Nutrient Management on Dairy Farms - Development and Application of the Cornell University Nutrient Management Planning System – a Case Study

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■ Take Home Message

Most decisions made on dairy farms have traditionally revolved around the economic impact of the particular decision on the profitability of the enterprise. With expanded knowledge and an increase in herd size to maintain profitability and economic sustainability, environmental sustainability has become as important an issue as profitability. With a greater emphasis on environmental issues, decisions become much more global, and the amount of information that needs to be accounted for can be overwhelming. Integrating this knowledge to make economic and environmentally sustainable decisions requires new tools. This paper describes the development of some of these tools and how application of them to make environmentally sustainable nutrition and cropping decisions potentially increases the overall profitability of dairy farms in New York State.

■ Introduction

In New York State, dairy farms account for a high proportion of all agricultural economic activity. To maintain the New York agricultural industry (both producers and service providers), dairy farms must be sustainable. Recognizing this, a multi-disciplinary group of Cornell faculty, staff, students, extension agents and farmers have been working together since 1993 to develop a process for integrating scientific knowledge necessary to improve dairy farm sustainability. ***This group defined sustainability as maintaining or improving profitability while protecting the environment***. Historically, environmental implications of dairy farming have been poorly understood and consequently, dairy farms have made decisions based more on economic than on environmental considerations (Crosscombe and Ewert, 1996). Now, however the environmental protection component of dairy farm sustainability may become the first limiting factor with the new USDA-EPA requirements for comprehensive nutrient management planning to protect water quality.

The purpose of this paper is to summarize the research we have conducted to understand the process needed for whole farm nutrient management, and the development and implementation of software tools for use by planners in developing whole farm nutrient management plans.

▪ Dairy Farming and Water Quality

Nutrients concentrate on livestock farms when more nutrients are imported as feed and fertilizer than are exported as products sold. Mass nutrient balances indicate more than two-thirds of the N, P and K imported on many dairy farms each year as purchased feed, fertilizer and N fixation remain on the farm (Klausner, 1993). However, data is lacking that relates this accumulation of nutrients to water quality.

▪ Is There a Problem?

We conducted two studies on dairy farms that relate accumulation of nutrients to water quality. The first was a dairy farm with 320 milking cows and 275 hectares in cultivated crops (primarily corn and alfalfa in rotation) selling 3,743,636 kg of milk/year. The soils are well drained silt loam and a nutrient management plan to minimize fertilizer purchases and hydrological risk developed by the farm's crop advisor was being followed. Nutrient losses from surface run-off and groundwater leaching were predicted using complex models (Hutson, et al., 1998). A groundwater-leaching model (LEACHN) predicted that the losses of N to the environment (volatilization from manure storage, leaching, and de-nitrification) were 35,364 kg N/year. Thus, 67 - 75% of the retained N, i.e. the surplus between inputs and products sold, was projected to escape into the off-farm environment (Hutson, et al., 1998). About 10% of this excess N would be expected to leach into the groundwater. Leaching is greater on the better-drained soils with 70 % of the leaching predicted to occur on 25% of the land area. The model predicted that the soil type was more critical to the amount of N leached than the crop. This study demonstrated the usefulness of this model for identifying the hydrologically sensitive areas on the farm.

A water monitoring program was conducted on this farm in which actual leaching and runoff of nutrients were measured by identifying an area drained by a single stream (drainage basin) and monitoring the concentrations of nitrate-nitrite nitrogen (N), phosphorus (P) and total solids in the stream draining that basin (Houser, et al., 1996). The geohydrology of the area indicated that the small stream that drains the sampling site selected was not charged by any subsurface flows other than that which leaches through or runs off the delineated drainage basin. During the period measured (April 26 to November 22 in 1995), the concentration of N and P averaged 14.4 ppm nitrate N and 0.41 ppm of total P, respectively. These levels exceeded the US federal water quality standard for groundwater (10 ppm N and 0.10 ppm P). This data indicates nutrients can reach ground and surface water from the dairy farm through surface runoff and leaching.

