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NUTRIENT MANAGEMENT PLANNING ON DAIRY FARMS: Options and Limits

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Nutrient balance on farms is complex and is a function of the flow of nutrients through the system and the efficiency of their utilization. The flow of farm nutrients involves many interrelated factors including but not limited to purchased inputs, soil, crops, animals, and sales. The quantity of nutrients remaining on the farm after sales is dependent on the flux of the farm size, increasing or decreasing, level of farm production, and the efficiency of nutrient utilization by the individual components comprising the whole farm.

Historically, farm inputs such as purchased feeds and fertilizers were minimal. The nutrients available were limited by the inherent nutrient resources of the farm and the crops grown. Nutrient balance on these farms was often negative, outputs exceeding inputs. Essentially these operations were mining the resources of the soil. As soil resources were depleted either imports increased, operations changed, or farms were sold and the operators moved on to more fertile territory.

The advent of chemical fertilizers, advances in crop genetics, and improvements in farm tillage resulted in massive increases in crop yields in the U.S. The result was an increase in farm nutrient inputs at all levels and a stabilization of farm soil fertility. Improved grain yields among other factors reduced the cost of imported grain to livestock farmers so it became economical to purchase grain produced off the farm. However, as more nutrients arrived and remained on the farm, the nutrient balance became positive.

A positive nutrient balance is not a bad management practice. Having more nutrients remain on the farm than leave improves soil fertility. However, these nutrients must remain on the farm and be recycled. If these nutrients are mismanaged they may leave the farm either through leaching or erosion by wind and water. The loss of these nutrients through erosion poses a significant threat to water quality in the region.

Waste Management and Water Quality

Waste management and water quality have been complementary issues for decades. Articles in the contemporary press in the late 1800's complained of odors, flies, runoff and general filth associated with animal waste in the city streets, a by-product of the transportation industry. In response to public pressure, Congress addressed the issue of cleaning up our waterways with passage of the Rivers and Harbors Act in 1886. This act was strengthened in 1946 with passage of the Federal Water Pollution Prevention Act. Other clean water legislation followed, most recently the Coastal Zones Management Act (CZMA).

Since passage of the Clean Water Act of 1972, great progress has been made in controlling point sources of pollution. However, as further point-source control measures become increasingly less cost-effective and as significant water quality issues remain unresolved more attention is being focused on the contribution of agriculture and other non-point sources in polluting our surface and ground water (Sharpley et al. 1994). The USEPA has identified agricultural runoff as the cause of impairment of 55% of surveyed river length and 58% of surveyed lake area whose water quality is compromised. In terms of agricultural pollutants this legislation has focused on nutrients, pesticides, and sediments.

Nitrogen (N) and phosphorus (P) are the two nutrients which generate the greatest concern. In areas where livestock densities are high and in close proximity to the public, nitrate contamination of ground water is a major concern. High levels of nitrate in ground water can cause metahemoglobinemia or 'blue-baby syndrome', a serious problem in young children. These same high nitrate levels also have a deleterious effect on the rumen microflora.

In marine systems, N is the major nutrient limiting plant growth. Elevated inputs of nitrogenous compounds into our estuaries and salt water bays can have detrimental effects on the environmental quality of those waters.

Phosphorus is the most limiting nutrient in aquatic systems. Elevated levels of P in our surface waters has been cited as a major cause of eutrophication and increased aquatic biomass. The negative effects associated with eutrophication are both economical and environmental (Sharpley et. al., 1993).

In 1979, P pollution of the waters of the Lake Champlain Basin was identified as an issue of major concern. Total P loading to Lake Champlain was estimated in a range of between 268 and 402 tons/yr. Agricultural runoff, particularly that associated with animal wastes, was named as the largest non-point source, and accounted for 52% of the total annual P loading in the lake (Beaman, T. T., 1992).

