SYMPOSIUM: DAIRY MANURE AND WASTE MANAGEMENT

Dairy Manure and Plant Nutrient Management Issues Affecting Water Quality and the Dairy Industry

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ABSTRACT

Specific requirements for dairy manure management to protect water quality from nutrient pollution depend on the organization of individual farms. Further, the management requirements and options are different for point (farmstead) and nonpoint (field-applied) sources of pollution from farms. A formal management process can guide decisions about existing crop nutrient utilization potential, provide a framework for tracking nutrients supplied to crops, and identify future requirements for dairy manure management to protect water quality. Farm managers can use the process to plan daily activities, to assess annual nutrient management performance, and to chart future requirements as herd size increases. Agronomic measures of nutrient balance and tracking of inputs and outputs for various farm management units can provide the quantitative basis for management to allocate better manure to fields, to modify dairy rations, or to develop alternatives to on-farm manure application. Changes in agricultural production since World War II have contributed to a shift from land-based dairy production to a reliance on capital factors of production supplied by the dairy industry. Meanwhile, management of dairy manure to meet increasingly stringent water quality protection requirements is still a land-based activity. Involving the dairy industry and off-farm stakeholders as participants in the management process for field, farm, and regional dairy production can be the basis for decision-making to reconcile the sometimes conflicting demands of production and water quality protection. (Key words: purchased feeds, farm policy, pollution, nitrate nitrogen)

INTRODUCTION

Management requirements for handling dairy manure to protect water quality depend on the organization of each farm, including the natural resources, structures and facilities, and goals of the farmer and farm family. The unique history of each farm and each region (including farms and the associated dairy industry, communities, and natural resources) results from the interactions between the evolving local and global surroundings and individual manager decisions. Farmer decisions also influence the course of events in the surroundings so that farms and their surroundings actually coevolve. Positive feedback between the farms and their surroundings may stimulate the growth of individual dairy cow productivity and of farm and regional milk production. Negative feedback may cause atrophy of farms and regional dairying activity. Contemporary issues in dairy manure management result from the dramatic changes in off-farm technologies that enhance productivity and production and from the heightened sensibilities to the environmental consequences of agricultural practices in the farm surroundings.

The challenge of dairy manure management to protect water quality is to reconcile the management emphasis on individual dairy cow productivity and on total farm production with the fundamental relationships of plant nutrients in crop and animal production and in the environment. Dairy manure management involves more than the "best" agronomic practices. Furthermore, dairy manure management for water quality protection is more than responses to correct contemporary problems. Manure management must also be considered...
as changes are planned for dairy farms and production regions.

POLLUTION SOURCES AND WATER RESOURCES

Sources of plant nutrient pollution are usually described as point or nonpoint (Table 1). Agriculture has been recognized primarily as a nonpoint, or diffuse, pollution source. Nevertheless, parts of a dairy farm, such as the farmstead, may be more similar to point sources, which are easily identified. The National Pollutant Discharge Elimination System (24) historically has limited point source considerations to concentrated animal feeding operations of more than 700 cows (1000 animal units). The permit process focuses primarily on the management of surface water runoff. In the future, as water quality concerns and herd sizes increase, more farms are likely to be considered as point sources of pollution. Further, water quality protection is expanding to include groundwater. Approaches to groundwater protection around livestock facilities may focus on well-defined areas, such as protection of well heads and of manure and feed storages. Farmstead assessment programs have been developed to help to identify the needs in these critical areas (10).

These point sources of pollution have characteristics similar to traditional point pollution sources in other industries in that they are generally addressed by technology-based approaches. Acceptable technologies can be readily identified and installed at the site. For instance, runoff management structures and facilities to meet the zero discharge targets of the National Pollutant Discharge Elimination System are designed to contain 25-yr, 24-h frequency storms. Successful installation of these technologies is generally recognized as compliance with environmental protection requirements. Once installed, many runoff control structures or farmstead improvements function as designed with few changes and with minimal management except for routine maintenance. The exception is the irrigation of contained runoff to crop fields, which links the farmstead with its point source character to the very different nonpoint source pollution from crop fields.