The second study involved evaluating the long-term environmental impact of dairy farming on well water quality at the Cornell Animal Science Teaching and Research Farm (Wang, et al., 1999). The farm had 321 lactating dairy cows that produced 2,501,818 kg of milk in 1979. By 1994, lactating cow numbers increased only 7.2% but milk production had increased 44% to 3,603,634 kg. During that period cropland changed very little, with an average of 385 hectares, primarily corn and alfalfa in rotation, producing the forage for the dairy herd. Almost all of the concentrates used were imported as purchased feed. The farmland is typical of that used for dairy farming in New York, with the crops being grown and most of the manure applied on the valley floor, which contains well-drained soils. The steep valley sides are mostly medium to poorly drained soils in permanent grassland. A land divide runs through the farm with the area on the north side draining into the St. Lawrence River and the south draining into the Susquehana River. The majority of the drainage is as groundwater. Water in wells in the intensively farmed valley floor (four wells located in a 28 hectare field and one well located in a 10 hectare field; well drained sandy loam soil) was sampled from 1979 to 1994 to monitor nutrient concentrations during that period. Mass nutrient balances (N, P, and K) were constructed using baseline (1979) and current data and changes have been related to changes in well water quality (Wang, et al., 1999).

The amount of imported N increased two fold during this period, as the result of increased imported feeds to support the 44% increase in milk production over the 15 year period of the study. The four wells in the 38 hectare field had an average increase of 54% in nitrate concentration in the water (3.24 ppm in 1979; 5.00 ppm in 1994). The well in the 10 hectare field contained 7 ppm in 1979 and had increased to 12 ppm by 1992, which exceeds the federal water quality standard of 10 ppm. During this time, the concentration of N in wells in the unfarmed hillside area remained small (0.6 ppm in 1992-1994). This has an important dilution effect, as 60% of the groundwater on this farm comes from seepage from the hillside area. Soil test P in the intensively cropped valley floor increased from 7 kg/ha in 1979 to 30 kg/ha in 1994. One way of evaluating the potential for water quality risk is the concentration of manure nutrients applied per unit of land. In the first and second studies, manure application averaged 185 and 170 kg of N and 28 and 32 kg of P per hectare, respectively. On both of these farms, accumulated nutrients at this level did have an impact on water quality.

▪ What can be done?

Based on these studies, we believe integrated whole farm nutrient management planning is needed to minimize the potential for increasing the concentration of nutrients in surface and ground water above acceptable limits. We propose three strategies for nutrient management planning: 1) Minimize N and P used per kg of milk sold by integrating animal and crop nutrient management; 2) Develop manure management systems that maximize recycling of nutrients and minimize potential for leakage of nutrients and pathogens into surface and ground water; and 3) Develop viable alternatives for removing excess nutrients from the farm.

A total of 25 Cornell University scientists across several disciplines (soils and crops, animal nutrition, veterinary science, engineering, economics, and integrated pest management) have been developing processes to improve whole farm nutrient management. In a project starting in 1993, two dairy farms were used as case studies to develop a process for integrating scientific knowledge for whole farm nutrient management (Fox, et al. 1996a; Klausner, et al., 1996; Hutson, et al., 1996; 1998; Rasmussen, et al, 1996; Klausner, et al, 1998). Animal and agronomic nutrient management plans that decreased the net excess of nutrients on the farm (Klausner, et al., 1996; Hutson, et al., 1996) increased predicted farm profitability (Rasmussen, et al., 1996). Partial budgets predicted that net farm income would increase because of more efficient use of nutrients both by the animals and crops. To evaluate the sustainability of the case study farms, they found that a tremendous amount of data had to be collected and integrated. Most of the tools available to do this were workbooks or stand-alone software programs that were not linked or were incomplete. They concluded that making this type of analysis available to many farms in a timely fashion requires the development of a family of computerized decision aid tools, and that the use of these tools will promote animal and agronomic efficiency that will have the double benefit of decreasing nutrient excess on farms and increasing farm profitability.

▪ Development of Computer Tools for Whole Farm Nutrient Management

In 1995 the project's focus turned to developing a family of computerized tools needed to make dairy farms more economically and environmentally sustainable by increasing efficiency of nutrient and resource use on each unique farm (Fox, et al, 1996b). These tools are being developed through a partnership between Cornell University, New York City Watershed Agricultural Council (WAC), and New York State agencies responsible for developing regulations to protect water quality (National Resource Conservation Service (NRCS), Department of Environmental Conservation (DEC) and The Department of Agriculture and Markets). Initially the software was programmed into three Excel speadsheets: 1) animal nutrition 2) manure and crop management and 3) crop rotation planning (Tylutki and Fox, 1997; Bannon and Klausner, 1997; Kilcer, 1997). It was later determined that a more professional and flexible product could be produced by programming two modules, a herd module (CNCPS 4.0) and an agronomic module (Cornell Cropware), using Visual Basic for Windows. We are currently at a midpoint in this project. The whole herd nutrition and feed allocation module was released July 2000. The crops, soils and manure nutrient planning module is currently being programmed and is scheduled for release Winter 2001. We then plan to develop an economic and record keeping module that will integrate the animal and crop modules.