In response to the increased levels of pollutants and the public and legislative response, there has been an interest in nutrient balances or environmental planning at the farm level (Lanyon and Beegle, 1989; OFA, 1994). In 1993, the Pennsylvania legislature passed a law that requires all farms with an animal density of two or more animal units (AU; 1000 lbs/AU) per acre to have an approved Farm Nutrient Management Plan drafted by a licensed consultant. In 1994, Ontario instituted a volunteer Environmental Farm Plan (EFP) Program. Other state and provincial governments are investigating limiting the use of fertilizer on land that exceeds a certain level of fertility. As researchers and professionals it is our job to determine what the limits are relative to farm nutrient utilization for a particular operation so that intelligent decisions can be made to protect water quality and maintain a healthy farm economy.

In 1994, Miner Institute began a three year project entitled 'Improving Nutrient Management on a 100-cow Free-Stall Dairy Farm". The project is sponsored by the Northeast Region SARE and ACE Program. Our goals are to conduct a detailed evaluation of the nutrient balance on the 100-cow Miner Institute dairy farm, evaluate the effects of long-term manure applications to four fields on the stratification of P within the soil and determine the nutrient cycling of four groups of cattle in the Miner dairy free-stall.

Nutrient Cycling on the Farm

Issues of water and soil quality, as well as nutrient use and management have spurred interest in farm system planning. Improvement in any of the aforementioned issues requires an integrated approach to planning or a systems approach to analyzing farming systems. This type of approach focuses on the pattern and sequence of crops over time, management decisions relevant to the inputs and production practices used, operator skill level, education, and goals, the quality of the soil and water, and the ecosystem within which the farm production occurs (Lanyon, 1992). This approach is necessary to the development of policies and programs which will ultimately determine our farming future.

Much interest has been seen in the area of farm mass nutrient balances. Development of a farm mass nutrient balance involves accounting for all farm inputs and outputs with the difference being the mass balance of the farm (INPUTS - OUTPUTS = BALANCE). This is illustrated in Figure 1.

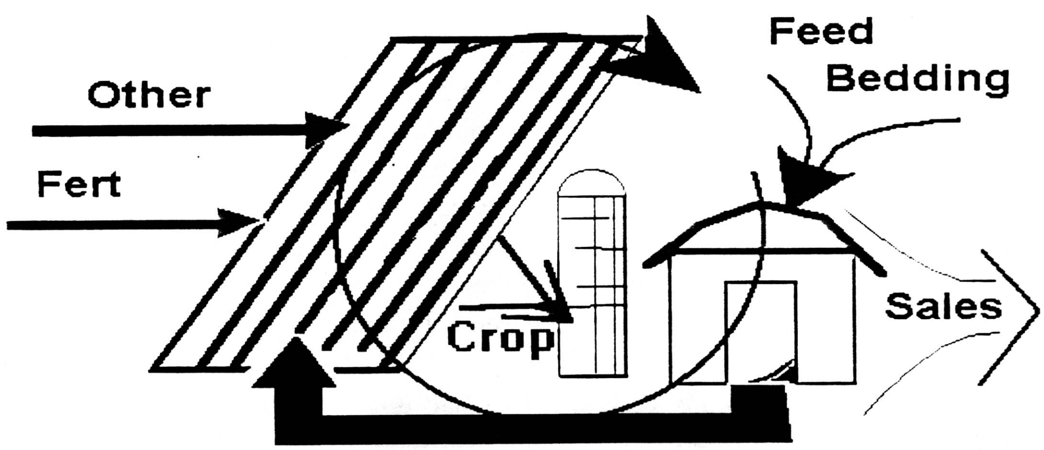

Figure 1. Nutrient flow on the farm. (Adapted from Lanyon and Beegle, 1993)

Mass balances allow us to assess the transformations and transfers that occur in and between the various components of a farming system and to assess the efficiency of nutrient use within the system better enabling us to improve soil and water quality.

