# Nutrient Accumulations and Losses from Dairy Farm – Or – The Ins and Outs of Dairy Farming Systems

Marcus Hollmann
Department of Animal Science, Michigan State University, East Lansing

## Summary

This paper discusses a systems approach encompassing the entire farming and rural community involved with the dairy industry. Nutrient (or pollutant) accumulations and losses need to be evaluated on the basis of a whole system approach and compared against the outflow of products from the system. Furthermore, this system is embedded in an environment that consists of natural, social, political, economic, cultural, and technological influences, which change the system over time. Proactively initiating these changes and thereby influencing the environment increases the sustainability of the system. Dairy nutrition impacts not only the production of dairy cows, but also dramatically influences the environmental load of nutrients released from the cows. Dairy nutritionists play a vital role in communicating between producers and science and consequently, in initiating the changes needed to sustain the dairy industry.

## Introduction

Detrimental environmental impacts of N (e.g., the Dead Zone in the Mississippi River Delta) and P (e.g., eutrophication of the Chesapeake Bay) have led to regulations for manure nutrient application and nutrient management plans. Fortunately, true to the motto ‘what goes in must come out’, we are in position to control N and P excretion from dairy animals to a certain extent by adjusting dietary composition.

In the scope of this presentation, I want to take a different angle on manure production and nutrient accumulations and losses. My goal is to challenge the reader on hers or his perspective and present a somewhat different idea to approach the environmental impact of dairy nutrition by including possible future developments. I am not claiming that my position is right with respect to the future, but presenting an argument that comes from a perspective of trying to avoid getting the future wrong in contrast to the virtually impossible task of getting it absolutely right. The idea behind this statement is to evaluate different possible futures and establish strategies to proactively innovate and enhance a beneficial change rather than retroactively or passively adjust to changes (Bawden, 1998).

## Background

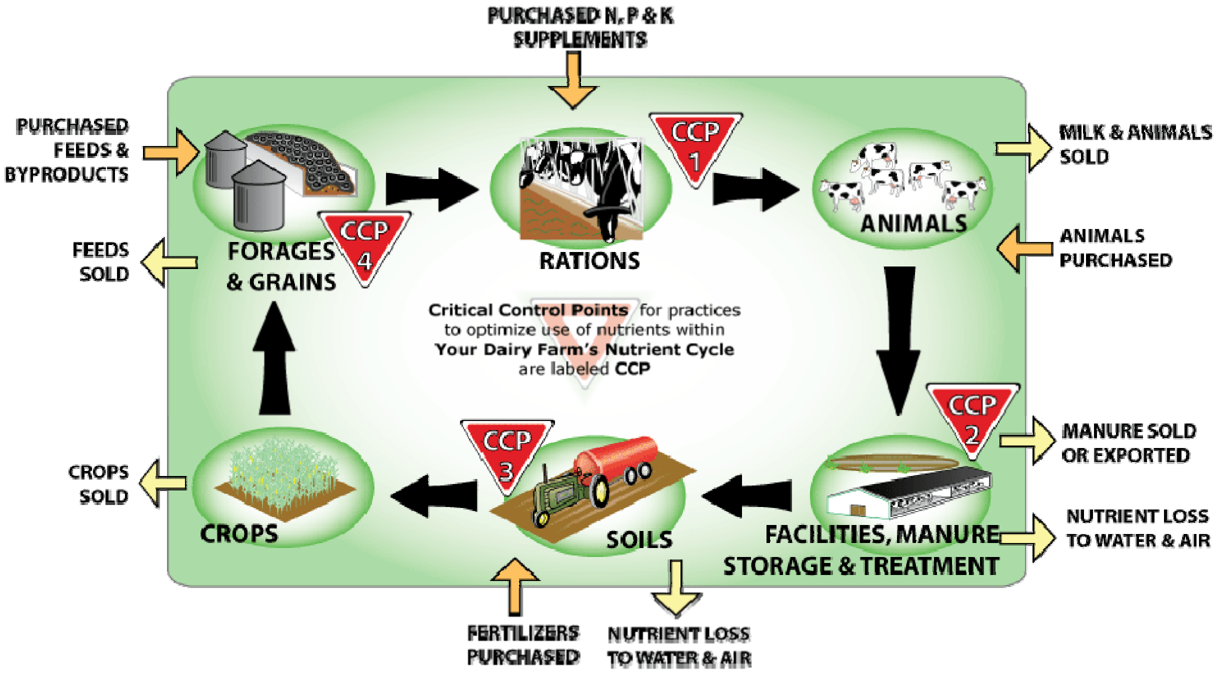
Over the last decade, feeding regimens of dairy cows and their replacements have been evaluated with regards to dietary concentrations of N and P. Practically, virtually all of the scientific studies have shown that dietary P can be reduced to 0.35% of the dry matter without negatively affecting lactational and reproductive performance of lactating dairy cows (Lopez et al., 2004). Reducing dietary P to 0.35% results directly in lower P excretion (Dou et al., 2002). Ebeling et al. (2002) collected runoff from cropland, where manure from cows fed either a low or high P diet had been applied at equal phosphate ($P_2O_5$) fertilization rates. Application of manure from the high P diet produced more dissolved reactive P in the runoff than from a low P diet (Ebeling et al., 2002). From a nutritional standpoint, there is absolutely no reason for supplementing dietary P above 0.35%, especially when land base is a limiting factor in a nutrient management plan.