▪ Cornell Net Carbohydrate and Protein System 4.0

The Animal Nutrient Management component is a whole herd version of the Cornell Net Carbohydrate and Protein System (CNCPS version 4.0) for all classes of dairy, beef, and dual-purpose cattle (Fox et al., 2000). The CNCPS evaluates and balances least cost diets for each group based on farm specific animal nutrient requirements and feed nutrients available. It then computes returns over feed costs and predicts annual feed budgets and total herd N, P, and K excretion from home grown and purchased feed for each alternative nutrient management plan evaluated.

The mechanistic submodels to predict microbial growth from feed carbohydrate and protein fractions and their digestion and passage rates (Russell, et al., 1992; Sniffen, et al., 1992; O'Connor et al., 1993 Pitt, et al., 1996) were retained as in the CNCPS version 3.0 released in September 1994 and as released with the Beef NRC (National Research Council, 2000) level 2. The model provides variable metabolizable energy (ME) and protein (MP), and amino acid supplies from feeds, based on variations in DMI, feed composition and feed fiber characteristics. The version of CNCPS 3.0 in the Cornell Penn Miner (CPM) Dairy program contains this same sub-model to predict the supply of energy and protein for balancing with the CNCPS, but uses a modified and expanded feed library.

This version of the CNCPS allows input data for all groups of cattle in the herd to be saved. Two assumptions are made in the initial phases of developing a nutrient management plan: 1) the herd is in a steady-state condition (neither expanding nor reducing herd numbers), and 2) the rations being fed are representative of the whole year. Additional inputs are required by CNCPS version 4.0. These include: group name, number of animals in the group, level of refusals targeted, and number of days to feed (365 is the default to represent steady-state). In addition to the importance of nutrient management planning, the feed budgets calculated by the modified CNCPS can be used for other purposes including planning for expansion and commodity purchases for risk management programs.

■ Cornell Cropware

The basis and approach for the Cornell Cropware program was published by Klausner and Halbohm (1995), Klausner (1997), Bannon and Klausner (1997) and Klausner et al. (1998). It contains a decision making component regarding the distribution of manure and supplemental fertilizer recommendations (Klausner, et al., 1998). The Nutrient Management Planning spreadsheet, released in 1997, is being revised to include the following features:

- Provides an agronomic database for each farm field including rotation, soil attributes, crop nutrient requirements, hydrologic sensitivity, past and planned manure application, environmental risk factors including P index (surface runoff) and N leaching,
- Cornell recommendations for waste and fertilizer nutrient application (N, P205, K20) for each field to meet crop requirements, considering nutrient priority and accounting for expected yield, prior crop, soil available nutrients, and previous manure applications,
- Estimated total manure, N, P_20_5 and K_20 mass balances based on manure nutrients available and crop needs, considering planned crop rotation, waste incorporation strategies and land acres to be spread on.
- Waste spreading schedules for each field (loads by spreader type), considering field restraints and crop requirements,
- Waste requirement by month, including estimation of storage sizing requirements,
- Livestock summary,
- Easy to use format,
- User customized output that facilitates analysis of “what-if” scenarios.
- Electronic download of soil test results, and
- Standard programming procedures for quality assurance, including program documentation and organization, and error trapping by alpha and beta testing.

The software is written in Visual Basic for Windows, which is an object oriented language that will allow integration of the components and provides a modular structure for ease of updating and revising. Included will be a system for common data entry that will provide farm data to all of the components, integration of all the software tools, and capability to interact with farm records.

