

# Nutrient Management Planning: Justification, Theory, Practice

D. B. Beegle,\* O. T. Carton, and J. S. Bailey

## ABSTRACT

Traditionally, nutrient management has been concerned with optimizing the economic return from nutrients used for crop production. Today, the agronomic and economic requirements of nutrient management remain central, but in addition, the process must consider the potential impact of these nutrients on environmental quality. The nutrient-management process is critical for maximizing the economic benefit from nutrients while minimizing the environmental impact. This process includes assessment, analysis, decision making, evaluation and refinement. A tactical nutrient-management plan developed from this process must be based on a firm set of strategic objectives agreed upon by the farmers and society. The nutrient-management process must also be practical to implement, if the performance goals are to be met. While nutrient-management plans have resulted in benefits to farmers and society, implementation has not been as great as desired. Several factors have been identified as key to the successful implementation of nutrient-management planning: the full participation of a broad range of stakeholders, the use of established infrastructure, targeted nutrient-management planning efforts, voluntary vs. mandatory programs, and the economics of nutrient management. Experiences in Pennsylvania, the Republic of Ireland, and Northern Ireland illustrate aspects of the implementation of the nutrient management process.

TRADITIONALLY, nutrient management has been concerned with optimizing the economic return from nutrients used for crop production. The main emphasis was on the expected crop response from adding nutrients to the soil. In practice however, nutrients, particularly manure, are not always applied to optimize plant nutrient use. Historically, a common farm occurrence has been applying inorganic fertilizer without giving credit for nutrients already applied in manure. This has contributed to soil fertility levels that exceed agronomic requirements (Coulter and Tunney, 1996). Such practice, or the improper or untimely application of manure, may release nutrients into the air and water, where they no longer contribute to the production of the crop. This represents an unsustainable waste of natural resources.

Today, the agronomic and economic requirements of nutrient management remain central, but in addition, we must consider the potential impact of these nutrients on environmental quality. Leaching of  $\text{NO}_3$  through the soil can increase ground water  $\text{NO}_3$  levels above safe drinking water limits, which can adversely affect the health of young children and livestock. Surface movement of N and P in runoff increases levels of these

nutrients in surface waters, which can lead to eutrophication and fish kills.

The focus of this paper is on nutrient-management planning, which is critical to optimizing the benefits from nutrient inputs while minimizing their negative impacts.

## JUSTIFICATION FOR NUTRIENT MANAGEMENT

Nutrient losses from agriculture into water originate from well-defined (or point) sources (e.g., farmyard) and from diffuse (or nonpoint) sources (Magette and Carton, 1997). In most countries, the impact of these losses on the environment, particularly water quality, follow a similar pattern. The Irish situation is used as an example to illustrate the trend. Public concern focused firmly on agriculture's impact on water quality in 1987 when an unprecedented number of fish kills were associated with discharges primarily from farmyards (Dollard, 1994). In response, farmyards were upgraded with a national investment exceeding £1.0 billion throughout a 10-yr period. The net effect was a significantly reduced numbers of fish kills, although current levels remain unacceptably high (Dollard, 1994). During this period, very little attention was given to controlling nonpoint sources or field losses of nutrient. Irish water quality has continued to decline throughout the last two decades with increases in the slightly to moderately polluted waters (Bowman et al., 1996). Agriculture is implicated in this decline. Nutrient management is the internationally accepted strategy to address farm nonpoint source or field nutrient losses.

The problems with nutrient pollution are not generally the result of mismanagement by farmers, but are a result of how our agricultural systems have evolved with no direct costs associated with environmental quality. For example, the field-based economic and agronomic incentives that can be effective for proper management of nutrients on a cash-crop or nutrient-deficit livestock farm, are not as significant on the intensive livestock production-oriented farm that is becoming more common today. Two examples from Beegle and Lanyon (1994a) are used to illustrate the nutrient balances on typical modern farms.

On a dairy farm, nutrients are harvested from the farm fields with the crops. The crops are then used as feed in the animal enterprise resulting in some nutrients (usually <25%) leaving the farm in the animal products. The remaining nutrients are returned to the farm fields

D.B. Beegle, Dep. of Agronomy, 116 ASI Building, Pennsylvania State Univ., University Park, PA 16802; O.T. Carton, Teagasc, Johnstown Castle, Wexford, Ireland; and J.S. Bailey, Dep. of Agriculture and Environmental Science, QUB, Newforge Lane, Belfast BT9 5PX, Northern Ireland. Received 25 Sept. 1998. \*Corresponding author (dbb@psu.edu).

**Abbreviations:** NMP, nutrient-management plan; BMP, best management practices; CAO, concentrated animal operation; DANI, Department of Agriculture of Northern Ireland; ECNMS, Erne Catchment Nutrient Management Scheme; ROI, Republic of Ireland; NI, Northern Ireland.

in the manure (Fig. 1a). Nutrients may be added to this cycle as fertilizer on the farm fields and as nutrients contained in feed purchased for the dairy operation, but the primary nutrient flow is from the farm fields to the barn and back. The most important nutrient-management consideration on this type of farm is accounting for all sources of nutrients, especially as purchased feed increases, and effectively recycling them in the cropping program. Klausner (1994) and Tunney et al. (1998) have highlighted the contribution of purchased feeds to the P balances on dairy farms. Neither crop production nor fertilizer use are directly connected to the output of such farms. Performance of these farms depends on the animal husbandry skills of the farmer, not just on success in crop production. Decisions about plant nutrient use in the fields are not as sensitive to the economic or agronomic criteria in crop production as on a cash-crop farm.

