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Improving Dairy Farm Sustainability II: Environmental Losses and Nutrient Flows

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This paper continues the analysis of nutrient management on a case study dairy farm in New York State. In Part I, it was found that 60 to 70% of the imported N and P were not accounted for in the exported milk, crops, and animals. The purpose of this paper is to present a process for accounting for the fate of the excess nutrients and to determine the extent to which they were contributing to air and water pollution from the farm. Environmental losses of N and net excess of P in different subsections of the farm were estimated. Losses of N from volatilization on the barn floor and in storage were estimated to be 16% of excreted N. As a partial check on these results, manure nutrient composition for lactating cows was analyzed at excretion, entering storage, and leaving storage. Soil leaching losses from the farm were calculated using the LEACHN model, and were 9% of total N inflows to the farm. Predicted nitrate N concentrations in the leachate were 10.6 ppm. Results from monitoring a stream originating from the farm gave an annual average of 14.4 ppm of nitrate N. About 80% of the total N inflows were accounted for as milk sold (25%), animals sold (2%), leaching losses (9%), and volatilization/denitrification losses (46%). Environmental losses accounted for 75% of the excess N. Projected scenarios for increased use of farm-produced forages, reduction in fertilizers, and increased feed conversion to milk resulted in only minor improvements in the nutrient imbalance on this farm.

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THIS TWO-PART ARTICLE reports on a process for integrating knowledge to develop and evaluate nutrient management plans for dairy farms. In Part I of this study (Klausner et al., 1998), it was shown that N inflows to the farm were primarily from purchased feeds, fertilizers, and N fixation by crops. Results of the mass nutrient balances indicated that 72% of the imported N and 57% of the imported P were not accounted for in the export of nutrients as milk, crops, and animals. The goal of this paper is to present a process for accounting for the fate of the excess nutrients and to determine the environmental implications of these nutrient imbalances. Volatilization of N from manure in handling and storage, and leaching and volatilization/denitrification of N from the fields were estimated. The net accumulation of P within subsections of the farm was also determined.

MATERIALS AND METHODS

Nutrient accounting on the farm was performed through environmental-loss estimates and mass balances. Figure 1 depicts the nutrient flows determined on the case study farm. The arrows identify flows crossing the farm boundary or traveling between subsections of the farm. The boxes in the figure represent main subsections consisting of: (i) an aggregate of all the barns containing animals and feeds, (ii) all manure in storage, and (iii) an aggregate of all fields, including unharvested crops and soils. Flows for volatilization and leaching apply only to N. The source of information for each flow is labelled in Fig. 1, where "m" represents flows that were measured, "r" was obtained from farm records, and "c" was calculated. The goal was to measure as many flows as possible and to calculate only those flows

Table 1. Manure production and predicted volatilization losses of N from the barn floor and storage.

Location	Handling	Manure production, lb/d	Scraping interval, h	N volatilization, % of excretion
Lactating-cow barn	liquid	48 900	0.67	0
Dry cow barn	liquid	6 600	84	17
Heifer barn	liquid	9 000	84	19
Calf barn	bedded pack	900	84	29
Storage	liquid			15
Overall		65 400		16

that could not be measured. For environmental losses, some measurements were made as a partial check.

Flows of nutrients presented in Part I of this study (Klausner et al., 1998) were purchased feeds, milk, fertilizers, and animals crossing the farm boundary, and flow of manure nutrients applied to the fields. The flow of nutrients from fields to barns was measured in this study from forage analyses and crop yields, which were determined by the farmer for each field using weigh scales. Nutrient analysis of manure and farm-produced feeds was performed by the Northeast Dairy Herd Improvement Association. Nutrient composition of purchased feeds was supplied by the manufacturers.

The three flows representing environmental losses of N were volatilization from manure in storage, volatilization and denitrification in the fields, and leaching to the groundwater. Measuring total atmospheric and leaching losses is difficult, and estimating their magnitude was the most challenging part of this study.