■ Evaluation of the CuNMPS on Dairy Farms

As software development proceeds, whole farm nutrient management strategies are being tested on two case study dairy farms and on one beef farm. The first dairy farm is a 500 cow dairy near Homer, NY; details of this study have been reported previously (Tylutki and Fox, 1997; Bannon and Klausner, 1997; Kilcer, 1997; Tylutki, et al., 1999; Tylutki and Fox, 2000). This farm has as a high priority the development and implementation of accurate, farm specific nutrient management plans, because it is situated over an aquifer that provides water for a nearby village and city, and has a protected trout stream running through the farm. We have found that the first step in developing an integrated animal and plant nutrient management plan is to evaluate the current diets for each group of cattle on the farm, and to accurately predict the current annual herd feed requirements and nutrient excretion. The next step is to develop alternative rations and feed budgets that will improve efficiency of use of nutrients and reduce excess nutrients on the farm, considering the resources available (soil, equipment, storage facilities, economics). The CNCPS version 4.0 was used to predict site-specific nutrient requirements, nutrient balances, feed budgets, manure production and N, P, and K excretion for each group of cattle on the farm with the current program. This result was then used by the crop rotation software to evaluate the match of the current feeding program with current crop rotations and yields by field and in total (Kilcer, 1997). Then, alternatives to improve nutrient use in the herd were developed with the CNCPS, and then were evaluated with the crop rotation software. The Nutrient Management Planning for Crop Production was used to predict mass nutrient balances, distribution of manure and supplemental fertilizer recommendations for the current program and each alternative considered.

The mass nutrient balance on this farm indicated that with the current crop production and feeding program, a high proportion of the nutrients imported remain on the farm (77% for N, 68% for P, and 65% for K). Only 36% of the N, 30% of the P, and 22% of the K fed are exported as milk or cattle sold, similar to other NY dairy farms (Klausner, 1993). The major source of excess nutrients on the farm is imported feed, since only 9% of the N, 13% of the P, and none of the K, respectively comes from purchased fertilizer because manure is managed to be used as the primary source of nutrients. Normally, purchased fertilizer accounts for about one third of the imported nutrients (Klausner, 1993). As various phases of the nutrient management plan have been implemented, the farm reduced use of commercial fertilizer to that recommended by the nutrient management plan with no yield loss.

Of the sources of imported nutrients on this case study farm (nitrogen fixation, fertilizer, feed) the mass balance indicated purchased feeds accounted for 74% of the N, 77% of the P, and 50% of the K imported. The initial evaluation indicated that the current feeding program is based on 54% purchased feed, typical for many dairy farms, including those based on pasture. The feed costs are $1,900/day for this farm, including both home-raised and purchased feeds. Manure production was predicted to be 39,090 kg daily, agreeing well with the manure production estimated in the crop nutrient management planning program (Bannon and Klausner, 1997), when wash water from the milking system and bedding are added. The crop rotation evaluation (Kilcer, 1997) indicates a major factor causing importation of nutrients is this farm has not been able to produce all of the forage needs and much of the protein required by the cattle.

A new feeding and cropping program was designed to minimize purchased feeds to minimize nutrient imports and reduce costs. The focus was on improving management of the hay crops to increase both yield and quality to allow for more home-grown forage to be fed while maintaining, or improving, milk production. Intensively managed grass was substituted for corn on the wet, erodable hillsides, and a feeding and management program was designed to provide and utilize high quality grass forage in the feeding program and more accurate ration balancing with the use of CNCPS 4.0 to reduce imported nutrients. Ration cost was predicted to be decreased $110 per day ($40,150 annually) by this change. These changes increase the percent of the ration that was home raised to 78%, reducing purchased N, P and K by 55, 48, and 82%, respectively. In the new plan, only the flat valley land is rotated with corn and alfalfa, and hectares seeded each year are reduced 22% by this change. However, an additional silo must be constructed to add this extra source of forage, and equipment changes must be made to permit rapid, early harvest of the grass forage. Critical to making farm specific plans work to reduce nutrient loading is the development of a Total Quality Management Program for nutrients (Tylutki and Fox, 2000). In 2000, we began implementing the new feeding program and will be measuring the impact of the changes made on nutrient balances and economic return.