Intensive livestock farming enterprises that concentrate large numbers of animals indoors, particularly non-ruminants, on relatively small land areas have emerged as a result of improvements in animal housing and the success of crop production on cash-crop farms in specialized geographic regions (Fig. 1b). Most, if not all, of the feed necessary can be economically transported to the farm where the animals are housed. The focus of the management activity is on animal production. In reality, the cash-crop farm and the intensive, modern livestock farm are connected by the flow of feed. However, nutri-

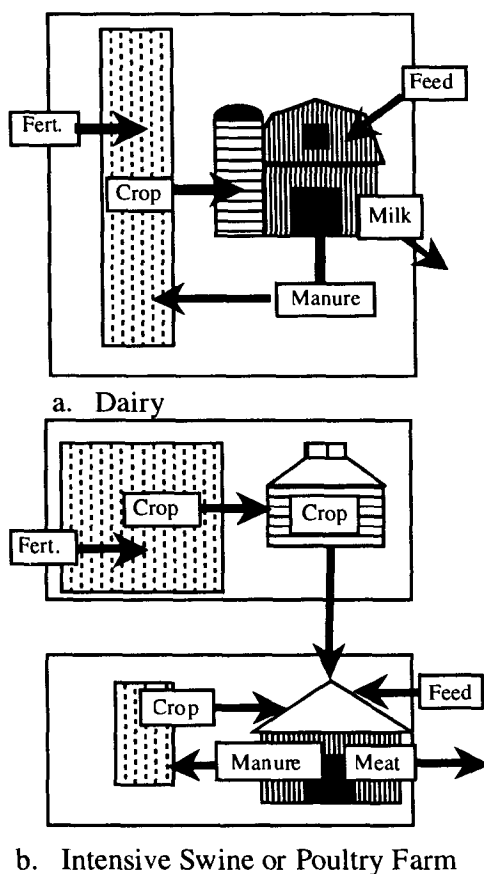


Fig. 1. Typical farm nutrient flows.

ents in this flow usually do not cycle back to the cash-crop farm. Lanyon (1990) has shown a relationship between increasing animal density and increasing excess N balance in the farm fields (Fig. 2). The nutrient excess on the intensive livestock farm has an associated increased potential for losses to the environment. Further, field-based agronomic practices may be of limited effectiveness in treating the total quantity of nutrients on the intensive livestock farm because of the small land area on the farm. It is very likely that nutrient management to protect environmental quality cannot be accomplished solely by implementing a nutrient-management plan (NMP) on the farm where the animals are housed.

The successful management of nutrients, that is, balancing crop nutrient requirements with nutrient additions, will depend on securing adequate land suitable for manure spreading on farms in the vicinity and on developing a manure transport system. This must become part of the nutrient-management process (Carton and Magette, 1998). Alternatively, off-farm organizations may deal with manure hauling to locations where the manure can be used directly or transformed into another product such as compost.

Today nutrient-management programs must not only address efficient crop-production criteria but must also reduce nutrient losses to the environment. The ultimate nutrient-management challenge will be our ability to achieve a better balance between nutrient inputs and crop requirements while sustaining agricultural production where nutrient surpluses exist.

## THEORY OF NUTRIENT MANAGEMENT IN PRACTICE

Nutrient-management strategies will not be the same for all farms. As seen earlier, it is important to recognize that there are nutrient balance differences between farms. These will affect the choice of strategy. Farms can be broadly classified on a nutrient-balance basis to assist in selecting the appropriate management options. These are nutrient-deficit, nutrient-balanced, and nutrient-surplus farms.

**Nutrient-Deficit Farms.** These are farms where nutrient imports are less than exports. They are usually low intensity with low animal density and/or minimal im-

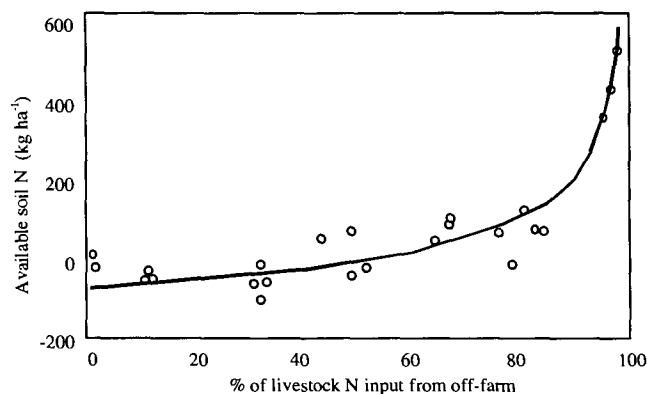


Fig. 2. Relationship between off-farm N input and available soil N balance (Adapted from Lanyon, 1990).

ports of off-farm feed. The manure produced on these farms is generally not adequate to meet total crop nutrient needs. Thus, additional nutrients in the form of purchased fertilizer or other sources are required for achieving optimum crop yields. Usually because of the nutrient deficit, these farms are not as likely to cause environmental problems unless there is gross mismanagement. Nutrient-management plans for this type of farm emphasize practices designed to make the most of nutrient efficiency and achieve the maximum crop response from manure nutrients. A well-planned nutrient-management program emphasizing economic and agronomic efficiency should reduce the need for purchased inputs and thus should improve farm profitability.