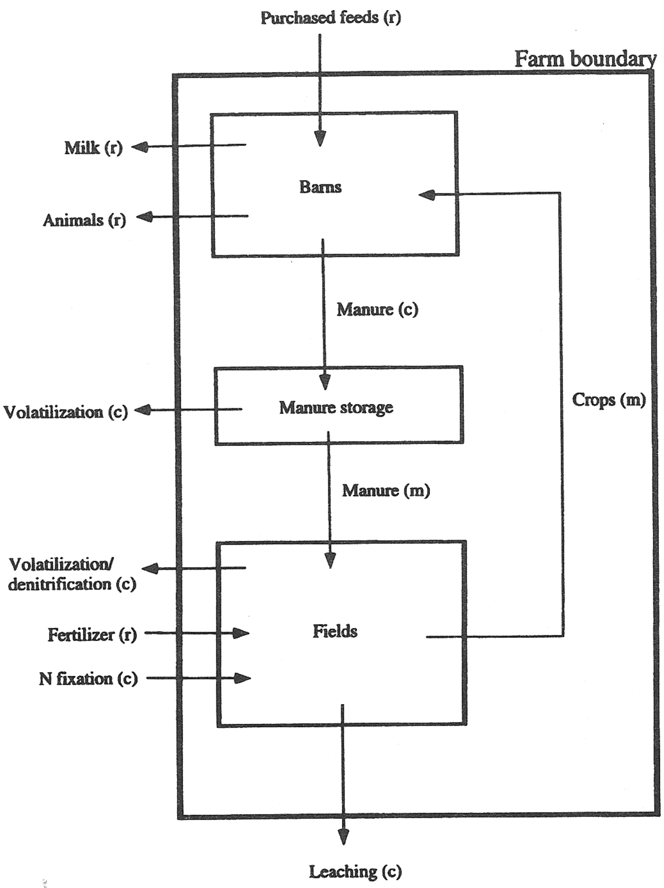

Fig. 1. Farm subsections (boxes) and nutrient flows (arrows) between subsections and across boundaries of the whole farm. Notation in parentheses indicates the source of information for each flow ("m" = measured, "r" = farm records, "c" = calculated).

There were four sources of manure on the farm (Table 1). The atmospheric losses from manure could not be measured directly, because there was no way to capture the N once it had volatilized. An estimate of these losses for lactating cow manure was obtained from the changes in manure N concentrations before and after storage. There were two opportunities for N to volatilize: while the manure was resident on the barn floor, and while the manure was in storage. Manure was sampled for nutrient analysis at excretion, entering storage, and leaving storage on three dates (23 June, 12 August, and 25 October).

On 23 June, fresh manure was collected from the barn floor by scraping 8-ft long sections of the alley. The alley was first cleaned, and after 30 min the manure was removed and sampled. However, recovery of the liquid fraction was difficult. For the 12 August and 25 October dates, samples of urine and feces from at least five animals were collected separately before reaching the floor. The problem with this method was that the relative amounts of urine and feces were not obtained. Therefore, standard values were used: 38.5% urine, 61.5% feces (ASAE, 1992; Morse et al., 1994). Both methods were limited by small sample size, and measurements were made only for the lactating cows, which produced 75% of the manure on the farm (Table 1).

Estimating storage losses of N from manure analysis posed different problems. The manure in storage was diluted with unknown quantities of wastewater from the milking center, fresh water from precipitation, and water addition for producing a more pumpable slurry. Also, it was impossible to track a unit of manure into and out of storage due to mixing with previously stored or unsampled manure.

Given these problems, the model of Muck and Steenhuis (1981) was used to estimate N losses from the barn floor and manure storage for all manure sources on the farm. Nitrogen loss from manure is a two-step process: conversion of urea to ammonia, and volatilization of ammonia. In the model (Muck and Steenhuis, 1981), the rate of urea conversion increased with temperature and decreased as urea was depleted. Ammonia volatilization rate increased with temperature, ammonia concentration, pH, and wind speed, and depended on depth of manure on the barn floor. Barn temperatures on the case study farm were recorded for 6 mo at three elevations in the barn, and were found to remain within 4°F of the ambient temperatures at a weather station 3 mi away. Thus, weather station temperatures were used for the whole year, except that barn-floor temperatures were assumed to remain above freezing. Indoor wind speed was taken as 0.7 mph. A depth of 0.04 in. was assumed for urine on the barn floor until the floor area was covered, after which depth was increased uniformly until the next scraping. Surface area of manure in storage was 2540 sq ft.

Measuring nonpoint source pollution of N and P from the fields is difficult. Atmospheric losses could not be captured, and the origin of nitrates detected in groundwater cannot be determined and could be from off-farm sources. Also, the concentrations of nitrates in groundwater do not give total quantity of leached N, because the volume of groundwater and its sources are also unknown.

