Impact of Dairy Farming on Well Water Nitrate Level and Soil Content of Phosphorus and Potassium

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ABSTRACT

The Cornell Teaching and Research Dairy Farm was used to study the historical influence of dairy farming on water quality and soil chemical properties. The farm has milked approximately 360 cows for the past 20 yr and is situated on 526 ha of cropland (390 ha utilized for dairy production) near Harford, New York. Mass nutrient balances (N, P, K) were constructed with historical data from 1979 and 1994 for the 390 ha used for dairy production. The amount of imported N increased more than 40% from 1979 to 1994, although there were year-to-year variations, depending on crop yields. Although nutrient balance (imported minus exported nutrients) as a percentage of imported nutrients on the farm remained relatively unchanged during this period, balance of N increased from 43.1 metric tonnes in 1979 to 66.0 metric tonnes in 1994. However, P and K remained about the same because of the reduced use of fertilizers in the 1990s. During the 15-yr period, total milk production increased more than 40% (2502 to 3604 metric tonnes from 1979 to 1994). Analysis of well water suggested that increasing amount of N balance on the farm resulted in increased well NO_3-N concentration. The mean of five wells located in the corn fields increased from 3.3 to 7.0 mg/kg in NO_3-N concentration, 70% of the EPA upper limit. Soil P increased from 6.0 to 24.0 (kg/ha) during the same period. Soil K did not change. Mass nutrient balances are important in determining the amount of nutrients remaining on farm. This study suggests N, P, and K balance can be used as an indicator of potential for increased NO_3-N concentrations in wells and soil P and K levels, respectively.
(**Key words:** water quality, mass nutrient balance, nutrient management)

Abbreviation key: BAL = imported minus exported nutrient.

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INTRODUCTION

Regulations being proposed in New York and other states target animal production as a nonpoint source of water pollutants. Pollutants are mainly from those imported nutrients not accounted for in the export of nutrients as milk and animals. Nutrients accumulate on a dairy farm if a greater quantity is imported as purchased feeds, fertilizer, and symbiotic N fixation than is exported as products sold (12). Most of the P and K not exported is either lost from the farm through surface runoff or accumulates in the soil. Excess N is subject to loss across farm borders by surface runoff, leaching into groundwater, and volatilization into the atmosphere. Nitrates in drinking water can harm animals and humans, and phosphorus runoff contributes to eutrophication of water bodies. Elevated K in soils and consequently in forages may negatively affect animal productivity (7).

Several studies (1, 4, 8, 12, 13, 20) have modeled nutrient flow on the dairy farm, and it is generally agreed that excess nutrients on farm are likely to adversely influence water quality. However, no one has published long-term studies that relate the changes in nutrient accumulation with well water quality. Our objective was to relate changes in nutrient imports and balance (**BAL**) of nutrients (imported nutrients minus exported nutrients) on a dairy farm to changes in well water content of N and soil P and K over a 15-yr period.

MATERIALS AND METHODS

Description of the Farm

Data were collected for this study at the Cornell Animal Science Teaching and Research Dairy Farm (T&R) located near Harford, New York. The valley floor is 1 to 3 km wide and is composed of well-drained soils (Howard association and Valois-Howard-Langford association; Figure 1). The fairly steep valley sides are mostly medium to somewhat poorly drained soils (Lordstown-Volusia-Mardin association; Figure 1) in permanent grassland. The elevation difference is about 200 m. The valley floor is intensively farmed. There are