**Nutrient-Balanced Farms.** These are characterized by nutrient imports being approximately equal to exports. The manure can meet a significant part, if not all, of the nutrient requirements for crop production. Because these farms are often at the upper limit of being able to safely handle all the nutrients produced, nutrient-management planning may offer potential environmental benefits. Practices to maximize the safe use of manure and to balance nutrient inputs with removals from farm fields are emphasized, rather than nutrient use efficiency. The economic return from improved nutrient management on this category of farm is likely to be minimal. That is, there should not be a large cost associated with implementing improved nutrient-management practices, but unlike the first category, there is little profit incentive either. The incentive for change on this category of farm is environmental protection.

**Nutrient-Surplus Farms.** These are farms where nutrient imports significantly exceed exports. The nutrients in the manure generally exceed those required for crop production on the farm. As already noted, it is unlikely that all of the manure can be safely recycled within these farms. Thus, only part of the nutrient-management program is field based. A significant component involves acceptable off-farm uses for the excess manure. There is likely to be an economic cost in implementing an environmentally sensitive nutrient-management plan for this category of farm. Nutrient-management programming most likely will result in environmental benefits as excesses on the farm are reduced.

This simplified classification scheme is intended to demonstrate the implications of differing situations for nutrient-management plans. In Pennsylvania, for example, this categorization is approximated using the animal density on the farm (Lanyon and Beegle, 1993). Farms with  $>1400$  kg ha<sup>-1</sup> but  $<2500$  kg ha<sup>-1</sup> of animal live-weight are usually near to balance for N. Farms with less or more than this animal density are either in the deficit or excess categories, respectively. A similar scheme can be developed for P.

Individual farms in each category will not necessarily fit all the characteristics described for the category. When there is a question about the classification, it should be resolved based on more comprehensive, site-specific information. Since agriculture is changing rapidly, farm classifications may change with time. There-

fore, farmers should periodically evaluate their farm's nutrient-management status to adjust their strategy as appropriate. More detailed evaluation of fields and practices will be necessary to identify specific management options or best management practices (BMPs) for each individual situation.

## NUTRIENT MANAGEMENT DECISIONS

Decision-making related to nutrient-management planning occurs at the strategic, tactical, and operational levels of management (Beegle and Lanyon, 1994a). Management changes will need to be addressed at each of these levels.

At the strategic level, management decisions are made by the top management of the farm regarding long-term goals and strategies for the operation. Examples of strategic decisions include whether to expand the livestock operations or not, or whether to acquire more land or reduce livestock numbers to achieve nutrient balance on the farm. A very broad cross-section of information is used at this level of decision-making. Most of the input for strategic decision-making comes from outside of the farm operation. Information on markets for expanded production, availability of labor, or regulations regarding nutrient management are examples of the type of information used in making strategic decisions.

At the tactical level, the emphasis is on implementation of the strategic goals. The time frame for tactical decision-making is usually from a few months to a few years and deals primarily with site-specific information about the operation. The most common example of this level of management is the farm nutrient-management plan, in which specific nutrient allocation decisions are made for the farm. This is the management level where most of the emphasis has been placed for environmental quality nutrient-management programs. It must be recognized however, that the desired performance in terms of environmental quality will not be achieved unless the tactical management is guided by appropriate strategic goals. For example, unless the strategic decision has been made to achieve nutrient balance on a high-density livestock farm by reducing animal density or removing excess manure from the farm, repeated refinements in the tactical manure allocation plan will not result in an environmentally acceptable nutrient balance on the farm.

The final level of management is the operational level. This is where the tactical plan is actually implemented and decisions are made about specific tasks to be performed by the farm labor. This type of decision-making is generally short term and requires in addition to a tactical plan, timely, very specific information such as weather forecasts, soil conditions, and availability of labor and equipment.

Successful nutrient management depends on addressing the strategic, tactical, and operational levels of decision-making. The tendency to work only at the tactical and operational level, which is familiar, before addressing the strategic issues of the problem must be

resisted. Also, it is important to remember that on many farms, all of these distinct levels of management may reside within one person, the farmer. This importance of the different levels of decision-making to nutrient management must not only be recognized by those working with farmers but also by the farmers themselves.

