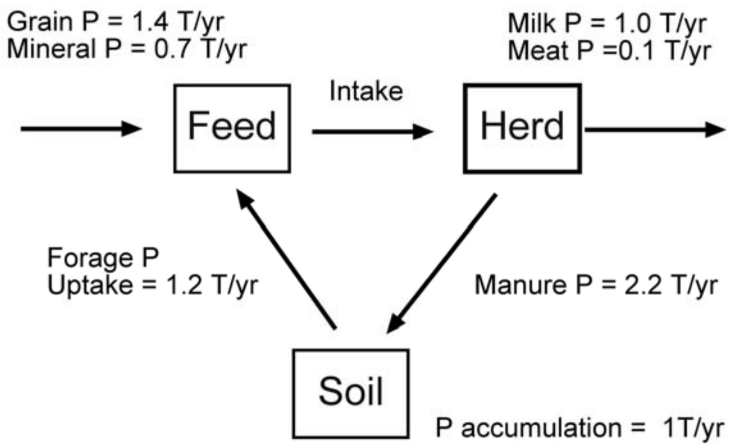

Figure 2. Phosphorus flows on a typical dairy farm.

Figure 2 shows P flows on a typical dairy farm in Maryland (Knowlton and Kohn, 2001). We assumed 100 mature dairy cows averaging 8,864 kg of milk per cow per year, 80 replacement heifers, and that cows were fed according to current standards. Forages (corn silage, alfalfa hay, and pasture) were assumed to be grown on the farm, and grains were assumed to be imported.

Phosphorus imports exceed P exports on this farm by 1 ton per year, and this quantity would accumulate in the soil. To balance P application with crop uptake, the herd size could be reduced substantially, and most grain would need to be produced on the farm. This change would decrease farm income. Otherwise, manure could be exported assuming it is of a form that can be easily exported and there is someone in the region who would want it.

These calculations assume that diets are supplemented with mineral phosphorus. If mineral P supplements could be reduced or eliminated, the P balance on this farm would approach 0 and reduction of herd size and exportation of manure would not be necessary.

Thus, reducing the amount of P in manure through nutrition is a powerful, cost effective, approach to reducing potential P losses from dairy farms.

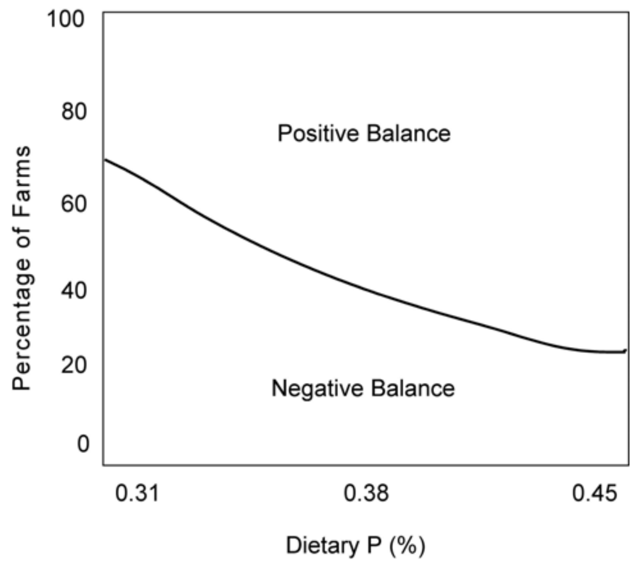

Figure 3. Percentage of 454 farms surveyed in MD, VA, PA, WV, and DE that would be in negative P balance given different levels of P feeding.

Figure 3 shows the results from a survey of 454 dairy farmers in the Mid-Atlantic region of the USA (Jonker and Kohn, 1999). If all farmers feed P at currently typical levels, 80% would be importing more P onto the farm than they would be exporting in milk and other products. As a result, P would be building up in their soils. If they were to avoid using mineral P supplements, on the other hand, 75% would be able to import manure from the few neighbors who still would have an excess. This figure demonstrates the importance of not overfeeding P on dairy farms.