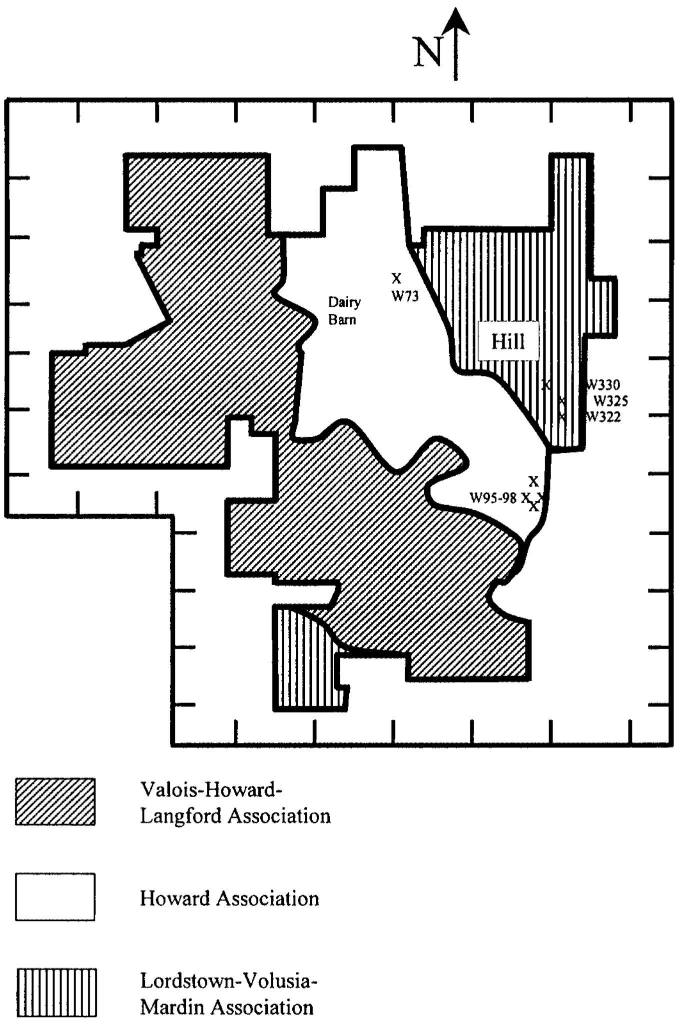

Figure 1. Map of case study farm showing soil series, well locations. Most fields in New York contain several soils. To determinee the most efficient cropping systems, however, it is of value to rate and group soils for field crops (3). The associations listed here are such groupings.

526 ha of cropland on the valley floor, growing primarily corn (*Zea mays* L.) and alfalfa (*Medicago sativa* L.) in rotation. Of the 526 ha, the 390 ha used for the dairy operation were included in this study. The total hectares in cropland have remained virtually unchanged since 1979, and crop production soil, and water analysis, and dairy herd records were available for 1979 and 1994. Therefore, mass nutrient balances computed for 1979 and 1994 were compared to changes in water NO_3-N and soil content of P and K. The dairy herd consisted of 369 cows and 359 replacement heifers in 1979; in 1994, the herd included 400 cows and 390 replacement heifers (Table 1).

In 1978 the United States Geological Service (USGS) conducted a study of the water movement in the landscape with the following results (18). A drainage divide runs through the farm with the area on the north side draining into the St. Lawrence River and the south draining into the Susquehanna River. The majority of the intensively farmed land is in this latter drainage system, where most of water drainage in this system was as ground water (98%) in deep gravel outwash aquifers. The source of 60% of the ground water is seepage from the upland (hillside) area in permanent grassland and thus 40% of the ground water is drainage from the valley floor, which was heavily farmed. There has been no farming activity above this farm, therefore, the well water is not recharged by other off-farm nutrient resources.

Mass Nutrient Balance

Mass nutrient balance is a gross accounting of nutrients that cross the farm boundary (12). The variables and inputs needed for calculating mass nutrient balance are described by Klausner et al. (12). In this study, mass nutrient balances were determined from records of homegrown feed, imports and exports of nutrients in feeds, fertilizers, cattle, milk, and estimates of N fixation for 1979 and 1994. Nutrient composition of homegrown feed, purchased feeds, and milk composition were analyzed by North East Dairy Herd Improvement (NEDHI), Ithaca, New York. Land area of legumes (alfalfa or mixed) was used to calculate symbiotic N fixation by the Cornell Nutrient Management Planning System (CNMPS) (11). In that program, atmospheric N input, through symbiotic N fixation by alfalfa, was estimated to be 60% of the legume N content at harvest for fields with less than 10% grass. For fields with more

TABLE 1. Herd description.

Year	Cows	Lactating	Dry	Heifers	% in Milk[1]	RHA[2] (kg)	Age (mo)	Milk[3] (mt)
1979	369	321	48	359	87	6802	39	2502
1994	400	344	56	390	86	10254	39	3604

[1]Percentage of cows in milk.

[2]Lactating cows rolling herd average.

[3]Annual milk production.

TABLE 2. Annual average precipitation (cm) in 1979 to 1981 and 1992 to 1994 in the farm area[1].

Year	1979	1980	1981	1992	1993	1994	1972–95[2]
Precipitation	104	98	98	97	104	104	99

[1]Data from Northeast Regional Climate Center at Cornell University.