### APPROACHES TO NUTRIENT MANAGEMENT

The motivations for farmers to change their practices are many. The reasons may be economic, social, or moral to name a few. As society demands more and more accountability from farmers, there will also likely be regulatory motivations provided. For example, under the Irish Waste Management Act, local authorities can require farmers to prepare and submit nutrient-management plans where they consider it to be necessary to prevent, eliminate, or minimize nutrient losses to water arising from the use of inorganic and/or organic fertilizers (DOE-Ireland, 1998).

There are two approaches to nutrient-management planning in a regulatory situation. One approach is to specify what should be done on all farms as a recipe for nutrient management. Lists of required standard practices (BMPs or Codes of Good Practice) specifying specific times, rates, and methods of manure application for farmers is an example of this approach. The Irish voluntary Code of Good Agricultural Practice to protect waters from pollution by  $\text{NO}_3$  will become mandatory in areas designated as vulnerable to  $\text{NO}_3$  leaching (DOE-Ireland, 1996).

Although this approach is relatively simple to administer, it does not accommodate specific conditions of particular farming operations or the nature, interests, abilities, or local conditions of individual farmers. Neither does this approach address needed changes in the current structure of farming. Closely specifying particular farming practices can also limit innovation by farmers and farm advisors in finding ways to deal with new requirements for crop production and environmental protection. Most innovation in this approach is focused on how to circumvent the standard requirements while *technically* complying with the regulations. Finally, there is no direct linkage between the required practices and the desired environmental outcome.

Another approach to farm nutrient management is to establish performance criteria or goals for farmers to meet as part of their farm nutrient-management plan. Performance criteria are outcomes to be achieved through nutrient management, such as meeting a discharge standard, achieving nutrient balance for the farm fields, or maintaining soil tests below a certain level. Performance criteria are not lists of specific practices or BMPs that all farmers must follow. They are goals that are established, and farmers and their advisors are given the freedom to develop and implement a plan integrating any practices or BMPs that are appropriate. There would be no official list of standard BMPs, but rather an extensive list of BMPs and assistance made

available to the farmer. Carefully established outcomes can promote solutions to meet the environmental challenges faced by farmers based on local conditions while stimulating innovation at the same time. Clearly defined, measurable outcomes or performance objectives are essential to this approach to nutrient management. As an example, the nutrient-management law in Pennsylvania establishes a field-by-field N balance as a regulatory performance criteria (Beegle et al., 1997).

A major strategic issue in manure-management policy is whether performance criteria should be based on N or P. In most places, except for the Republic of Ireland and the Netherlands, manure application guidelines and regulations are based on balancing N, which usually results in excess P conditions. This is driven by practical and economic motivations because basing nutrient management on P requires more land for safe manure-nutrient utilization and usually results in a significantly negative economic impact. It is likely that some compromise will be necessary on this issue.

Fortunately, there are alternative management options to either improve the nutrient balance or minimize the negative impact of the nutrient imbalance. Standard BMPs, such as proper timing and application of manure, are important in all nutrient-management plans designed to minimize nutrient loss. Also, structural best management practices such as conservation tillage, contour and strip farming, and buffer strips are important. Cropping systems can sometimes be modified to better match the crop requirements with the manure nutrients (Ford, 1994). Improved ration formulation in animal feeds has been shown to potentially have a significant impact on the nutrient levels in the manure (Lynch and Caffrey, 1997). The use of phytase in nonruminant animal feeds to improve the efficiency of P utilization by the animals has been successful. Manure treatment such as adding aluminum or iron sulfate or waste materials such as fly ash to lower the solubility of P in manure has been shown to effectively reduce P loss to water (Moore and Miller, 1994). Finally, recognizing that not all areas on a landscape contribute equally to nutrient losses and managing these critical source areas accordingly (Gburek and Sharpley, 1998; Magette, 1998) is important.

It is unlikely that any of these approaches, or others that may develop from active research, will individually solve the problem. However, this research is providing a developing suite of strategies and technologies that can be integrated into a management plan, based on the site-specific situation, to practically and effectively address the environmental concerns about agricultural nutrients without taking the extreme approach of strict, inflexible limits on nutrient applications.

### IMPLEMENTATION OF NUTRIENT-MANAGEMENT PLANNING

The nutrient-management process has been described previously (e.g., Carton and Magette, 1998; Beegle and Lanyon, 1994a). It starts with a simple assessment of the overall nutrient balance on the farm and proceeds

to a more detailed assessment of nutrient inventory and crop requirements. Based on this assessment, management options appropriate to the farm situation are selected. The selected management options are integrated into the tactical NMP for the farm. At the core of the NMP is a simple plan for the farmer that provides recommendations on the quantities of manure and fertilizer to apply to each field. The actual plans themselves will take on many forms. An NMP can be written with a paper and pencil or it can be developed with computer software (Thompson et al., 1997). The key concept is that the plan allocates the available manure nutrients in a way that maximizes the economic benefit of the nutrients while minimizing the environmental impact. On farms with nutrient surpluses this will also include plans for dealing with the excess nutrients.