Farm fields are classic nonpoint sources of pollution (Table 1). Pollutant discharges from these areas are not confined to a specific location, or "end-of-pipe". The discharges, such as NO3 N leaching through the plant root zone, actually may be invisible to the normal observer. Each unit of land may contribute only small quantities of pollutants that are not significant until combined with the pollution from other land areas. The consequences of nonpoint source pollution may be observed far from the original discharge areas, and the benefit of reduced nonpoint source pollution may only partially accrue to the polluter. Changes in land use to reduce nonpoint pollution may be considerably different than for point source pollution.

Traditional erosion control and surface water runoff management generally protects surface waters from nonpoint source pollution, although controlling losses of P in surface runoff can be difficult as soil P increases (6). In contrast to surface water protection, ground water protection, especially from NO3 N contamination, is a complex function of field management and unpredictable hydrologic conditions.

Nutrient utilization potential and dairy manure management to protect water quality are closely related to crop yield. Agronomic and management decisions and the factors influencing those decisions, as well as quirks of seasonal weather, influence crop yield. Field-

<table>
<thead>
<tr>
<th>Source of pollution</th>
<th>Surface waters</th>
<th>Groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point</td>
<td>Manage runoff from facilities and farmstead</td>
<td>Protect well heads Malone manure and feed storages Manage field activities</td>
</tr>
<tr>
<td>Nonpoint</td>
<td>Implement erosion control practices</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 1. The nutrient management focus around dairy farms to protect surface water and groundwater quality.
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Based management to control pollution requires constant attention and the flexibility to respond to unfolding management situations within and between growing seasons. In the future, timing of manure applications and the appropriate handling procedures are likely to be prescribed for field management. Applications close to the crop growing season and incorporation of manure to reduce potential ammonia volatilization are already in place in other countries (25). These technology-based approaches do not ensure satisfactory performance if the projected crop yields are not achieved. Porter (21) suggests that, for complex management situations, specification of expected outcomes instead of particular methods can stimulate innovation rather than impose unproductive handicaps.

Nonpoint source management is complicated by the potential for surface water protection practices to aggravate groundwater impacts. Additional infiltrating water from runoff control practices may move excess nitrate through the crop root zone into groundwater (5). Target NO₃ N concentrations for percolating soil water may be difficult to achieve because of the low efficiency of N utilization by crops such as corn (22). Magette et al. (18) observed that annual variations in crop production because of weather may result in frequent discharges of NO₃ N from crop fields into groundwater that exceed the maximum critical level of 10 mg/L of NO₃ N even when recommended nutrient management practices are followed. The nutrient selected as the management criterion will influence the rates of manure application and ultimately the costs of compliance. Restriction of P applications to balance crop removal limits manure applications more than supplying available N requirements of the plants (26).

Farms have different nutrient status based on soil characteristics, history of fertilizer use, and the sources of feeds fed to the animals (1, 7). On some farms, soil nutrient levels may be low in the fields, little fertilizer may be used, and the crops produced may provide the major fraction of the animal rations. Dairy manure applications to fields on those farms are unlikely to pose an environmental threat if the manure is managed according to normal agronomic guidelines. In contrast to such “self-sufficient” farms, other farms rely heavily on fertilizers or off-farm feeds for the animals.

As the focus of a farm shifts from the productivity of the land base to the purchase of feed and other materials to support the animals, crop production on that land base may be inadequate to utilize fully the residual nutrients of animal manure in an environmentally acceptable way. Increased crop yields and intensified cropping patterns are possible mechanisms to increase the nutrient utilization capacity. However, dairy farm record information indicates that, as herd size increased in the northeastern US, the land available per cow decreased by 20%, and the feed purchased per cow increased by over 15% (23). These two trends, one of decreasing on-farm crop production per cow and the other of increasing amounts of nutrients brought onto the farms in purchased feeds, conflict with the potential for on-farm utilization of the resulting residual nutrients in manure.