For these reasons, the LEACHN model of Hutson and Wagenet (1991, 1992) was used to simulate the movement of water and the transformations and losses of N from the soil. The model has been used and tested by other researchers (Soulsby and Reynolds, 1992). The principal inputs to the model were soil hydraulic conductivity, crop cover, precipitation and temperature, and N transformation rate constants. Soil type information (Soil Conservation Service, 1971) was used to determine water retention and conductivity (Hutson and Wagenet, 1992). Cropping patterns for each field were obtained from farm records. Over 95% of the land area had slopes less than 8%, and the majority of land had slopes less than 3%. Thus, the hydrology was simplified to include only evapotranspiration and vertical flow through the root zone; runoff and subsurface lateral flow were neglected. The hydraulic conductivity of the soil at the lower boundary of the root zone was established previously by Hutson et al. (1988) to match water table fluctuations in the region (Fritton and Olson, 1972).

Transformations of N among plant residue, manure, other organic matter, ammonia, urea, and nitrate, as well as volatilization and denitrification of N, were simulated in LEACHN as described in Hutson and Wagenet (1991). Because water movement and N transformations vary with depth in the soil, the soil horizon was divided into 10 vertical sections, each 4 in. in depth. Volatilization and denitrification increased with temperature, soil moisture content, and concentration of nitrate and ammonia. Rate coefficients for the transformation of organic N to inorganic N were chosen to coincide with the organic N decay rates of Klausner et al. (1994).

Uptake of N by alfalfa was estimated from the average crude protein content of harvested alfalfa (*Medicago sativa* L.) (20%), from the estimated percentage of uptake N that is harvested (33% for year 1, 20% for subsequent years) (Johnsson et al., 1987), and from average dry matter yields. Nitrogen taken up by plants was supplied by mineral N if available; the balance of N uptake was assumed to be met by N fixation.

Soil properties and cropping patterns varied with location. To account for spatial variation, the cultivated land on the farm was divided into 164- by 164-ft sections, and simulations were performed on each section. Information from soil survey maps was digitized into a geographic information system (GIS), and the simulations were coupled to the GIS format. Manure application history was not available (Klausner et al., 1997), so the manure and fertilizer application rates were assumed to follow the nutrient management plan. Implications of this assumption are discussed later.

As a partial check on the LEACHN results, concentrations of nitrate N, total P, and sediment were measured in a stream that originated in the center of the home farm field cluster and that was fed from the outflow of tile drains and runoff (if any) from the fields. The exact area of land that drained into the stream was difficult to determine because of the flat slopes on the farm. An estimate was made of the drainage area for the stream using USGS contour and stream maps, on-site inspections with the farmer, and a map of the tile drains. This gave an approximate area of 42 acres. Streamflow during the study ceased during periods of no precipitation, suggesting that the stream was not fed by underground springs or saturated zones from off-farm sources. Streamflow was determined by constructing and calibrating a 90° V-notch weir and installing a float and automatic recording device. An ISCO continuous sampler was used to collect 0.84-oz (25-ml) water samples every 90 minutes. Samples were preserved by refrigeration and addition of 0.034 oz (1 ml) of 0.1 N HCl per 3.4 oz (100 ml) of sample, and were tested in duplicate at the Cornell Nutrient Analysis Lab.

Table 2. Nutrient concentrations (% of wet mass) in lactating-cow manure measured at excretion, entering storage, and leaving storage. Adjusted values leaving storage are corrected for the decrease in total solids content due to addition of water.

Nutrient	At excretion	Entering storage	Leaving storage	Leaving storage (adjusted)
Total solids	8.5	8.6	6.7	8.6
Total N	0.75	0.54	0.37	0.47
Ammonia N	0.15	0.26	0.15	0.19
Urea N	0.15	0	0	0
Organic N	0.45	0.28	0.22	0.28
P	0.084	0.096	0.064	0.082
K	0.31	0.34	0.18	0.23
pH	7.4	7.6	7.1	--

RESULTS

Nitrogen Losses from Manure

Manure compositions measured for lactating cows at excretion, entering storage, and leaving storage are given in Table 2. Urea accounted for 20% of the total N at excretion, but urease activity reduced this to zero after retention on the barn floor. Total N concentration was reduced by 28% after retention on the barn floor, but P and K concentrations were also lower, which suggests that different manure was being sampled. In storage, concentration of total N decreased by 31%. However, the dilution of stored manure was evident from the reduction in total solids content from 8.6 to 6.7%, as well as decreases in P and K concentrations. To correct for the dilution, the manure nutrient concentrations leaving storage were adjusted for total solids by multiplying by 1.28 (8.6 ÷ 6.7) (Table 2). This gave P and K concentrations closer to those entering storage. With this correction, the apparent N loss from storage was 11%.