The NMP must be practical to be effective. For example, calculated manure-application rates must be achievable in the field. This usually results in the fields being grouped to receive manure at standard rates within a given range. The variability and uncertainty involved in manure management must be a major consideration. It is tempting, especially with computer-generated NMPs, to develop plans that are much more precise than the data warrants. Regulators must consider this fact and need to be educated as to the realistic levels of precision being achieved in practice. A slightly *imperfect* but practical NMP will almost always provide greater positive results than a *perfect* one that is not practical to implement.

Finally, the plan must be implemented and records must be kept to document the implementation and serve as a guide for future revisions. The NMP will only be effective if it is implemented, continually reevaluated, and revised or refined as necessary to reflect current conditions. Therefore, the NMP should be periodically assessed to ensure that it is meeting the purpose for which it was designed. Assessment is also required whenever changes take place on the farm that affect nutrient sources and demands. These changes can include increases or decreases in animal numbers or types, alterations in cropping systems, adoption of different feed rations, or anything else that impacts the source of, or need for, nutrients.

Daniel et al. (1997) concluded that both the technical and institutional components are central to the successful implementation of any nutrient-management program. Some of the technical components have been described earlier. Some of the institutional elements relating to the implementation of nutrient-management program components will now be discussed. These include stakeholder involvement, targeting, voluntary vs. mandatory programs, and assessment of the potential benefits of nutrient management.

**Stakeholders.** Experience has shown that successful implementation of nutrient-management policy must involve full participation of a broad range of stakeholders. Key stakeholders include the farmers, allied agri-industry, public agencies, policymakers, regulators, environmental groups, and the consumer. The consumer needs to be involved with the policymakers to establish the

performance criteria. The farmers and allied groups need to work to ensure that this is done in a fully informed manner and that all of the implications of a policy are clear. For example, the consumer must realize that a nutrient-management policy may increase food prices or increase taxes if subsidies are to be used to maintain low food prices. Regardless of the approach, the cost of achieving the objectives must be clear to all.

The same group of stakeholders must be part of the implementation process once reasonable and achievable performance objectives for the program are set. Traditionally, the approach has been that once nutrient-management policy is set, it is passed on to the regulators to establish a command process to implement it. This is usually achieved through a government agency. However, the new paradigm of involving all stakeholders in not only establishing performance objectives but also ensuring their implementation has a much greater probability of success.

Experience has indicated that the traditional approach can be improved where the regulators provide the farmers with a clear representation of the agreed-upon performance criteria and then support the development of an NMP to achieve the stated objectives. Implementing the program is generally achieved by using the established public and private agricultural infrastructure. A U.S. and Irish example are given to support the importance of the stakeholder approach to the successful implementation of nutrient-management programs.

In Pennsylvania, nutrient-management legislation was enacted in the spring of 1993 (Beegle and Lanyon, 1994b). This legislation established a stakeholder advisory board to oversee the development of the regulations to implement legislation. As a result, it took more than 4 yr to develop the regulations. However, most of the stakeholder groups agree that while it was a long and arduous process, the resulting regulations are much more likely to be practical for the farmers and effective in meeting the environmental goals.

In this newer stakeholder approach, the regulator's role becomes one of assisting with compliance rather than enforcing compliance. For example, farmers could work with their normal advisors whether they be public agencies such as cooperative extension or private agri-dealers or consultants to develop a plan to meet the performance objectives. A plan developed in this way—through traditional relationships—is much more likely to be implemented and achieve the objectives than a plan handed down from a regulator. Consequently, nutrient-management programs in Pennsylvania and Maryland put a strong emphasis on plans being developed by the private sector.

An example of stakeholder involvement in Ireland is the Erne Catchment Nutrient Management Scheme (ECNMS). This scheme, launched in 1996 and funded by the European Union Peace Fund, offered an NMP service to intensive farmers (i.e., stocking rates<sup>1</sup> > 2 LU ha<sup>-1</sup>) on both sides of the Republic of Ireland-Northern

<sup>1</sup> LU = Livestock unit, which is equivalent to one 500-kg dairy cow.

Ireland border. The aim of the scheme was to lower the inputs of agriculturally-sourced P to the Erne system by recycling nutrients more efficiently on farms. The Erne catchment is the fourth largest in Ireland (4212 km<sup>2</sup>) and is equally distributed between Northern Ireland (NI) and the Republic of Ireland (ROI). A significant proportion of the catchment is classified as *sensitive to eutrophication* under the terms of the European Community Urban Waste Water Directive. It is estimated that agriculture contributes about 67% of the P loading to surface waters in the Erne system, with the remainder coming from sewage (R.H. Foy, personal communication, 1997).

The infrastructure for the nutrient-management scheme had largely been put in place some years earlier in NI. All of the farms had previously been surveyed as part of a Department of Agriculture of Northern Ireland (DANI) initiative on *farm pollution control*. The majority of farm owners (70%) had already implemented *action plans*, bringing their farmyards (manure and dirty-water storage facilities; clean- and storm-water separation) up to minimum acceptable standards. Good working relationships had been established with DANI staff and farmer awareness of the problems of farm pollution had been heightened as a result of this earlier initiative. This was an element in the successful implementation of the scheme.

**Targeting.** Targeting nutrient-management efforts has been identified as another key to successful implementation. Targeting can take many forms. Targeting has been done on the basis of watersheds, types of farm operations, animal density on farms, environmental risk assessment, etc.