■ Herd Management Strategies

Reducing nutrient losses from dairy farms requires attention to the entire nutrient cycle, especially improving nutrient utilization in the herd. Ironically, herd management is often overlooked as a means to improve nutrient management while greater emphasis is placed on manure management and nutrient application. Herd management can usually be implemented with the least time and financial cost. Strategies that have been investigated and their potential effect are listed in Table 3.

Table 3. Estimates of the potential impact of different technologies on reducing nitrogen and phosphorus losses per unit of milk produced from a typical dairy farm.

Technology	% Reduction in feed N and P	% Reduction in manure N and P
Milking 3 times daily	5	7
Using bovine somatotropin	6	8
Extending photoperiod with artificial lighting	4	5
More feeding groups per farm	4 – 5	5 – 8
Balancing RUP for amino acids	4 – 6*	6 – 9*
Avoid overfeeding of RDP and RUP	4 – 20*	5 – 40*

*primarily affects nitrogen

RUP = ruminally undegraded protein, RDP = ruminally degraded protein

Milking 3 times daily, using bovine somatotropin and using artificial lighting increase milk production per cow. These practices reduce the total consumption and excretion of nutrients for a given level of milk production (Dunlap et al. 2000). Using more groups of lactating cows (e.g. fresh, peak, late) theoretically provides for an opportunity to feed cows closer to their requirements (St-Pierre and Thraen, 1999). Using several technologies simultaneously can substantially reduce nutrient losses from the farm and over accumulation of phosphorus in soils. These technologies are often cost effective even without considering nutrient management consequences.

▪ Regulations Revisited

In Maryland, N- and P-based nutrient management plans are mandated (Simpson, 1998). In the whole of the USA, runoff from manure storage facilities and animal holding areas is prohibited, and large farms are required to have nutrient management plans (Environmental Protection Agency, 2001). Unfortunately, most N leaves the farm through volatilization and leaching, not runoff from the barn floor, or due to over application of manure. The regulations for N are not likely to have much impact on environmental quality. This may have been one of the reasons Maryland shifted emphasis toward P. However, the Chesapeake Bay is over-fertilized by both N and P.

Farmers have got to be concerned when environmental regulations don’t have the desired impact on the environment. In the short term, the public may be appeased by knowing that “something” is being done, but if water and air quality do not improve, there will be a demand for more, not necessarily better, regulations. There will be regulations unless air and water quality improve, farm organizations need to be involved not only to make to make those regulations feasible, but also to make them have the desired environmental impact.

Implementation of various manure management technologies is known to have only a small impact on water quality. Yet regulations and government-sponsored incentive programs focus on manure management. On the other hand, farmers have been producing more food with lesser environmental impact per unit of food produced. A study from Denmark showed that farmers reduced N loses to the environment by 10% from the mid 1980' to the mid 1990's (Schrøder, 1995) . The result was not achieved because of the manure management legislation that was imposed. Almost all of the improvement was attributed to improvements in N utilization within animals as a result of reducing animal numbers to achieve the same level of production.

The Netherlands uses a different approach for nutrient management than the rest of Europe and North America. Rather than simply prescribe technologies like nutrient management plans, farmers are taxed for nutrients that are imported but not accounted for in exported products. The farm organizations themselves approved of this approach. Farmers are rewarded, by improved competitiveness, for changes that actually help the environment. For example, there is an even greater incentive to feed protein closer to requirements. Forage legumes use the N they fix very efficiently compared to non-legumes. Thus, using some forage legumes reduces unaccounted for N on the farm, reduces N loss to water, and reduces taxes in the Netherlands. The farmers are rewarded for achieving a goal, but how they achieve it is up to them.

Summary

Most legislation and cost share programs designed to reduce nutrient over-fertilization of water resources have focused on manure management. In Maryland, nitrogen-based nutrient management plans are currently required, and phosphorus-based nutrient management plans will be mandatory by the year 2005. These regulations will have a small impact on water quality, but the improvement will not be sufficient to restore most ecosystems. Improved feeding and animal management programs, and improved crop selection, can have a substantial impact on reducing nutrient losses from animal production systems.

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