Calculated losses of N on the barn floor were highly dependent on temperature and scraping interval (Fig. 2). With the very short scraping intervals in the lactating cow barn (Table 1), barn floor losses were predicted to be less than 2% of excreted N. For the longer scraping intervals in the other barns (Table 1), losses varied between 10% at 40°F and 40% at 68°F. Storage losses were estimated to be 15%, which was similar to the value of 11% measured for the lactating cow manure. Volatilization losses for each barn are given in Table 1. The overall N loss from manure was 16% of excreted N.

Nitrogen Losses in the Fields

The 12 cultivated soil types on the farm were silt loams varying from moderately well drained to well drained. Table 3 shows the land areas and predicted leaching for the different soil types grouped into four categories by drainage. The

Table 3. Grouping of soils into four drainage classes and N leaching from each class and crop type.

Class	Drainage, in./yr	Area acres	Area % of total	N Leached lb/year	N Leached % of total	Crop	N Leached, lb/(acre × year)
1	2.4–2.6	156	24.3	450	3.6	Alfalfa	2.9
						Corn	2.7
						Grass	2.3
						Idle	4.6
2	5.4–5.9	277	43.1	2040	16.6	Alfalfa	7.0
						Corn	7.7
						Grass	7.1
						Idle	11.0
3	14.7–15.4	163	25.3	8500	68.9	Alfalfa	41.2
						Corn	65.5
4	16.1–16.5	47	7.3	1340	10.9	Alfalfa	20.2
						Corn	33.4

N leached per area was higher in the more well drained soils but was only slightly affected by crop type. About 70% of the leaching occurred from the third drainage class, which comprised only 25% of the land area. Less leaching per unit land area was predicted for the fourth drainage class because of its lower average moisture content.

Cultivated fields on the farm consisted of three noncontiguous clusters: the home farm, north of the home farm, and southwest of the home farm adjacent to a large lake. Table 4 gives the acreages, drainage, and atmospheric and waterborne losses of N for each cluster of fields and for the whole farm. Almost four times more N was lost through volatilization/denitrification than through leaching. Most of the N leaching and the highest concentrations of nitrate N in the leachate occurred on the southwest fields, which were the most well drained. For the whole farm, the average nitrate N concentration for the entire year was predicted to be 10.6 ppm, which is close to the national standard of 10 ppm.

Results of the stream monitoring are shown in Table 5. Streamflow occurred during three main periods. Streamflow existed at the time of installation in March, although the flow rates were very low (less than 0.002 cu ft/sec). Streamflow increased in early April and then levelled off to a low flow which ceased around 7 May. Flow did not reoccur until late October, stopped, and then started again in November before freezing in December. The greatest outflow of nutrients and sediment occurred in the last period. Overall, the average nitrate N concentration was 14.4 ppm, which is higher than the 9 ppm predicted by the model for the home-farm field cluster (Table 4). Concentrations of total P and sediment suggested that some runoff and erosion occurred from the field.

Table 4. Land areas, drainage, and predicted atmospheric and waterborne losses of N for three major field clusters and all fields combined.

	Field clusters North	Home farm	Southwest	All fields
Land area, acres	94	383	166	643
Drainage, in./yr	6.5	5.6	14.5	8.0
Volatilization+ denitrification N losses, lb/yr	6 200	30 600	8 800	45 600
Leached N, lb/yr	1 390	4 380	6 560	12 300
Mean N concentration, ppm	10.0	9.0	12.0	10.6

Table 5. Stream monitoring results: streamflow quantities and nutrient and sediment concentrations during three main periods of flow, and total or average results for the entire year.