Reducing crude protein concentrations closer to presumed requirements yields lower N excretions, mainly by reducing urea-N excretion (VandeHaar and St-Pierre, 2006). However, animal responses to changes in dietary crude protein are less predictable than a change in dietary P for two main reasons. Firstly, the animal does not have a requirement for N or crude protein *per se*; rather, it has a requirement for specific amino acids at the tissue level for protein synthesis, especially dietary essential amino acids. Secondly, microorganisms in the reticulo-rumen metabolize the rumen degradable portion of the dietary crude protein (RDP) and produce their own amino acids, which then flow to and are absorbed from the small intestine. However, the quantity of amino acids flowing from the rumen is rather unpredictable (Lapierre et al., 2006). Nonetheless, the effects of overfeeding N and P on excretion have been well documented in the research literature.

## Defining the system

At this point, I would like to digress and define The System more closely, as I will use it in the remainder of the paper. A simple system is represented by a single farm operation, importing feeds, fertilizer, equipment, and fuel/energy and exporting milk, meat, animals, manure, nutrients, pollutants and heat released into air and water (Figure 1). However, the boundaries of The System ought to be established broader to encompass its true complexity and the flow of nutrients and pollutants, which hardly can be reduced to a single farm. Indeed, *the farm represents a sub-system* of The System, which includes many farms and their aggregation and interactions, or for the current topic, dairy farms and related farming entities upstream and downstream in the flow of nutrients and supplies via land, water, and air. Moving hierarchically upwards from an individual farm towards a larger system establishes new emerging properties like trades and organizations that are not part of the lower system, but part of its environment or surroundings. Furthermore, The (larger) System ought to account for natural, social, political, economic, cultural, and technological influences from and effects on the environment surrounding The System, as it is part of even larger systems. Most modern dairy farm sub-systems already import from outside their boundaries to enhance their effectiveness at materials transfer and transformation, productivity, and profitability. To make matters even more challenging, the environment is not static, but dynamic and evolving over time. This dynamic drives The System and its sub-systems to change or evolve over time (Bawden, 1998). This systems approach should highlight two ideas: (i) that decisions made on an individual farm are in part driven by factors beyond the farm boundaries; and, consequently, (ii) that those decisions have impact on a greater scale than just the farm boundaries.