[2]Mean precipitation.

than 10% grass, N fixation was estimated to be 36% of the forage N content at harvest. N fixation from lightning, which is difficult to quantify and is not thought to be a significant source of fixed N (21), was not included. Nutrient composition of purchased or sold cattle was also computed by CNMPS (2.53, 0.72, and 0.19% of animal live weight for N, P and K, respectively). The amount of feed refusals (orts) moved to other farm units (beef and sheep) were calculated to be 6.5% of the feed consumed.

Water and Soil Data

Water analysis data from five wells in 1979 to 1981 and 1992 to 1994 were used to evaluate the effect of changes in mass nutrient balances during the 15-yr period. The annual crop yields (dry matter) are about 8 and 5 metric tonnes/ha for corn silage and alfalfa silage, respectively. Water samples taken from these five wells (Figure 1), located in corn fields in 1979 to 1981 and 1992 to 1994, were analyzed by the Cornell Nutrient Analysis Laboratory for NO_3-N concentration. The total N is determined by Kjeldahl method with a model 1030 Kjeltec autoanalyzer with cupric sulfate and potassium sulfate as the catalyst. The NO_3-N was then determined colorimetrically (17). Water was sampled throughout the year, without emphasis on periods when aquifers were being recharged by snow melt and heavy rain. Therefore, data gathered in this study should represent the average water quality within a year. The average precipitation was 99 cm (with a standard deviation of 13 cm) per year from 1972 to 1995 (Table 2). The precipitation was 104, 98, 98, 97, 104, and 104 cm for 1979, 1980, 1981, 1992, 1993, and 1994, respectively (Table 2). The annual average temperature of this area is 8°C. The well water is not recharged with other off-farm nutrient resources because there is no farming activity above this farm. The variation of well water NO_3-N concentration can therefore be an indicator of the impact of nutrient loading on this farm.

Soil test data, analyzed in the Cornell Nutrient Analysis Laboratory, for the years 1979, 1988, and 1994 were used to evaluate accumulative effects of positive mass nutrient balances. Soil samples taken in spring from the plow layer (0 to 25 cm) of the fields were analyzed for pH, P, and K. The P and K were extracted with pH 4.8 Morgan's solution and determined by inductively coupled plasma emission spectrophotometry.

The mean value of NO_3-N concentration in the period 1979 to 1981 was compared with that in 1992 to 1994 in each well by using a Student's two sample *t*-test. To understand the impact of nutrient accumulation on soil, mean soil pH, P, and K values (from alfalfa fields, corn fields, and alfalfa + corn fields) for 1979, 1988, and 1994 were compared (1979 vs. 1988, 1979 vs. 1994, and 1988 vs. 1994) by using a Student's two sample *t*-test. The Student's two sample *t*-test procedure from MINITAB v.11.21 (14) was used in this study. $P < 0.05$ was considered significant unless otherwise noted.

RESULTS AND DISCUSSION

Water Quality

Sampled wells differed in depth but all were located in corn fields (Table 3). Four of the five wells were more than twice as high in NO_3-N concentration ($P < 0.05$) and the other was 40% ($P < 0.05$) higher in 1992 to 1994 than in 1979 to 1981. This may be the effect of the increasing amount of N BAL on the farm in 1990s. Therefore, the probability of leaching increased, and well NO_3-N concentrations increased in comparison to those in 1979 to 1981. The four wells located near the boundary of the farm may represent the NO_3-N in the water leaving the farm in the gravel aquifer. This result

TABLE 3. Comparison of mean NO_3-N concentration (mg/kg) from wells located in corn fields[1] in 1979 to 1981 and 1992 to 1994.

Well #	Depth (m)	1979 to 1981			1992 to 1994		
		Mean	SE	n[2]	Mean	SE	n
W73	15	5.8^a	0.3	33	15.0^b	0.3	79
W95	1	2.3^a	0.4	23	5.1^b	0.3	61
W96	2	2.2^a	0.2	33	4.8^b	0.3	62
W97	7	1.6^a	0.1	34	3.4^b	0.2	63
W98	15	4.7^a	0.2	35	6.9^b	0.2	64

[a,b]Means in the same row with different superscripts differ ($P < 0.05$).

[1]All wells located in Howard soil.

[2]Sample size.

TABLE 4. NO_3-N concentration (mg/kg) in water from wells in hillside area.