Time period	Total streamflow	Nitrate N concentration	P concentration	Sediment concentration
	cu ft	ppm	ppm	%
March–May	2 400	0.33	0.20	0.11
October	27 400	18.8	0.51	0.11
November–December	88 300	13.4	0.38	0.13
Total or average	118 100	14.4	0.41	0.13

Nutrient Balances

To account for all nutrient sources and losses on the farm, mass nutrient balances were performed on each subsection of the farm comprising the barns, manure storage, and fields (Bacon et al., 1990; Saama et al., 1994). Table 6 gives the flows of N crossing the boundaries of the whole farm and subsections of the farm. Each column gives the inflows (positive) and outflows (negative), and the net sum of

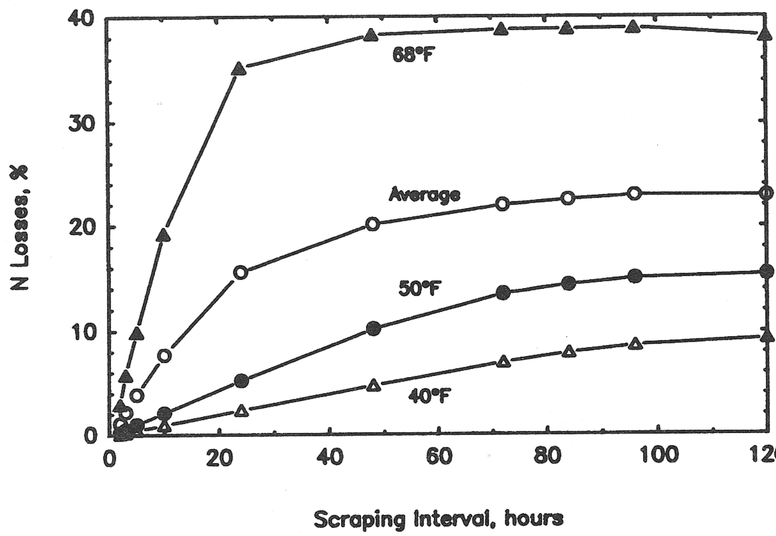

Fig. 2. Predicted volatilization of N from manure on the barn floor as dependent on scraping interval and temperature. Curve labeled "average" shows N losses for the whole year using monthly average temperatures.

Table 6. Flows of N (lb/year) into (+) and out of (-) subsections of the farm. Each column shows the mass flow rates into and out of that subsection (see Fig. 1).

Type of flow	Barns subsection	Manure storage subsection	Fields subsection	Whole farm
Purchased feeds	+87 700	--†	--	+87 700
Milk	−37 200	--	--	−37 200
Animals	−3 500	--	--	−3 500
Fertilizer	--	--	+27 100	+27 100
Excretion	−131 500	+131 500	--	--
Manure to fields	--	−110 600	+110 600	--
N fixation	--	--	+29 300	+29 300
Crops	+92 700	--	−123 800	--
Leaching	--	--	−12 300	−12 300
Volatilization/ denitrification	--	−20 900	−45 600	−66 500
Net excess‡	+8 200	0	−14 700	+24 600
Net excess as percentage of inflows§	5%		−9%	17%

† Dashed lines indicate flows of this type do not cross the boundary of this subsection.
‡ Net excess = sum of inflows and outflows for that subsection.
§ Net excess as percentage of inflows = 100 × (net excess) ÷ (sum of inflows for that subsection).

inflows and outflows for that section of the farm. The first column of numbers shows a mass balance for the barns subsection. Inflows were purchased feeds and crops, and outflows were milk, animals, and manure. Excess N in the barns subunit was only 5% of the N inflows to the barns. This suggests that accumulation of N in the barns subsection was not significant.

The second column of numbers in Table 6 gives the N flows associated with manure storage. The inflow was N excretion, and outflows were N to the fields and volatilization losses. Excretion of N for the whole herd was determined from the difference between manure N applied to the fields, estimated in Part I (Klausner et al., 1998), and volatilization losses (16%, Table 1).

For the fields (Table 6), N inflows were fertilizer, manure, and N fixation, and outflows were harvested crops and losses through volatilization/denitrification and leaching. There was a net N deficit of 9% of total inflows to the fields, which indicates that over 90% of the N flows into and out of the fields were being accounted for. Comparison of the crops outflow of N from the fields with the crops inflow of N to the barns showed that crop N production was 33% larger than the herd N intake in the study year; this excess would result in carryover of inventory to the following year. About one-third of the total N inflows to the fields were lost to air or water.