The ECNMS initially targeted the three subcatchments with the highest soil P levels and poorest water quality (Dils et al., 1998). In this project, 600 target farms were selected by DANI using risk-assessment criteria (i.e., proximity to a watercourse and the physical state of collection and storage facilities for organic manures), and the owners were asked to participate in the scheme. In contrast, there was limited targeting in the ROI element of the Erne project. The program was promoted by public meetings and some farmers were contacted and invited to participate. Farmer uptake was significantly higher in NI compared with the ROI.

In Pennsylvania, nutrient-management regulations (Beegle et al., 1997) are targeted toward *concentrated animal operations* (CAOs). Farms with more than 2242 kg liveweight ha<sup>-1</sup> will be required to have an approved NMP. In the ROI, pig and poultry farms above a given size (pig units with capacities of 100 or 300 sows, depending on soil type; poultry units with capacities >100 000 units<sup>2</sup>) have also been targeted for nutrient management-plans as part of their Environmental Protection Agencies' Integrated Pollution Control licensing requirements (EPA-Ireland, 1997). CAOs were targeted in both cases because most of them have excessive manure nutrients and thus a greater potential for environmental problems. Through this targeting, greater re-

turn is expected for the limited technical and financial resources available.

**Voluntary vs. Mandatory Programs.** An important and often controversial factor in the implementation of a nutrient-management program is whether they should be voluntary or mandatory. While there is some targeting in the ROI, the remaining programs are voluntary, including the ECNMS. Nutrient management is the cornerstone of the Irish Department of Agriculture and Food's voluntary Rural Environment Protection Scheme (REPS) (Implementation of European Council Regulation (EEC) No. 2078/92). One of the objectives was "To establish farming practices and controlled production methods which reflect the increasing concern for conservation, landscape protection and wider environmental problems." Under the terms of REPS, the more extensive farmers (i.e., <2 LU ha<sup>-1</sup>) are financially compensated for preparing and implementing an NMP, as well as a range of other environmental measures. Nutrient management in the ROI has also been given a further statutory basis by the Waste Management Act, 1996 (DOE-Ireland, 1998). The act provides that local governments may require farmers in areas with water-quality problems to prepare and implement NMPs.

In Pennsylvania, there is also a mixture of voluntary and mandatory programs. About 5% of the farms in the state that are considered to be CAOs are required to have an approved nutrient-management plan for their farm. Initially, a large proportion of the public funding and technical assistance resources are being targeted to this group. However, there is also a major effort to encourage voluntary participation by the remainder of the farmers in the state. Legal incentives and financial and technical assistance are also available for the volunteers. So far, about an equal number of nutrient-management plans have been developed for the volunteers as for the mandatory farms.

A number of issues related to the voluntary vs. mandatory question need to be considered. The first is economics. Where there is potential economic benefit, voluntary programs based on education, technical assistance, and in some cases, some financial assistance to encourage adoption has been very successful. For example, the Irish Government has set a target of 30% of Irish farmers (43 000) participating in REPS by 1999. This will require a total government expenditure of £350 million.

As noted earlier, however, in nutrient management, only farms with a deficiency of nutrients consistently show an economic benefit to implementing an NMP. This was a major factor in the success of the ECNMS in NI. A survey of farmers in the program indicated that 75% of the farmers implemented their nutrient-management plan and saved an average of £22 ha<sup>-1</sup> yr<sup>-1</sup> on fertilizer purchases.

Unfortunately, farms that receive an economic incentive are often farms that are least likely to have environmental problems related to nutrients. On more intensive farms with significant potential for environmental problems (e.g., CAOs), the economics are often not an incentive to voluntary adoption of nutrient-management

<sup>2</sup> 100 000 broilers or 50 000 layers.

planning (Young et al., 1985; Lemberg et al., 1992). In fact, the farmer may incur significant costs for planning and implementing the plan (Magette et al., 1998), which is a disincentive to voluntary uptake of the nutrient-management process. This is often the source of misunderstanding in discussions of nutrient-management policy. Many people assume that improved nutrient management is always economically beneficial and thus cannot understand why voluntary programs are not more successful.

Some of the negative economic disincentives can be overcome by public financial assistance in the form of grants, cost sharing, low interest loans, tax breaks, etc. In both Ireland and Pennsylvania this approach has been used with some success. The Chesapeake Bay Program in Pennsylvania is an example (Perkinson, 1994). This program has invested about \$20 million in cost sharing and technical assistance for nutrient management over the last 14 yr. It has been successful on the farms that have received the financial assistance. A 1996 evaluation (Bay Journal, 1998) indicated that N loss from cropland has been reduced by 9% and P loss by 2%, compared with the 1985 baseline. Nitrogen and P losses from farmsteads have been reduced by 13 and 21%, respectively. However, the cost/kg of nutrient kept out of the Bay has been high. Equally, the scope of the impact has been somewhat limited, due to the emphasis on cost sharing expensive practices like manure storages.