Well[1]	Depth (m)	1992 to 1994		
		Mean	SE[2]	n
W322	3	0.2	0.1	37
W325	3	0.6	0.2	39
W330	1	0.4	0.1	39

[1]All wells located in Volusia soil.
[2]Standard error.
[3]Sample size.

reflects the effect of the increasing amount of N BAL on the farm between 1979 and 1994. The average N BAL increased from 111 to 170 kg/ha between 1979 and 1994, increasing the potential for NO_3-N leaching into the wells.

Although the NO_3-N concentration in the four wells (W95, W96, W97, and W98; Table 3) increased ($P < 0.05$) in 1992 to 1994, the mean values were lower than the Environmental Protection Agency (EPA) standard of 10 mg/kg. However, the mean NO_3-N concentration in the well (W73) located near the center of the heavily farmed area exceeded 10 mg/kg during the period measured. This well probably receives more than average impact from the farmed area. Most of the manure was applied to fields in corn and much of it was spread daily; thus the effect could have been greater if the N had been conserved by storage as liquid followed by incorporation in the soil. The concentration of NO_3-N in water from wells (Table 4) in the hillside area in permanent grass remained lower than 0.6 mg/kg in 1992 to 1994. On a whole farm basis, the upland area dilution effect is important in decreasing the NO_3-N concentration in well water in the valley. The impact of dairy farming on water quality was also reported by Hutson et al. (8). They reported that in a stream draining cropland not charged by any surface or subsurface flows other than that which leaches or runs off this cropland, mean NO_3-N and P concentrations were 14.4 mg/kg and 0.4 mg/kg, respectively, during the period measured (March to December). Both of these were above federal water quality standards of 10 and 0.1 mg/kg, respectively. The farm produced a similar amount of milk (3744 vs. 3604 metric tonnes), had a similar hectare per cow (0.76 vs. 0.77), and had a similar amount of manure N (191 vs. 170 kg/ha) and more P (32 vs. 50 kg/ha) applied per hectare. As in our study, the soil is well drained to moderately drained with slopes generally less than 6%. In that study (8), they also concluded that the imbalance between nutrient imports and exports appeared to be related to high concentrations of NO_3-N and P in the water.

Given the few mass nutrient balance data (only 1979 and 1994), we cannot regress the mass nutrient balance with the NO_3-N concentration in the wells. However, we believe the increase in mass nutrient balance had the effect on water quality indicated by the values in Table 3.

Soil Chemical Properties

Soil P test level increased ($P < 0.05$) in alfalfa fields and corn fields between time periods. Soil P test level increased ($P < 0.05$) from 5.3 to 22.0 kg/ha in the alfalfa field and from 7.1 to 33.7 kg/ha in corn fields during the same period (Table 5) because of the accumulation of manure P. The major route of P loss is through surface water runoff (9). The cropland of this farm is relatively level. Therefore, little loss from runoff occurs.

TABLE 5. Mean values of soil chemical properties from corn and alfalfa fields in 1979, 1988, and 1994.

Year	P (kg/ha)			K (kg/ha)			pH (kg/ha)		
	Alf[1]	Corn	Total[2]	Alf[1]	Corn	Total[2]	Alf[1]	Corn	Total[2]
1979									
Mean	5.3^a	7.1^a	6.0^a	121.0^a	220.0^a	164.9^a	6.3^a	5.8^a	6.0^a
SE	1.1	1.0	0.8	15.0	22.5	14.2	0.1	0.1	0.1
n[3]	21	34	55	21	34	55	21	34	55
1988									
Mean	7.4^b	12.9^b	12.3^b	131.0^a	169.0^b	160.0^a	6.6^b	6.5^b	6.5^b
SE	0.1	2.3	2.0	39.1	20.9	18.3	0.1	0.1	0.1
n	10	20	30	10	20	30	10	20	30
1994									
Mean	22.0^c	33.7^c	24.0^c	188.0^a	284.0^a	205.2^a	6.9^c	6.9^c	6.8^b
SE	5.7	7.4	5.5	39.7	10.6	37.3	0.1	0.1	0.1
n	10	15	25	10	15	25	10	15	25

[a,b,c]Means in the same column with different superscripts differ ($P < 0.05$).
[1]Alf = Alfalfa.
[2]Mean value of alfalfa and corn fields altogether.
[3]Sample size.

TABLE 6. Summary of nutrients recycled from crop production[1] in case study farm.