**Figure 1.** Whole farm nutrient cycle. Courtesy of Michigan State Univeristy Extension Dairy Team (2006).



## Nutrient flow patterns within agricultural production systems

Traditionally, nutrients have flowed within a cycle in the whole farm system. This cycle is by no means perpetual, as there are nutrient inflows and outflows from the whole farm (Figure 1). However, changes during the last century have extended the cycle of the nutrient flow over a larger area, emphasizing the need for a larger system that includes the single farm as a sub-system. Yet, based on the paradigm of the industry, improvements of labor and land productivity and value of products have been implemented over the same time period in dairy farms to increase economic efficiency and farm income (Hoshiba, 2002). However, industrial production is not a connected cycle, but straight-line, where raw materials are transformed into products, while left-over or byproducts of those processes are disposed of as waste. Dairying is largely inefficient in transforming dietary nutrients into milk and, to a lesser degree, meat. For example, efficiency of dietary N recaptured in milk rarely exceeds 30% under modern-day management; the remaining 70% are excreted (VandeHaar and St-Pierre, 2006). Moreover, huge volumes of byproduct (manure) accumulate during the transformation of feed to milk. Often, the production of milk is based on large imports of feed grains and in many cases forages from other sub-systems (other farms or even different geographical regions). Under these circumstances, manure is not seen as a valuable resource anymore, but as a waste product, which farmers have to get rid of. The once cyclic nutrient flow has given way to a straight-line industrial waste-disposal system. The subsequent environmental problems that we are currently experiencing are an artifact of enhancing economics without attention to the overall sustainabilism of the system (Hoshiba, 2002).

Fortunately, output of nutrients is predictable in cattle, especially for a herd of lactating cows, which have relatively small retention of N and P (Hollmann et al., 2006). “Virtually all of the chemicals excreted by and emitted from dairy cattle come from the rations” (D. K. Beede, 2006, TriState Dairy Nutrition Conference presentation). The animal does not make any new nutrients; it just transforms nutrients. Back to the initial statement of ‘what goes in must come out’, we can control what comes out and, to a lesser degree how it comes out, by controlling what goes in.

## Cost of manure production

Kawakami et al. (2000), as cited by Hoshiba (2002) proposed five criteria to evaluate agricultural production systems: (i) economic efficiency; (ii) input of fossil fuel (energy); (iii) environmental load; (iv) animal welfare; and, (v) human welfare. To date, economic efficiency or net farm income has been used almost solely to evaluate a farm operation. The reason may not only lie in the dependence on industrial production economics and ideas, but also in the ease of calculating the annual bottom line of a farm. It seems more challenging to base criteria (ii) through (v) on a comparable, simple number-system.

For the remainder, I will focus discussion on the environmental load, as it is impacted by diet and animal efficiency. The underlying definition of sustainability is referred to as ‘sustainability of stewardship’ or ecological sustainability (Douglass, 1984). Over the past years, most people have neglected to include a cost for manure production and nutrient excretion when determining the profitability of a farm. This becomes obvious using the simple and specific example of the exploding availability of corn distiller’s grains (**CDG**). Including CDG in a dairy cow’s ration may seem feasible at some feed prices. However, if supplementation of CDG to dairy cows increases the dietary P content above requirement, more P will be excreted inevitably, thus increasing the amount of P in the manure. For compliance with nutrient management plans, the land base needed to receive the manure and use it at agronomic rates escalates at the same rate that dietary P content rises above requirement of the cows. When considering CDG in diets, as an example, the cost of storing, hauling, and access to manure-spreadable land for the additional P must be added to the original cost of CDG.

The CDG example also may clarify the need to evaluate nutrient accumulation on the basis of The System. On an individual farm, one could simply refuse to feed CDG. However, CDG itself is produced as corn within The System. Therefore, the P content of CDG cycles within The System; it is neither added nor accumulated to The System. Yet, P may accumulate in certain sub-systems. Refusing to dispose (fed) CDG in one sub-system does not lead to outflow of P from The System. **The vast majority of P inflow to The System occurs as inorganic P fertilizer**. Phosphorus outflow from The System via milk and meat (Which even may re-enter The System as portion of human wastes!) does not counterbalance the P inflow; consequently, P accumulates within The System. The dairy industry taking on an industrial waste product (CDG) to transform it into a valuable good (milk) poses the question about the polluter and the remediator. Still, the cost of disposing waste and manure are not new *per se*; they rather were hidden, have been accumulating, and surface now as costs (with interest) of a wide variety of environmental impairments.