The second dairy farm is the Cornell Teaching and Research Center, a 350 cow dairy. The focus on that farm is to identify and apply the process needed for integrating crop production with herd nutrition to most efficiently provide nutrients needed by the dairy herd (Wang, et al. 2000b). The first step involved development and evaluation of a linear optimization component for the CNCPS 4.0 that can be used to optimize available feed resources by allocating them across the groups in the dairy herd based on best use of their content of nutrients (Tedeschi, et al., 2000; Wang, et al., 2000a). After development, this model was applied to predict the nutritionally and economically optimal dairy herd feeding and crop management strategies and to evaluate the environmental and economic consequences for different alternatives available on this farm (Wang, et al. 2000b). Feeding the lactating cows according to their production level vs all fed one ration was predicted to reduce annual N, P, and K mass balance by 14, 9, and 9%, respectively. Improving forage quality was predicted to improve returns over feed costs by $28,634 per year. Improving forage yields to the maximum potential for the farm was predicted to improve annual mass balance for N, P and K by 29, 49, and 105%, respectively and to increase annual returns over feed costs by $70,579. Changing crop production to more grass and corn and less alfalfa was predicted to reduce annual N and K mass balances by 19 and 31%, respectively and to increase annual returns over feed costs by $39,383. By changing four alternatives together (grouping lactating cows by level of milk production, improving forage quality, optimizing crop yield and rotation), N, P and K mass balance is expected to be reduced 52, 55, and 97%, respectively. Increasing milk sold 10% by increasing production per cow by 10% vs expanding herd size at the same production level is expected to lower mass balance for N, P, and K by 8, 12, and 24%, respectively with a $34,132 higher return over feed costs. These studies indicate optimizing forage management (quality, yield, and allocation across the herd) to optimize nutrient use can reduce risk to water quality while improving farm profitability. We are now in the intervention phase in which we are implementing these changes and are measuring the impact of these changes on nutrient balances and cost of milk production.

▪ Plans for Implementation and Future Development

The application of the research presented involves providing the Cornell University Nutrient Management Planning System (CuNMPS) to planners for use statewide. The CuNMPS can then be used to develop, for a particular farm, the most sustainable dairy farm nutrient management program while meeting State and Federal guidelines for a comprehensive nutrient management plan to protect the environment. The herd nutrition component, CNCPS version 4, was released in June 2000, on a CD containing the program, documentation of the program, and 46 papers published on it. This CD is available to any New York or academic user at no charge and any out of state commercial user at a nominal cost by contacting us at our email address (cunmps@cornell.edu). The Cornell Cropware will be available in winter of 2001. Our partners in this project (New York City Watershed Ag Council, New York Natural Resource Conservation Service, New York Department of Environmental Conservation, and New York State Department of Agriculture and markets) expect the CuNMPS to be a key component used in developing Comprehensive Nutrient Management Plans (CNMP) for Animal feeding operations (AFO) on New York farms by farm planners (National Resource Conservation Service and Soil and Water Conservation District planners, Cornell Cooperative Extension, Watershed Planners, and private sector feeding and crop advisors).

We intend to support this network of users by providing revised nutrient management computer software programs based on new scientific findings in order to improve their accuracy, especially as we gain field experience in their use. The herd nutrition software is dynamic and universal, using inputs that describe the herd, feeds available, and environmental conditions to compute supplemental nutrient needs in any specific production situation. The first release of the crops, soil and manure management software uses averages from empirical relationships between fertilizer and manure applications and crop responses from small plot studies across New York State to make fertilizer recommendations. Thus the current software uses crop responses to N and P fertilization in an average year to make fertilizer recommendations. However, when weather conditions do not fit those average conditions, nutrient recommendations can be under or over actual plant requirements. Future versions being planned involve the development of a more dynamic approach for making N and P recommendations based on soil and current and expected weather conditions on a particular farm in the northeast and integrating Cornell CropWare with field mapping and GPS technology. The next CuNMP module will include crop record keeping capability, prediction of feed supply with alternative crop rotations, and partial budgeting analysis to project changes in farm income from alternative crop and nutrient management plans. Future versions will allow exchange of information between modules including feed production to the herd nutrition software, herd feed requirements and nutrient excretion to the crops and manure management software, and linkage of both to farm inventories and business records.

The continuing cooperative effort of university researchers, producers, agribusiness and government professionals is crucial in the development, implementation and support of nutrient management strategies of optimizing herd nutrition, minimizing nutrient excretion per unit of production, and identifying crop rotations that best meet herd requirements while making the best use of soil resources. ***Information and updates on the CuNMPS can be obtained by using our website (http://128.253.135.170) or email address (cunmps@cornell.edu)***.

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