Table 7 shows the mass nutrient balances for P. In the barns subsection, net excess was only 12%, but in the fields, the excess P was substantial (35%) and accounted for 65% of the excess P for the whole farm, suggesting that P was accumulating in soil. Soil tests for this farm confirmed high P levels, ranging from 8 to 84 lb/acre and averaging 34 lb/acre on the home-farm cluster. On the remote field clusters, soil tests were lower and ranged from 2 to 42 lb/acre and averaged 11 lb/acre.

IMPLICATIONS

In Part I, N inflows to the farm were primarily from purchased feeds (61%), fertilizer (19%), and N fixation by

Table 7. Flows of P (lb/yr) into (+) and out of (-) the whole farm and subsections of the farm. Each column shows the mass flow rates into and out of that subsection (see Fig. 1).

Type of flow	Barns subsection	Fields subsection	Whole Farm
Purchased feeds	+16 700	--†	+16 700
Milk	−7 700	--	−7 700
Animals	−1 100	--	−1 100
Fertilizer	--	+4 000	+4 000
Manure	−18 300	+18 300	--
Crops	+14 500	−14 500	--
Net excess‡	+4 100	+7 800	+11 900
Net excess as percentage of inflows§	12%	35%	57%

† Dashed lines indicate flows of this type do not cross the boundary of this subsection.
‡ Net excess = sum of inflows and outflows for that section.
§ Net excess as percentage of inflows = 100 × (net excess) ÷ (sum of inflows for that section).

crops (20%). A total of 103 400 lb/yr of N, or 72%, was coming onto the farm that was not accounted for in the exports of animal and plant products. In this paper, about 80% of the N inflows were accounted for as milk sold (25%), animals sold (2%), leaching losses (9%), and volatilization/denitrification losses (46%). An additional 20% occurred as carryover of inventory to the following year due to unusually heavy crop yields in the study year. Atmospheric and water-borne losses of N to the environment totalled 78 800 lb N/year (Table 6), and represented 75% of the excess N. Leached N represented 12% of the excess N on the farm and 7% of N inflows to the fields. Volatilized N represented 64% of the excess N and 40% of N inflows to the fields.

These results suggest that excess nutrients are directly related to pollution of air and water from the farm. However, it is difficult to put these results into perspective, because there are no similar data to compare with other farms. For example, it is not known whether 9% of N inflows ending up in the groundwater is high or low. On the other hand, mass nutrient balances on other farms indicate a similar excess in nutrient imports. Nutrient flows on a Pennsylvania dairy farm with 65 lactating cows (Bacon et al., 1990) showed whole farm N and P excesses of 50 to 60%. In Dou et al. (1996), excess N was approximately 55% for a model farm with 100 lactating cows. Klausner (1993) showed excess N and P of 64 to 79% for four dairy farms ranging in size from 45 to 1300 cows, with no apparent trend with farm size. Excess N averaged 84% in conventional livestock farms and 79% in organic livestock farms in Denmark (Halberg et al., 1995). To the extent that excess nutrients result in environmental pollution, as they apparently did in this study, the mass nutrient balances for other farms are cause for wider concern about the sustainability of dairy farming as currently practiced.

Apparent excess of N in the barns subsection of Bacon et al. (1990) was 22 to 25% and thus was higher than the present study (5%). Losses of manure N of 16% are within the broad range of 0 to 75% summarized by Dou et al. (1996). Excess N in the fields was 20 to 30% in Bacon et al. (1990) but did not include environmental losses; the atmospheric and leaching losses from the fields in this study were 35% of N inflows and were therefore comparable to Bacon et al. (1990).

Table 8. Projected whole-farm N flows (lb/yr) for the case study farm under various scenarios of improvement in nutrient use efficiency.

Type of flow	Actual farm	Reduced purchased feeds	No N fertilizer	Increased animal efficiency
Purchased feeds	+87 700	+52 800	+87 700	+87 700
Milk	−37 200	−37 200	−37 200	−52 800
Animals	−3 500	−3 500	−3 500	−3 500
Fertilizer	+27 100	+34 800	0	+40 400
N fixation	+29 300	+37 400	+29 300	+29 300
Net excess†	+103 400	+84 300	+76 300	+101 100
Net excess as percentage of inflows‡	72%	67%	65%	64%

† Net excess = sum of inflows and outflows.
‡ Net excess as percentage of inflows = 100 × (net excess) ÷ (sum of inflows).