In NI, acceptance of the nutrient-management scheme was excellent, with more than 90% of farmers taking part voluntarily. This particular success was also attributed to several economic factors: Firstly, the scheme was provided free of charge, that is, soil testing, nutrient management plans, and consultancy services were paid for in-full out of EU funds. As a bonus, farmers received a small payment for attending a training course. Secondly, farmers were clearly shown the significant savings that they could make on their fertilizer costs by implementing nutrient-management planning.

Another approach to overcoming the economic barriers to voluntary implementation of NMPs on farms is using market incentives. This is being tested in the Chesapeake Bay watershed, where a consortium called the Dairy Network Partnership has developed a program to market Chesapeake Milk. A portion of the milk from the region will carry the Environmental Quality Initiative mark. Each time a consumer purchases Chesapeake Milk at a slightly higher price (five cents per 2 L), the extra money will be returned to dairy farmers in the region who are achieving a high standard of natural resource protection. The money will also be used to assist other farmers in enhancing environmental protection practices on their farms. This program is currently focusing on farmstead nutrient-management issues, but will likely be expanded to include NMPs if it is successful.

In Pennsylvania's neighbor, Maryland, there was a very successful nutrient-management program that was completely voluntary. However, recent public outcry over outbreaks of the toxic dinoflagellate, *pfiesteria*, in

the Chesapeake Bay has resulted in a major shift to a very comprehensive, completely mandatory nutrient-management program. The legislation in Maryland has mandated that all farms will implement—and P-based NMPs by 2005 (T. Simpson, University of Maryland, unpublished data). It will be interesting to follow the implementation of this program in Maryland. This is an example of what can occur if public and political attention is focused on nutrient management-related issues.

**Evaluation.** The evaluation of nutrient-management efforts has focused on farmer participation. There have been measurable benefits to nutrient-management planning such as cost savings in NI and reductions in N and P in the Chesapeake Bay. Surveys of actual on-farm implementation of nutrient-management plans have not reached expectations to date. For example, in a Rural Clean Water watershed project in Pennsylvania (ASCS, 1992), where there was intensive financial and technical assistance, only 22% of the farms with an NMP implemented 70% or more of the plan. Also, only 57% had implemented 30% or more of the plan. Similarly, in the ECNMS in NI there was only an estimated 20 and 30% full and partial implementation, respectively, of the prepared NMPs. Generally, there is also little implementation of the process on farms outside of these projects.

## CONCLUSIONS

Successful nutrient-management planning is one part of a very complex process. It begins with an understanding of how nutrients cycle in agriculture and how this can result in environmental problems. From this understanding, a strategic vision can be developed for dealing with specific nutrient-management issues. The process for developing NMPs has been well developed. However, implementation at the farm level is vital for the NMP to achieve its stated objectives. Experience to date provides some valuable lessons to help ensure implementation. Successful implementation begins with involving a broad range of stakeholders. These stakeholders are critical for developing clear and achievable objectives for the nutrient-management effort. Targeting of nutrient-management programs has been shown to be important for successful implementation. This targeting may be based on existing or potential environmental problem areas, on the types of farm operations, or on more formal risk-assessment criteria. Targeting allows better allocation of program resources focusing on desired outcomes. The structure of nutrient-management programs can have a significant impact on implementation. An often controversial issue is whether nutrient-management goals can be met by voluntary programs or whether mandatory controls are necessary. Generally voluntary programs are preferred. However, depending on the situation, some regulation may be necessary. Education and financial and technical assistance are important for the success of any nutrient-management program, however they are especially critical if voluntary programs are to be successful. Finally, working within the existing infrastructure of an agricultural system will usually be more successful. More and more nutrient-

management programs are involving the private sector in the process.

Solving nutrient-management problems will not be simple. It is likely that significant changes in agricultural systems may be necessary to achieve the ultimate goal of achieving nutrient balance. However, nutrient-management planning will continue to be a key component of this effort.