A FORMAL MANAGEMENT PROCESS

Dairy manure management for water quality protection is different for strategic, tactical, and operational management. Strategic decisions specify the long-term goals for the farm. Operational management determines the daily activities, and tactical management applies to the intermediate period. The technical information for operational management is generally very farm-specific, subject to rapid changes, and relatively well structured. The nature of the farm organization, the resources available for management, and the purposes of management are all fixed at the operational level. Tactical information is more comprehensive than the operational information and integrates details of farm organization with general management guidelines. At the tactical level, there is flexibility in allocation of organizational resources to meet management goals. Strategic management information comes from many sources, both from the farm and from off the farm and is relatively poorly structured and often subjective. Farm goals and resources are the essential variables of strategic management.

The proposed formal management process is typical of operations management in the business world (11, 14) and involves planning, implementation, and management control.
Management is iterative and focuses on decision-making about the physical production process. Further, the process may be applied at each level of decision making by management. The iterative process may be applied to operational management to ensure that manure is spread at the appropriate rate in the correct field on the right day as prescribed in the tactical plan. Those involved in the operational events will compile appropriate input and output records describing the actual activities. Operational managers will monitor the nutrient status of growing crops during the season to determine that the nutrients applied are adequate to meet the projected yields. Additional nutrients may be supplied if the crops appear to be deficient. If pest pressure or some other factor appears to be limiting crop growth, appropriate action to ensure crop productivity will be required.

Annual allocation plans for plant nutrient supplies from all sources, including manure and fertilizers, in accordance with the anticipated plant nutrient utilization by the crops and the relevant planning criteria for water quality protection are examples of the outcomes of tactical management. The tactical plan will provide the framework for the daily operational activities, will specify the records to be collected during implementation, and will provide the basis for an annual assessment of management performance.

Tactical performance assessments can be used to enhance subsequent operational management. If planned crop yields are not being achieved, production problems may exist, ranging from crop variety selection to machinery operation and unexpected field conditions. Tactical assessments also can be used as input to the strategic decision-making process. If the projected annual performance targets are not achieved, then some additional strategic action may be needed. For instance, if field nutrient balances consistently exceed the performance criteria and all appropriate tactical and operational actions have been taken, then a strategic decision concerning the "disposal" of the excess nutrients may be necessary. Alternatively, it may be appropriate for the various stakeholders in dairy production and water quality protection to reevaluate the performance criteria.

The specific technical support required for the management process depends on the management level and activity. Knowledge of a scientific discipline is likely to be most relevant to tactical management decisions and to some aspects of field operations. So many other factors influence farm decision-making at the strategic level that detailed knowledge of scientific disciplines will be less important. Flexibility in operational management will be required to formulate an action plan based on the particular sequence of events and conditions that develop within the framework of the tactical plan. Products, practices, and information from science and industry have important roles in the tactical and operational management. The type and availability of technical support for a farm or a dairy region significantly influence the character of the farm or region. Therefore, as part of the surroundings, science and industry also play an indirect role in the strategic evolution of farms.

Performance criteria for the management activities come from a variety of sources. Through market purchases or local ordinances, the general public can set both expectations for farm management and rewards for farming practices. Governmental agencies have a significant role in protecting the health, safety, and welfare of the people. The criteria for controlling nonpoint sources of pollution may need to emphasize performance standards based on specific management outcomes (such as some indicator of nutrient balance) more than installation of individual technologies (such as manure storage structures). Specification criteria that limit activities, such as manure application within a certain distance of an open sinkhole, should be reserved for situations that cannot be addressed by criteria based on measurable outcomes. Because outcomes can be achieved in many ways, these criteria are better adapted to the real operational situations encountered in field management. A balanced approach to nutrient management performance criteria is likely to include both outcome and specification criteria. In any case, the criteria may need to ensure society of responsible management activity rather than to specify discharge criteria. Criteria for discharge of nutrients leaving the root zone may be too difficult to measure and may be out of the manager’s control because of the influence of weather on soil water movement.
MEASURING NUTRIENT MOVEMENT