In 1993, the NRC published estimates for the mass balance of N and P for all harvested cropland across the U.S for 1987. The P mass balance was 63% of total inputs. This means that in 1987, 63% of the P inputs were either put into storage or became a threat to water quality. Phosphorus is relatively immobile in the soil. A positive mass balance would result in a build-up of soil P levels over time (McCollum. 1991). The increase in soil P occurs principally in the plow layer with conventional tillage and at the soil surface with no-till (Lang, 1994). Phosphorus immobility and its being sequestered in the plow layer act in concert to increase the potential for pollution resulting from surface runoff.

In the NRC study, the mass balance for N ranged from 33% to 40%. The variation was due to the range in efficiencies with which legumes can fix atmospheric N. However. 35% of the total N harvested was accounted for by legumes. which receive very little N fertilizer. If legumes were removed from the equation the mass balance for N would range between 60 and 65%.

This study provides a national perspective on the situation but provides little useful information toward regional or local benefit. Farming systems are highly variable across and within regions. Therefore, to be of greatest benefit, a mass balance should be conducted on a farm or local basis.

Lanyon and Beegle (1989) conducted a mass balance study on a 138-acre dairy farm in Pennsylvania. They found that 53% of input P and 86% of the input N remained on the farm. Fertilizer accounted for 23% and 37% of the input N and P, respectively. In the national estimate fertilizer inputs made up 45% and 79% of the input N and P, respectively.

Using detailed farm records, a farm nutrient mass balance for 1992 and 1993 for the Miner Institute farm was conducted (Table 1.). The N mass balance was 76% and 83% for 1992 and 1993, respectively. For P the mass balance was 72% and 80% for 1992 and 1993, respectively.

It would appear that since the nutrient balance for both N and P increased between 1992 and 1993 that the potential to pollute may have increased as well. However, what is untold are the changes in management that had occurred during the two years. Two decisions were made: one was to liquidate some low-producing cows and increase the inventory of heifers. This had the effect of increasing the purchased feed while having little effect on milk production. The second decision was to increase manure use on our alfalfa land thereby reducing purchased fertilizer. The result was a 0.07 ton decrease in purchased P fertilizer. Note that in 1992, 111 acres of alfalfa were harvested, whereas 108 acres were harvested in 1993. N-fixation is a function of the N yield, therefore, since N-fixation was higher in 1993 than in 1992 on essentially the same acreage, we must conclude that, on a per acre basis, crop yields in 1993 were higher than in 1992.

The reduced cow numbers resulted in reduced consumption of farm produced feeds. That coupled with no decrease in harvested acreage of forages and grain and the increased yield of alfalfa had the effect of increasing the on-farm inventory of feeds. This increase in inventory is reflected in the increase of nutrients reatined on the farm. At the end of 1993, the on-farm inventory of N and P was 12 tons and 0.9 tons respectively. These nutrients are essentially on reserve and do not constitute any direct threat to the environment.

Table 1. Annual nutrient inputs, outputs and balances on the Miner Institute dairy farm for 1992 and 1993.

Unit	Nitrogen 1992	Nitrogen 1993	Phosphorus 1992	Phosphorus 1993
Inputs:	----- tons -----		----- tons -----	
Feed	9.49 (40)[a]	11.81 (45)	1.76 (49)	2.05 (54)
Fertilizer	8.00 (34)	7.04 (27)	1.74 (48)	1.67 (44)
Livestock	0.12 (.5)	0	0.03 (0.8)	0
Other	0	0	0.07 (1.8)	0.07 (2.0)
N-Fixation	5.99 (25)	7.59 (29)	NA	NA
Sub-total	23.60	26.44	3.60	3.79
Outputs:				
Milk	4.28	4.23	0.69	0.68
Livestock	0.63	0.29	0.18	0.08
Crops	0.85	0.15	0.15	
Sub-total	5.76	4.52	1.02	0.76
Balance	17.84	21.96	2.58	3.03
	76%	83%	72%	80%

[a]Number in ( ) represents% of sub-total.