	Corn (mt)			Alfalfa (mt)			Total (mt)		
Year	N	P	K	N	P	K	N	P	K
1979	27.9	4.5	16.8	23.6	2.4	19.3	51.5	6.9	36.0
1994	19.6	3.3	11.8	30.4	3.2	24.1	50.0	6.5	35.9

[1]210 ha of corn and 180 ha of alfalfa.

During this period, the soil test level of K did not increase ($P > 0.05$). Unlike P, K leaching losses can be substantial (2), which may account for the lack of increased soil K, despite a positive K (metric tonnes) balance on the farm. Although the soil concentration of K did not increase ($P > 0.05$) in this study, soil K levels are considered to be high to very high (3). A high K level in the soil will increase the K content in forage (2). High K content in forage has recently been identified as a primary factor in milk fever in dairy cattle (7).

Mass Nutrient Balance

Annual farm milk production increased 1102 metric tonnes between 1979 and 1994 (Table 1). Increased milk production (from 6802 to 10,254 kg/yr) per cow accounted for 80% of this difference; increased cow numbers accounted for the other 20%. During the same period, the average annual milk production per cow in New York State increased from 5332 to 7208 kg (15, 16).

Table 6 summarizes the mass nutrient balances computed for this farm for N, P, and K, respectively. Imported Nitrogen BAL on the farm increased from 67 to 71% of imported N, and K BAL decreased from 71 to 57% because of the reduced application of fertilizer K in the 1990s by the farm manager. These mass balances generally agree with other balances determined on dairy farms (10, 12, 19). Although percent N BAL on the farm was similar in 1979 and 1994, the total metric tons of BAL resulted from imported N increasing from 43.1 metric tonnes in 1979 to 66.0 metric tonnes in 1994. The BAL P was two percentage units lower, but BAL increased by nearly 2 metric tonnes, despite the reduced use of fertilizer. The reduced use of purchased fertilizer reduced K BAL by 5.3 metric tonnes.

Purchased feed was the major source of the imported N (66 and 79% in 1979 and 1994, respectively; Table 7). Because nutrients provided by homegrown feeds did not increase (Table 6), more feeds were imported to support the increased milk production during this period. In comparison to 1979, imported feed nutrients increased 73, 104, and 107% for N, P, and K, respectively, in 1994.

CONCLUSIONS

Annual farm milk production increased 44% (2502 to 3604 metric tonnes) and rolling herd average increased 51% (6802 to 10254 kg) between 1979 and 1994, which was supported by increased use of purchased feeds. Increased export of milk N did not offset the increase of imported N to support a 44% higher total milk production. Well water NO_3-N concentration increased significantly ($P < 0.05$) over a 15-yr period, which appears to be related to increased manure N application per hectare.

TABLE 7. Mass balance of N, P, and K in 1979 and 1994.

	N (mt)		P (mt)		K (mt)	
Year	1979	1994	1979	1994	1979	1994
Imports						
Feed	42.9	74.0	7.0	14.3	8.5	20.0
Fertilizer	5.6	3.5	7.5	3.5	16.8	2.2
N fixation	16.2	15.7				
Total Imports	64.6	93.3	14.6	17.9	25.2	22.3
Exports						
Milk	13.8	17.3	2.7	3.6	4.1	5.4
Animals	2.1	2.6	0.6	0.7	0.2	0.2
Miscellaneous[1]	5.6	7.3	0.9	1.1	3.0	4.0
Total exports	21.5	27.3	4.2	5.5	7.2	9.6
Balance	43.1	66.0	10.4	12.4	18.0	12.7
Balance (kg/ha)	111	170	27	32	46	33
% Total imports	67	71	71	69	71	57

[1]Feed refusals.

Reduced use of fertilizer offset the increased amount of imported P and K through feed.

This study demonstrates the impact of increasing imported nutrients to support a higher annual milk production, which has been a common trend on New York and other states dairy farms (6, 13). Purchased feeds are mainly concentrates that have higher energy and protein value for balancing rations to support increased milk production. However we cannot assume that milk production can be increased on the same land base by simply importing more concentrates. Regulations may dictate that dairy farming be based on nutrient accumulation and nutrient holding potential or require that manure be exported rather than be based on milk production and profits (5). Because purchased feeds are the primary source of nutrient imports, decreasing the ratio of purchased to homegrown feed will decrease the excess nutrients BAL on the farm, thus decreasing the potential of leaching and run-off to the environment.

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