A key element in plant nutrient management of the future is development of an approach that identifies and measures the process variables in order to meet the performance criteria. The ratio of a process outcome to the expected value is an example of an assessment to measure management success. Management response depends on the relationship of the outcome to a specified control range. In management by exception, no action is needed when a value falls within the acceptable range. If the value is outside the range, then corrective action may be required. Observations of interpretive variables, secondary features of the production process that influence but do not describe the process, can provide background information for management options to change performance. For instance, as part of the tactical management plan, a manager may need to know little about the details of corn production management in a particular year if crop yields goals are met. If yields goals are not met, then information on weather conditions or some key features of production may be useful. If the production for a particular year appears to be simply an anomaly compared with that during the last 5 yr, there may be little need to alter the tactical plan drastically in the next implementation cycle. A large amount of information is potentially available on a farm. Restraint should be exercised in the selection of interpretive variables and in the extent of the observations. Determining appropriate process variables and defining performance criteria are critical needs of contemporary management.

Agronomic nutrient balance can be a performance criterion in dairy manure management to protect water quality. The process of farm material transfer in and out of management units, ranging from individual fields to entire farms, can be measured. Tracking crop production, feed purchases, manure movement, wastewater irrigation, and other farm material movements through appropriate record keeping is a management activity that supports nutrient management implementation in the field and on the farm (15, 16). Nutrient balances can be calculated from the information assembled in this monitoring activity. Nutrient inputs and outputs are not likely to be exactly balanced (4, 9). Therefore, compliance must be established by a suitable performance range. Selection of such a range should include strategic considerations of the consequences of different ranges for dairy farms, the dairy industry, communities, and water quality.

An additional issue to be resolved in the establishment of performance expectations for dairy manure management is that, when dairy manure is applied, both N and P are applied. This pairing of nutrient applications in manure means that standards for N management may conflict with standards for P supply. Consequently, these plant nutrients cannot be treated independently, based on their agronomic characteristics, but must be treated as components of a farm material. Performance criteria need to reflect this association (17).

Farm practices to meet performance criteria for water quality protection are likely to vary among farms, depending upon the organization of each farm. The off-farm input use in the crop and animal production activities reflects the strategic goals of a farm. The activities on farms that rely heavily on off-farm inputs of fertilizers or feeds require much closer documentation of plant nutrient fate than farms with fewer off-farm inputs. Nutrient management for water quality protection is essentially related to the capability of the land-based crop production system to utilize nutrients. If the nutrient inputs from off-farm are limited, then the nutrients in the managed flows originate primarily from the land base to which dairy manure is applied. Therefore, the possibilities of overapplication of nutrients on these farms are limited to the supply, or stock, of nutrients on the farm. If this stock of nutrients is depleted through losses to the environment, crop production and then animal production will decline as a result of the ensuing deficiencies. The farmer will be prompted to correct the situation, or the farm will fail. When fertilizer is relied upon to replace (or exceed) losses or feed is imported to compensate for inadequate crop production, the potential for pollution is not limited to the original nutrient stock.

ORGANIZATION AND EVOLUTION OF FARMS

As farm organization changes, the nature of dairy manure and the sources of nutrients may change. Moving from solid or semisolid ma-
nure to separation of liquid and solids and to field irrigation of the liquid can shift the balance of field-applied N forms to more readily volatilized and more readily nitrified NH\textsubscript{3} and NH\textsubscript{4}. Further, the C:N ratio is reduced in the field-applied liquid following solids removal. More readily available N and relatively less C mean that management and timing of liquid dairy waste applications relative to crop utilization potential become more critical than when complex organic forms are significant N components in field-applied manure.