## Today's and tomorrow's needs of nutrient control

Much research and effort has been devoted to methods to limit pollution of waters with N and P. Although some questions remain, it is safe to say that the major issue is application of and compliance with the generally accepted practices and acceptable soil tests for sustainable crop removal. Nonetheless, in the face of constant changes one must look ahead and be prepared for tomorrow's challenges. Recently, emissions of pollutants from animal agriculture have received greater attention. Without a doubt, livestock producers will face regulations limiting release of methane, ammonia, nitrous oxides, volatile organic carbons (VOC), and particulate matter, to name the most important ones. Indeed, restrictions were put into law in California last year. Each of the pollutants does not stand alone; all of them are part of The System, where impacting one pollutant may impact other pollutants. Exclusively concentrating on reducing either air emissions or nutrient losses to runoff or leaching may worsen the impacts or amounts of another pollutant. Partially preventing ammonia emissions from manure increases its N content and, consequently, increases N that can become prone to runoff and leaching. As another example, (partial) defaunation of the rumen to reduce enteric methane generation may reduce ration dry matter digestibility and may sequentially decrease nitrogen digestibility and change N partitioning in the reticulo-rumen (Koenig et al., 2000). Because of a reduced dry matter digestibility, more organic matter is excreted, which in turn can be degraded during anaerobic storage generating potentially more methane than manure containing less organic matter (Hindrichsen et al., 2006).

Two major concerns surface, when abstracting the previous examples. Firstly, a change in one part of The System or a sub-system may affect the other sub-systems and the whole system. Nitrogen retention in the manure decreases air pollution with ammonia, but increases the risk of N loss to leaching, runoff, or both. Reducing enteric methane generation also may limit milk production, if dry matter digestibility is lowered. Secondly, a change in a sub-system may not affect the output from the overall system at all. This scenario occurs when increased N losses to waters offset better air quality because of less ammonia emission. Or, in the case of methane emission, its production is just shifted to a subsequent sub-system. Again, a holistic evaluation of nutrient flow within The System rather than in its sub-systems is warranted.

Further, we need to examine the inflow to and outflow from The System, which includes the entire U.S. dairy industry. If the milk production is kept constant, how will a proposed change affect the overall impact on the environment? Lowering dietary crude protein content to maximize N efficiency will reduce milk production per cow (VandeHaar and St-Pierre, 2006). More cows are needed in order to maintain the same milk production in The System. However, more cows also mean that more N is needed for maintenance. Still, N efficiency of the increased maintenance requirements is about 30%. Under these circumstances, N outflow is lower on a per-cow basis; yet, more cows are kept in The System. Obviously, the nutrient (pollutant) output has to be measured against the production of milk (or meat) to assess an overall reduction in output of nutrients (pollutants). However, I want to remind the reader that a complete evaluation of an agricultural production system and its sustainability also should include the fossil fuel input as well as animal welfare and human resource use and welfare.

We need to assess to our best ability the overall impact of changes made within a sub-system or system. The following example ties the use of energy (fossil fuel) into the assessment. Roasting soybeans increases the portion of rumen undegradable protein and we expect to feed cows more accurately to their requirements for rumen undegradable protein (RUP). Hence, replacing non-treated soybeans with roasted soybeans in a diet presumably reduces N excretion or enhances N efficiency. However, one cannot just evaluate this nutrition procedure by its cost-efficiency (Does the increase in milk production and its subsequent increased revenue offset the cost of roasting?), but one also has to question on the basis of an environmental load and the energy input. Does the reduction of N excretion offset the generation of pollutants from the fossil energy input for the roasting process?

This conceptual idea may be realized in three ways: (i) because farmers think it is morally the right thing to do; (ii) regulations; or, (iii) incentives. Moral and environmental awareness undoubtedly have been changing. However, the pace is too slow to substantially enhance environmental stewardship short and mid-term. And without a doubt, it ends when the profitability of the farm is in question. Regulations, like required nutrient management plans or caps on maximum emissions certainly do get attention; yet, they are rarely a favorite within the farming community. On the other hand, incentives are probably favored. However, someone will have to pay out incentives. Profitable and secured prices for products represent possibly the best approach. They would have to be campaigned in public as the social cost of a clean environment and poses a contradiction to the cheep-food policy of this country. As mentioned earlier, environmental impairment represents a hidden cost; but its retroactive cleanup may be more costly than its prevention. From this point of view, higher food prices in conjunction with limiting the environmental load generated during the process of food production would signify a shift of where society spends – overall hopefully less - money.