The nitrate N concentrations in the stream were higher than predicted by LEACHN (14.4 ppm measured vs. 9.0 ppm predicted for the home farm). This is probably due to the use of the nutrient management plan from Part I to estimate historical manure and fertilizer application rates, which were lower than the actual rates. From the mass balances, excess P imported onto the farm was concentrating in the fields, where soil tests for P were high and streamflow results indicated significant losses of P. The P concentration of 0.4 ppm in the stream is within the range of 0.05 to 1.1 ppm reported for discharge from agricultural fields but much higher than the 0.03 ppm reported for uncontaminated streams (Dunne and Leopold, 1978).

The farm in this study was highly productive and profitable, with a milk production of 26 000 lb/(cow × year) and annual yields of 6.0, 3.7, and 5.9 tons of dry matter per acre for corn (*Zea mays* L.) silage, high-moisture corn, and alfalfa, respectively. The land base was sufficient to supply necessary crop needs, and the animal density of 1.1 animal units per acre (Klausner et al., 1998) was within or close to current guidelines. Moreover, the farmer in this study was already sensitive to environmental issues.

In light of this, the significant environmental impacts from this farm are notable. It is difficult to extrapolate the results for this farm to farms with different sizes, production levels, land bases, and management practices. However, the fact that nutrient excesses related directly to environmental pollution on this farm could apply to many farms for which nutrient excesses are occurring. Use of a record keeping system (Lemberg et al., 1992) will be essential for nutrient accounting on a large number of farms.

Given that excess nutrients contribute to environmental pollution on this farm, a reasonable goal might be to bring inflows and outflows into closer balance. Ways to increase nutrient use efficiency include:

- Increase the percentage of feed N from farm-produced feeds (51% in this study).
- Increase the percentage of excreted N that is actually applied to the fields (84% in this study).
- Increase the percentage of N applied to corn that is converted to crop N (corn N-use efficiency was 25% in this study).
- Increase the percentage of total N intake that is converted to milk N (19% in this study).

Using projected increases in these efficiencies as outlined below, we estimated independent changes from each for the N mass balance for the farm. Table 8 shows whole-farm N balances for the existing farm and for projected improvements in the use of farm-produced feeds, N fertilizer, and animal efficiency. The first column gives the mass nutrient balance from Part I, showing again that 72% of the imported N was not accounted for in the export of animal products. The second column shows a projected N balance when the percentage of feed intake N was increased to from 51 to 75%, thereby reducing the imports of purchased feeds. Crop acreage was increased proportionately, so that inflows of fertilizer and N fixation also had to be increased. In this scenario, milk production, the ratio of alfalfa to corn, and animal intake of N were assumed not to change. With these optimistic assumptions, the N excess for the farm was reduced by 19 100 lb/year, but the excess N was still 67% of the N inflows to the farm.

The third column in Table 8 shows the effect of completely eliminating all N fertilizer, by increasing the retention of N in stored manure or the uptake of N applied to corn. In reality, this would be difficult to achieve without loss of yield. With no reduction in yield, N excess was reduced by 27 100 lb/year, but the inflows were still in excess by 65%.

The last column in Table 8 shows the effect of a projected increase from 19 to 25% in the efficiency of animal conversion of N from feed to milk. This would have to be achieved in ways such as better preservation of protein in ensiled feeds (Knowlton et al., 1992). For the same N intake, milk outflow of N was increased, and by conservation of mass, production of manure N would have to decrease. This in turn increased the fertilizer N requirements. The net effect was a minor change in nutrient imports and an excess N of 64%.

These hypothetical scenarios reveal the magnitude of the problem for this farm. Despite optimistic assumptions, major improvements in excess N were not predicted, although small improvements were achieved in each case. Thus, significant improvements will probably come about through a combination of changes in a number of areas. These include increased use of precise ration balancing systems, collection of better quality information on feeds and animals, optimum use of farm-produced feeds, excellent silage preservation management, conservation of nutrients in manure, crop nutrient management planning to minimize fertilizer use, and the best possible crop, harvest, and pest management.

CONCLUSIONS

Estimated volatilization and leaching losses of N on the case study farm accounted for 75% of the excess N imported onto the farm. The stream-monitoring results appeared to confirm significant pollution of groundwater. These results suggest that the imbalance between nutrient imports and exports was directly related to pollution of air and water from the farm, and could apply to many other farms. Assumed increases in the efficiency of use of farm-produced feeds, manure nutrients, or feed conversion to milk were projected to result in only minor improvements in the N imbalance.

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