## REFERENCES

- Agricultural Stabilization and Conservation Service. 1992. Pennsylvania Conestoga Headwaters Project: 10-year report, 1981–1991. USDA-ASCS, Washington, DC.
- Bay Journal. 1998. Chesapeake Bay nutrient report card: A special report. Alliance for the Chesapeake Bay, Baltimore, MD. 6:1:8.
- Beegle, D.B., and L.E. Lanyon. 1994a. Understanding the nutrient management process. *J. Soil Water Conserv.* 49:23–30.
- Beegle, D.B., and L.E. Lanyon 1994b. Nutrient management legislation in Pennsylvania. *J. Soil Water Conserv.* 49:84–86.
- Beegle, D.B., L.E. Lanyon, and D.D. Lingenfelter. 1997. Nutrient management legislation in Pennsylvania: A summary of the final regulations. *Agronomy Facts* 40. Penn State Univ., College of Agric. Sci., Coop. Ext. Service, University Park, PA.
- Bowman, J.J., K.J. Clabby, J. Lucey, M. McGarrigle, and P. Toner. 1996. Water quality in Ireland 1991–1994. EPA–Ireland, Wexford, Ireland.
- Carton, O.T., and W.L. Magette. 1998. Teagasc manure management guidelines with special reference to intensive agricultural enterprises. p. 32–56. *In* O.T. Carton (ed.) Draft guidelines for nutrient use in intensive agricultural enterprises. Teagasc, Johnstown Castle, Wexford, Ireland.
- Coulter, B.S., and H. Tunney. 1996. The background to the P debate. p. 1–15. *In* O.T. Carton et al. (ed.) Phosphorus recommendations for grassland good agronomic practice. Teagasc Johnstown Castle, Wexford, Ireland.
- Daniel, T.C., O.T. Carton, and W.L. Magette. 1997. Nutrient management planning. p. 297–310. *In* H. Tunney et al. (ed.) Phosphorus loss from soil to water. CAB Int., Oxon, UK.
- Department of the Environment–Ireland. 1996. Code of good agricultural practice to protect waters from pollution by nitrates. Dep. Environ., Dep. Agric., Food For., Dublin, Ireland.
- Department of the Environment–Ireland 1998. Protecting our freshwaters: Nutrient management planning guidelines for local authorities. Dep. Environ. Local Gov., Dublin, Ireland.
- Dils, R.M., N.M. Coyle, J.S. Bailey, and R.H. Foy. 1998. Nutrient management planning: Lough Erne, Northern Ireland. p. 60–61. *In* R.H. Foy and R. Dils (ed.) Practical and innovative measures for the control of agricultural phosphorus loss to water. Stationery Office, Dep. Agric. Northern Ireland, Belfast.
- Dollard, R. 1994. Combining community environmental objectives and standards with EU agricultural and environmental measures in Ireland. p. 53–60. *In* M. Maloney (ed.) Agriculture and the environment. Royal Dublin Soc., Dublin, Ireland.
- Environmental Protection Agency–Ireland. 1997. Application guidance notes pig and poultry sector. EPA, Wexford, Ireland.
- Ford, S.A. 1994. Economics of pasture systems. Dairy Economics Fact Sheet 1. Penn State Univ., College of Agric. Sci., Coop. Ext. Service, University Park, PA.
- Gburek, W.J., and A.N. Sharpley. 1998. Hydrologic controls on phosphorus loss from upland agricultural watersheds. *J. Environ. Qual.* 27:267–277.
- Klausner, S. 1994. Nutrient management planning. p. 383–392. *In* K. Steele (ed.) Animal waste and the land water interface. Lewis Publ.–CRC, New York.
- Lanyon, L.E. 1990. Developing and implementing nutrient management systems for Pennsylvania farms. Pennsylvania State Univ., College of Agric. Sci., Dep. of Agron., University Park, PA.
- Lanyon, L.E., and D.B. Beegle. 1993. A nutrient management approach for Pennsylvania: Plant nutrient stocks and flows. *Agronomy Facts* 38-B. Penn State Univ., College of Agric. Sci., Coop. Ext. Service, University Park, PA.
- Lemberg, B., W.T. McSweeney, and L.E. Lanyon. 1992. An information management technology program for an ex ante nutrient loss reduction from farms. *J. Environ. Qual.* 21:574–578.
- Lynch, P.B., and P.J. Caffrey. 1997. Phosphorus requirements for animal production. p. 283–296. *In* H. Tunney et al. (ed.) Phosphorus loss from soil to water. CAB Int., Oxon, UK.
- Magette, W.L. 1998. Factors affecting losses of nutrients from agricultural systems and delivery to water resources. p. 7–31. *In* O.T. Carton (ed.) Draft guidelines for nutrient use in intensive agricultural enterprises. Teagasc, Johnstown Castle, Wexford, Ireland.
- Magette, W.L., and O.T. Carton. 1997. Agricultural pollution control. p. 781–797. *In* G. Kiely (ed.) Environmental Engineering, McGraw Hill, London.
- Magette, W.L., O.T. Carton, and V. Power. 1998. Implications of the Irish EPA's new licensing requirement for intensive agricultural enterprises. p. 25–28. *In* T. Matsunaka. (ed.) Environmentally friendly management of farm animal waste. Kikanshi Insatsu, Sapporo, Japan.
- Moore, P.A., and D.M. Miller. 1994. Decreasing phosphorus solubility in poultry litter with aluminum, calcium, and iron amendments. *J. Environ. Qual.* 23:325–330.
- Perkinson, R. 1994. Evolution of nutrient management in the Chesapeake region. *J. Soil Water Conserv.* 49:87–88.
- Thompson, R.B., D. Morse, K.A. Kelling, and L.E. Lanyon. 1997. Computer programs that calculate manure application rates. *J. Prod. Agric.* 10:58–69.
- Tunney, H., R.H. Foy, and O.T. Carton. 1998. Phosphorus inputs to water from diffuse agricultural sources. p. 25–39. *In* J.G. Wilson (ed.) Eutrophication in Irish waters. Royal Irish Acad., Dublin.
- Young, C.E., B.M. Crowder, J.S. Shortle, and J.R. Alwang. 1985. Nutrient management on dairy farms in southeastern Pennsylvania. *J. Soil Water Conserv.* 40:443–445.