Increases in dairy herd size may shift the balance of the off-farm and on-farm ration components supplied (23). Under these circumstances, feeding of dairy animals can become less a function of the land base where the animals are housed and more related to the manager’s ability to assemble external factors of production at the dairy production location. This shift in the balance of production factors from land-based or natural resource-based to capital inputs can have far-ranging implications for the farm, the community, the environment, and the industry.

**PRODUCTION INCENTIVES AND LAND CONSTRAINTS**

Land-based agronomic recommendations and economic incentives for crop production can guide dairy manure management until the strategic emphasis of the farm shifts from production factors that are based on natural resources to those that are capital-based. Capital-based production factors are produced by other activities rather than simply being untransformed elements of nature. Fertilizers, feeds, structures, and equipment are examples of capital production factors and are different from the other major factors, labor and natural resources. Protection of water quality is an activity based on resources or land. Thus, dairy manure management for local crop production or for water quality protection will become increasingly less consistent with milk production goals that emphasize the use of capital factors of production.

Since World War II, there has been considerable emphasis and accomplishment in the production of corn and soybeans (that contributed to the availability of soybean oil meal) (2, 13). When the production of these easily transported commodities was combined with the recognition of the role of concentrates in dairy cow productivity, the groundwork for intensified dairy production was established (Figure 1). Dairy cow productivity and concentrate consumption per cow have increased together since the 1940s in the US (12, 13). Availability of purchased, rather than only home-grown, feeds also made it possible to increase the number of cows per farm beyond the crop production capability of the farm resources (12). Enhanced dairy cow productivity and greater milk production per farm based on more cows were complemented by the wide range of dairy cow productivity advancements and the development of suitable dairy herd production technologies. These changes from land-based production to capital-based production similarly intensified the urgency of the emerging issues of dairy manure management.

Increasing management of milk marketing through government programs also influenced the development of the dairy industry. Decreases in the relative milk price received by farmers through the 1980s continue to be another element in the intensification of production efforts (20). To maintain income when confronted with relative decreases in milk price, many farmers have increased productivity per cow (including increased concentrate feeding when grain prices are favorable) or increased the number of cows per farm. Future increases in the costs of the inputs for intensification could limit the suitability of these options. Throughout much of the postwar period, the per unit area productivity and the total production of feed grains and soybeans have continued to increase (13). Future trends of these feed crops will influence the feasibility of increasing concentrate feeding as a means to enhance milk production.

Unlike this pattern of intensification, the environmentally safe utilization of manure is linked primarily to the land base upon which the manure is produced. Milk producers are thus caught in the contradictory situation of responding to capital-based incentives to increase productivity and production and to increased emphasis on land-based requirements for environmental protection. Addressing environmental issues by requiring change in pro-

Producer behavior diminishes the significance of the rational connections that exist between contemporary patterns of dairy production and economic competitiveness. Further, it avoids the structural connections among those who have a stake in the dairy production process.

STAKEHOLDERS IN DAIRY MANURE MANAGEMENT

The dairy industry and various jurisdictional communities can adapt the management process and physical measurements framework described for individual farms to evaluate alternatives for future development in dairying regions. However, the emphasis will be on the strategic implications of change in the dairy industry. These groups need to develop an informed, strategic vision that reconciles production advances with the environmental constraints that will affect the industry. Industries and communities that focus on individual farmer responsibility or provide only enhanced support of operational activities for individual farms to meet new expectations without a corresponding strategic vision may not equitably distribute the responsibility for water quality protection or the burden of compliance.