Comparing the two farms, the N balances were similar at 86% on the Pennsylvania farm and 80% for Miner farm average, . However, the P-balance on the Pennsylvania farm was 53%, whereas, that of the Miner Farm was 76%. On the surface it would appear that the Pennsylvania farm has a better management system for P. However, these differences may more accurately reflect differences between soil fertility levels than differences between farming systems.

Nutrient Cycling in the Dairy Cow

As evidenced in the previous discussion. Nutrient mass balances for individual farms while providing a portrait of the farm and reflecting the impact of farm management over time, should only be compared to other farms and regions with care.

A dairy farm is composed of several integrated production units the most significant being the dairy cow. The cow is the primary consumer and producer in any dairy farm. A lactating cow will consume upwards of 4.0% of her body weight at or soon after peak lactation, for a large Holstein that can amount to 72 lb of DM a day. Depending on genetics, environment, and management, this intake is hoped to generate a certain level of milk production. Regardless of the aforementioned factors, this level of intake will result in manure production.

Economically, we view production as milk sales. Environmentally, we must consider the production of manure and the nutrients it contains. Lanyon and Beegle (1989) found that purchased dairy nutrients accounted for 38% and 33% of the inputs of N and P, respectively on a Pennsylvania dairy farm. In this same study, for the dairy unit alone the nutrient mass balance was 85% and 76% for N and P, respectively.

On the Miner dairy farm in 1993, 134 lactating cows and heifers consumed 16.9 tons of N and 3.3 tons of P (Table 2). Purchased nutrients accounted for 63% of the total N inputs and 49% of the total P inputs. The balance for N and P was 73% and 77%, respectively.

A factor affecting the yearly mass balance is changes in farm inventory. This inventory may exist either as crops or livestock. If the operator is expanding his herd by raising more heifers, the high nutrient inputs relative to output will impact the whole farm mass balance.

Table 2. Nutrient inputs, outputs and balance for 86 lactating cows and 35 breeding age heifers at the Miner dairy farm in 1993.

	Nitrogen	Phosphorus
Units	----- lbs[a] -----	
Inputs:		
Forage	8644 (26)	1974 (31)
Concentrates	21315 (63)	3194 (49)
Mineral	0.0	609 (9)
Supplies	3910 (11)	727 (11)
Sub-total	33870	6504
Outputs:		
Milk	8459	1363
Meat	581	162
Sub-total	9040	1524
Balance	24830 (73)	4980 (77)
% remaining	73%	77%

[a] Number in ( ) represent % of sub-total.

Looking at the N mass balance on both farms it would appear that the Pennsylvania dairy farm is less efficient at utilizing N even though off-farm purchases were 40% less than that of the Miner dairy farm. Part of the reason may lie in the class distribution of the herd. In terms of the mass balance, the mass balance for heifer rearing is very close to 100%. If heifers are being raised as replacements then there are no salable outputs until she begins to lactate: i.e. all in and nothing out. Therefore, the greater the ratio of heifers to lactating cows then the higher both the N and P mass balance for the farm as a whole. In the case of the Pennsylvania farm, this ratio was 0.83 : 1 whereas on the Miner dairy farm the ratio was 0.34 : 1.

The information in the Table-2 was generated using farm records. In a subsequent study group intake, milk yield and raw manure production for four groups of dairy cattle in the Miner dairy free-stall was measured. The groups consisted of: breeding-age heifers (HEF, 41 hd, 750 lbs), lactating Jersey's (Jer, 26 hd,), low-group lactating Holsteins (HolLow, 12 hd),, and a high-group lactating Holsteins (HolHi, 38 hd). Diets were formulated using farm produced forages and were balanced by Nutrena Feeds.