Another idea of incentives are climate exchange markets providing for emission offsets under cap and trade programs for trading and reduction of greenhouse gases (Shih et al., 2006). Establishing an emission cap will most likely pass on the cost of emission to energy prices. Returning back to the example of roasted soybeans, under a cap and trading program, the pollutants emitted during generating the energy are now part of the cost of energy. The farmer and his consultant can now determine, whether or not it is cost-effective to roast the beans and have the environmental load up front included as a dollar-value, which is very well comparable to the bottom line. Furthermore, the farmer may be able to trade or claim incentives for keeping the ammonia-emission from his farm under a certain cap. This may generate income to at least offset higher energy cost.

## Controlling nutrient accumulation and losses the day after tomorrow

No holds should be barred here! The idea of this section is designed neither to formulate concrete plans or tactics nor to be comprehensive and complete; but it is rather hoped to be creative and to encourage the reader to think of strategies for different future scenarios. Again, the future will have cultural believes, political frameworks, and economic bases that have evolved from today's environment. However, no one can be certain in which way and to what extent.

For example, enteric methane formation in ruminants through feeding strategies may be reduced from about 6% of dietary gross energy intake to about 2% (Johnson and Johnson, 1995). Furthermore, manure treatment may entirely eliminated methane generation from anaerobic storage (inhibition of methanogenesis or methane utilization for green energy), leading to an overall reduction in methane release by 78%; assuming that two-thirds of methane are of enteric origin. Dairy producers may be able to trade valuable methane credits at climate trading markets to offset their costs and generate additional income. This scenario is not only based on the assumption that methane production can be significantly reduced, but also that the cultural, social, and political framework is provided to generate carbon credits that have a sufficient value for livestock farmers.

Designs of facilities have changed tremendously over the past decade. There is no question, they will continue to change! Enclosed, ventilated barns provide the opportunity to force the out-coming air through a filter; again assuming the removed pollutants more than offset the energy input. Some facility designs may enable a certain degree of separation of urine and feces, leading to significant reductions in ammonia emissions.

Feeding regimens will change as well. Do we have to feed the same diet each day? Are there instances where feeding a different diet, e.g. varying in crude protein or fat content, at certain days of the week reduces the environmental load generated? Can we improve N efficiency to >40%? Can we formulate diets to acidify urine to reduce ammonification? What advances will biotechnology make, and, more importantly, which advances do we want it to make and what will be the costs – from an economical and a social/cultural perspective? What will be the acceptance of biotechnology by the consumer? Is the consumer willing to pay extra for food, granted that it decreases cost for handling environmental impairments and results in betterment of the environment?

This list is certainly neither comprehensive nor complete. Most importantly, we do not have the answers to these and many more questions. However, we need to develop strategies from these different scenarios in order to sustain dairy farming within its rural setting the day after tomorrow. Re-evaluation of the future using the strategies will already decrease the number of possible scenarios, as we can eliminate the ones that seem without reach using the adjusted strategies.

## The role of the nutritionist

The nutritionist for this discussion is synonymous with a consultant, extension agent, or feed company. Traditionally, the nutritionist utilizes research results and hers or his own experience to formulate diets that are expected to be profitable for clients. However, the flow of knowledge should not be a one-way street. Indeed, the nutritionist ought to report the practical findings, requests, and needs from the farm level back to the research community. The nutritionist is the viable link and communicator between the farmer and researcher. However, the modern nutritionist will increasingly have to recognize political, social, and cultural texture to serve the producer better. In my opinion, it is one opportunity and obligation of the herd nutritionist to inform and work with the producer to reach compliance of regulations *proactively* rather than reactively. Sustainability of The System (the entire farming and rural community) is not measured anymore solely on its ability to produce food profitably and sufficiently. Sustainability is progressively more determined by the stewardship of The System and its sub-systems, and its ability to find an accepted place in the community (Douglass, 1984).