Imposition of the “dairy rule” in Okeechobee County, Florida to address P pollution of the lake from dairy wastewater and runoff has had far-reaching consequences for dairy producers, the industry, and the community. Modification of dairy barn facilities to comply with the dairy rule, even with 75% of the cost shared by the state, still resulted in lost production during construction and increased costs of production of approximately $1.10/cwt for the expected life of the facilities (3). The per cow costs were greater on the smaller (<1000 cow) dairies. The buyout of 19 dairy barns in Okeechobee County resulted in >90.7 Gg/yr (>2 million cwt) less milk marketed, or

Figure 1. Relationships in the recent evolution of dairy manure management issues.
reduced sales of $30 to 34 million. Projections suggest that almost $50 million in economic activity and at least 465 jobs will be lost in the community (19).

The Okeechobee County experience suggests that the industry and the local community have genuine stakes in not only the impacts of changes in dairy farm management upon water quality but also the remediation consequences (Table 2).

Dairy manure management may seem to be a land-based responsibility of the milk producer to protect the water quality concerns of local or distant communities. However, the dairy industry has a stake in the use of capital factors of production in dairy production related to the supply and pricing of inputs as well as the demand and pricing of the outputs (milk and dairy products; perhaps culled cows and dairy calves). The infrastructure of local communities has often developed a dependence on the vigor of the dairy industry and the continuing supply of the capital factors. Distant communities have a stake in dairy production that ranges from a feed market to a steady and abundant supply of dairy products. Before the land-based dairy manure issues can be resolved, communities and the dairy industry must recognize their dependence on the conditions that have evolved.

ENVIRONMENTAL POLICY

The dairy industry in an intensive dairy production region may serve its clientele very efficiently, but new performance criteria dealing with the consequences of intensification on water quality may ultimately limit the apparent efficiency. For instance, the industry may need to consider the potential effect on dairy manure management of promoting individual cow productivity and increasing farm and regional production with imported feeds rather than considering only the business efficiencies associated with supporting a vigorous dairy area.

The unrestrained use of capital factors of production generally concentrates in areas where their adoption is most successful (8). The widespread adoption of successful dairy management practices, such as intensification of milk production per cow through purchased concentrates or increased number of cows per unit area in a location based on imported feeds, may generate problems associated with the land-based consequences of those practices. As dairy managers assume more responsibility for the control of production by depending upon capital inputs instead of natural resources, the need to consider potential water quality consequences becomes more compelling. A formal, participatory management process (14) that incorporates the business and biophysical dimensions of contemporary milk production can promote insights into the evolution of the industry and associated communities that may avoid the trauma of dairy dispersals and possible regional atrophy.

FEED CROPS FARM POLICY

Society at large may be changing perspectives, not just on water quality expectations, but also on government policies, such as farm programs, that encourage the cultivation of corn and soybeans. Reduced emphasis on research and development to increase productivity of corn and other feed crops, limited land areas for the expansion of feed crops, and fiscal constraints on federal government programs that promote feed crops production all influence the trend in feed crops production. Continuation of rapid increases in the availa-
bility of the primary feed concentrates (corn grain and soybean oil meal) that have shaped milk production is questionable. Without the increased productivity and production of feed crops through technological innovation and policy incentives, a significant subsidy to increased productivity and production of feedstuffs or extend the supplies of the ration policy incentives, a significant subsidy to somatotropin, may substitute for the primary ingredients that contribute to dairy cow productivity and total production per farm. These changes and the search for alternatives will affect not only the costs of milk production, but also the flexibility of milk producers to absorb the additional costs of water quality protection.

CONCLUSIONS
A formal participatory management process for field, farm, and regional production processes can be the basis for farm, industry, and community decisions about issues related to dairy manure management. The rapid transformation of the industry in the recent past has been based on special technological and policy circumstances. Sensitivity to perceived point and nonpoint source pollution from individual farms and uncertain growth in feed crop production require new visions, plans, and practices supported by new partnerships if dairying is to respond to the changing conditions.

REFERENCES
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14 Reference deleted in proof.