Inputs, milk output and balance of N, and P are given in Table 3. The mass balance for N ranged from 100% for the HEF to 73% for the HolHi group.

It is important to remember that the mass balance in this study was determined by the difference between inputs and sales or milk production. It is not surprising that the groups with the highest production also had lower balances. In addition, the inclusion of the heifers in the mass balance increased the overall balance by roughly 10%.

Table 3. Input, milk output, and balance of nitrogen and phosphorus for four groups of dairy cattle in the Miner free-stall.

	Nitrogen	Phosphorus
Inputs[a]	----- lb/hd - d-----	
HolHi	1.36	0.20
HolLow	0.99	0.14
Jer	1.03	0.16
Hef	0.40	0.06
Outputs (Milk):		
HolHi	.36	.06
HolLow	.13	.02
Jer	.30	.05
Hef	NA	NA
Balance:	----- % ----- Remaining	
HolHi	73	71
HolLow	87	85
Jer	71	69
Hef	100	100
Average:		
Lactating	75	73
All	84	82

[a] Groups- HolHi (Holstein high); HolLow(Holstein low); Jer (Jersey); Hef (Heifers)

Lanyon and Beegle (1989) found that production in the dairy unit accounted for 15% and 24% of the N and P inputs, respectively, whereas, the N and P in the manure accounted for 34% and 54% of the respective input nutrients. Of the total input nutrients, 49% and 22% of the input N and P respectively were not accounted for in this study.

Collecting, measuring, weighing, and sampling the manure in a free-stall is not the easiest nor the most pleasant task one would want to do. To compare it to a quagmire of variation is a gross understatement. This may explain why so many studies use 'book' values. However, we were interested in determining the recovery of N and P in the manure. The recovery of N in the dairy manure ranged from 35% for the HolHi to 57% for the Hef (Table 4.)

It is important to understand what the numbers are telling us. In the first case we determined that based on milk sales 75% of all the N fed to a cow was unaccounted for in the milk. One would assume then that it should show up in the manure. Not so in this case, we were only able to recover at best 57% and at worst 40% of the intake N in the manure. Recovery of P was better.

Table 4. Input, manure output, and balance of nitrogen and phosphorus for four groups of dairy cattle in the Miner free-stall.

	Nitrogen	Phosphorus
Inputs[a]	----- lb/hd - d-----	
HolHi	1.36	0.20
HolLow	0.99	0.14
Jer	1.03	0.16
Hef	0.40	0.06
Outputs (Manure):		
HolHi	.47	.11
HolLow	.51	.13
Jer	.43	.12
Hef	.23	.07
	----- % -----	
Balance:	Recovered	
HolHi	35	54
HolLow	52	93
Jer	41	75
Hef	57	@ 100
Average:		
Lactating	40	68
All	46	85

[a] Groups- HolHi (Holstein high); HolLow(Holstein low); Jer (Jersey); Hef (Heifers)

In the Miner study, if we combine both milk and manure outputs we find that we were able to account for 63% of the intake N and 95% of all the intake P compared with 49% of the intake N and 78% of the intake P in the Pennsylvania study. Differences in recovery rates between the two studies may reflect the manner in which contribution of the manure was obtained. In the Pennsylvania study, manure application was obtained through farm records and book values were used for composition. In the Miner study, pen weights for raw maure were measured directly and samples were analyzed for composition. Differences may also reflect loses that occur during storage of the manure and inefficiencies of nutrient retrieval from storage.

Summary

What is the fate of nutrients brought on to the farm? Is all the N and P not sold a potential pollutant? 'What represents an acceptable mass balance?

Nutrients arrive on farms in a variety of ways and forms. On a dairy farm these nutrients arrive predominantly as feed nutrients. Increasing production of legumes on the farm will reduce off-farm purchases of protein feeds and nitrogen fertilizers. Application of manure to legume stands to supply P can also reduce farm purchases of P fertilizer.