## Conclusion

Nutrient accumulations and losses from dairy farms are part of a larger system. Utilizing a systems approach, where the boundaries of the system encompass the entire farming community, is warranted in evaluating overall accumulations (inflow outweighs outflow) and losses (outflow outweighs inflow) of nutrients. Sustainabilism is no longer defined solely by the economic well-being of the farm or the industry as a whole, but by their environmental stewardship and acceptance within the society. Envisioning several future scenarios and development of strategies to sustain sustainability in years to come under those scenarios are key to actively initiate change rather than reactively adjust to changes brought upon by the environment surrounding The System. The Nutritionist has the obligation (or rather the opportunity!) to formulate those strategies with the farming **and** the science community with the idea to not predict the future wrong (which leaves ‘opportunity’ for some mistakes along the way) instead of the impossible undertaking of predicting the future correctly.

## Acknowledgements

I thank Dr. David K. Beede, Michigan State Univeristy, for his thorough review of the paper and his helpful suggestions. I also appreciate input from Dr. Richard Bawden, Michigan State Univeristy.

## Work cited

Bawden, R. 1998. Scenario planning. In: *Greenhouse beyond Kyoto – Conference.* Canberra, AUS.

Dou, Z. X., K. F. Knowlton, R. A. Kohn, Z. G. Wu, L. D. Satter, G. Y. Zhang, J. D. Toth, and J. D. Ferguson. 2002. Phosphorus characteristics of dairy feces affected by diets. J. Environ. Qual. 31(6):2058-2065.

Douglass, D. K. 1984. The meanings of agricultural sustainability. In: *Agricultural sustainability in a changing world order.* D. K. Douglass, ed. Westview Press.

Ebeling, A. M., L. G. Bundy, J. M. Powell, and T. W. Andraski. 2002. Dairy diet phosphorus effects on phosphorus losses in runoff from land-applied manure. Soil Sci. Soc. Am. J. 66(1):284-291.

Hindrichsen, I. K., H. R. Wettstein, A. Machmuller, and M. Kreuzer. 2006. Methane emission, nutrient degradation and nitrogen turnover in dairy cows and their slurry at different milk production scenarios with and without concentrate supplementation. Agric. Ecosyst. Environ. 113(1-4):150-161.

Hollmann, M., K. F. Knowlton, C. M. Parsons, M. D. Hanigan, and T. N. Rensch. 2006. Daily manure production from a lactating cow facility. J. Anim. Sci. 84:260 (abstr.).

Hoshiba, S. 2002. Perspectives for realizing agricultural production systems with material circulation. In: *Greenhouse gases and animal agriculture.* J. Takahashi and B. A. Young, ed. Elsevier Science B. V.

Johnson, K. A. and D. E. Johnson. 1995. Methane emissions from cattle. J. Anim. Sci. 73(8):2483-2492.

Koenig, K. M., C. J. Newbold, F. M. McIntosh, and L. M. Rode. 2000. Effects of protozoa on bacterial nitrogen recycling in the rumen. J. Anim. Sci. 78(9):2431-2445.

Lapierre, H., D. Pacheco, R. Berthiaume, D. R. Ouellet, C. G. Schwab, P. Dubreuil, G. Holtrop, and G. E. Lobley. 2006. What is the true supply of amino acids for a dairy cow? J. Dairy Sci. 89(e_suppl_1):E1-14.

Lopez, H., F. D. Kanitz, V. R. Moreira, L. D. Satter, and M. C. Wiltbank. 2004. Reproductive performance of dairy cows fed two concentrations of phosphorus. J. Dairy Sci. 87(1):146-157.

Shih, J.-S., D. Burtraw, K. Plamer, and J. Siikamaki. 2006. Valuation of air emissions from livestock operations and options for policy. In: *Workshop on agricultural air quality: State of the science.* Potomac, Md.

VandeHaar, M. J. and N. St-Pierre. 2006. Major advances in nutrition: Relevance to the sustainability of the dairy industry. J. Dairy Sci. 89(4):1280-1291.