Nitrogen and P not sold does not necessarily become a pollutant. As we have seen, most of the N and P end up in either the milk or manure. However, if the animal inventory on the farm is growing then some of these remaining nutrients will be sequestered in animal tissue. Depending on the environment, a portion of the nitrogen in the urine can be volatilized and lost as ammonia gas (VanHorn et. al., 1991). Also, depending on the equilibrium state of the farm, N and P can be found in storage on the farm in the form of feeds if feed production or purchases temporally exceed animal needs. In addition, bulk purchases of bedding materials or fertilizers may have a similar impact.

What is acceptable? A mass balance is essentially a measure of inefficiency, therefore, it can only be as good as the least efficient unit in the system. In the case of the dairy farm we are restricted by the cow's efficiency in converting nutrients into milk. According to the NRC requirements the inefficiency for N use is around 70% The inefficiency of P use ranges from 69% to 80% (Morse et. al., 1992). On dairy farms mass balances lower than these figures are attainable by diversifying sales to crops as well as milk.

Mass balances of nutrients in agricultural systems can provide powerful tools to ascertain trends in nutrient use and provide mechanisms by which management changes may affect environmental impact. Whole farm nutrient balances can provide an overall view of the system balance and yearly trends, but only offer limited information on the dynamics of nutrient use within the specific units within the farm. Accurate use requires not only estimates of mass balance but current and past management, farm status, and information regarding the source of the information used to obtain reliable and useful estimates.

References

Beaman, T. T. 1992. Design and initial implementation of a comprehensive agricultural monitoring and evaluation network for the Lake Champlain Basin. NY-VT Strategic Core Group. February 1993. Lake Champlain Basin Program Technical Report No. 2. U.S. Environmental Protection Agency, Boston, MA. 77 pp.

Lanyon, L. E. and D. B. Beegle. 1989. The role of on-farm nutrient balance assessments in and integrated approach to nutrient management. J. Soil and Water Cons. 44:164-168.

Lanyon, L. E. and D. B. Beegle. 1993. Nutrient Management. Agronomy Facts 16. Penn State Cooperative Extension. University Park, PA.

Lanyon, L.E. 1992. Implications of dairy herd size for farm material transport, plant nutrient management, and water quality. J. Dairy Sci. 75:334-344.

McCollum, R.E. 1991. Buildup and decline of soil phosphorus: 30-year trends on a Typic Umprabuult. Agron. J. 83:77-85.

Morse, D., H.H. Head, C. J. Wilcox, H. H. VanHorn, C. D. Hissem and B. Harris Jr. 1992. Effects of concentration of dietary phosphorus on amount and route of excretion. J. Dairy Sci. 75:1979.

National Research Council. 1993. Nutrient requirements of dairy cattle. 6th rev. ed. Natl. Acad. Press. Washington, D.C.

National Research Council. 1993. Soil and Water Quality - An agenda for agriculture. Committee on Long-Range Soil and Water Conservation. Natl. Acad. Press. Washington, D.C.

Ontario Farm Association. 1994. Ontario Environmental Farm Plan Workbook. Ontario Federation of Agriculture. Toronto, Ont.

Sharpley, A. N., S.C. Chapra, R. Wedepohl, J.T. Sims, T. C. Daniel, and K.R. Reddy. 1994. Managing Agricultural Phosphorus for protection of surface waters: Issues and Options. J. Environ. Qual. 23:437-451.

Sharpley, A. N., T. C. Daniel, and D. R. Edwards. 1993. Phosphorus movement in the landscape. J. Prod. Agric. 6:492-500.

VanHorn, H. H., R.A. Nordstedt, A.V. Bottcher, E. A. Hanlon, D. A. Graetz, and C. F. Chambliss. 1991. Dairy Manure Management: Strategies for recycling nutrients to recover fertilizer value and avoid environmental pollution. Cooperative Ext. Cir 106. University of Florida. Gainesville.