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WHOLE FARM NUTRIENT FLOW AND MANURE MANAGEMENT

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INTRODUCTION

Best management practices for dairy farms in the Pacific Northwest have focused on protecting surface water quality by providing winter manure storage and preventing contaminated runoff. These practices take an important step toward protecting water quality, but they do not address growing concerns about nutrient imbalances on dairies.

Since the 1940s, the widespread adoption of synthetic fertilizers has reduced the need for manure as a nutrient source in crop production. This has led to separation of crop and animal production, increased use of imported feeds, and a growth in animal numbers relative to land area on dairy and other livestock farms. A net flow of nutrients into areas with a concentration of dairies is now common (Lanyon, 1995).

Most of the imported nutrients pass to the manure and then to the soil. If manure nutrient applications exceed the capacity of the crop to take up the nutrients, a surplus will remain in the soil at the end of the growing season. Excess available N will be in the form of nitrate, which is subject to winter leaching loss. Potassium is not a leaching problem, but K accumulation can lead to excess K levels in forage crops produced on the farm. Phosphorus also accumulates in the soil, and can be lost by runoff to surface water.

Even the best on-farm management cannot prevent excess nutrient accumulation if nutrient flows are greatly out of balance. Nutrient flows must be better understood to help determine the best approaches to sustaining long-term dairy productivity and water quality. By measuring whole-farm nutrient flows – imports, exports, and major on-farm transformations, we can gain a better grasp of the situation that we face, and of potential solutions.

METHODS

Farm Descriptions. We measured nutrient flows on three dairy farms in western Washington. Two of the farms are typical of larger, feed-intensive dairies, while the third is a small pasture-based farm. We compared data from these farms with data published for a dairy in New York (Klausner et al., 1998). The New York farm has similar management to the larger Washington farms, except that it produces a larger proportion of its feed on farm. All of the farms manage their land for feed production and use manure as a major source of crop nutrients. Farm data are compared in Table 1.

Table 1. Farm Descriptions[1]

	Farm 1	Farm 2	Farm 3	New York
Grass acres	115	381	55	6
Corn acres	90	190	0	310
Alfalfa acres	0	0	0	255
Milking Herd	418	994	40	320
Youngstock	46	135	27	290
Animal Density (AU/acre)[2]	2.9	2.7	1.0	1.1
Milk Produced (lb/cow/yr)	19,800[3]	25,100[3]	13,100[4]	26,000[3]

[1] Washington data are for 1996
[2] Animal Density equals animal units (AU) divided by acres; 1 AU equals 1000 pounds (live animal weight)
[3] Holstein breed
[4] Guernsey and Jersey breeds

Nutrient imports, exports, and transformations. We measured nutrient imports, exports, and major transformations on each farm in 1996 and 1997. Imports include purchased feed, fertilizers, bedding, and animals. Exports include milk, animals, and exported manure. Within-farm measurements include manure application, feed production and nutrient uptake, and pre-sidedress and post-harvest soil nitrate on a field-by-field basis.

We determined feed and fertilizer nutrient (N, P, and K) imports by working with the farmers, their nutritionists and fertilizer dealers, and their records. We estimated animal nutrients imported and exported based on animal inventories provided by the farmers and standard animal nutrient and weight estimates (IATP and CLM 1996). Bedding samples were analyzed for nutrients, and bedding volumes were calculated from farm records. Exported milk N was determined from milk sales and milk analysis. Milk P and K were determined from standard milk nutrient concentrations (Grusenmeyer, et al. 1995). Post-harvest soil nitrate was determined in samples collected at depths of 0 to 12 and 12 to 24 in. from each field in the fall. Pre-sidedress soil nitrate was determined in samples collected at the 0 to 12-in. depth in each cornfield when the corn was about 12 in. tall.

Manure samples were collected from the field at the time of application, so they reflect manure nutrient values after storage. Farmers applied liquid manure primarily through traveling gun sprayers at farms 1 and 2, but also used slurry wagons. Separated solids and dry stack manure were applied using manure spreaders at all three farms. Farm 3 received imported liquid manure in 1997, which was applied from a slurry wagon.

To collect samples from the traveling gun we placed up to 10 buckets across the path of the gun, and retained composite samples from the buckets. We used the volume in the buckets to estimate the rate of application, and used records from the farmers and manure applicators to determine the area receiving manure during each application.

Application rates from the slurry wagons were estimated by determining the volume of the wagon and the number of loads applied to the field area. In 1996, we collected solid manure samples on tarps, and weighed the tarps to estimate the application rate. In 1997 we calculated the weight of a spreader load of manure at each farm, and recorded the number of loads applied to each field. During 1996 and 1997 we collected and analyzed 13 liquid and 8 solid manure samples at farm 1, 19 liquid and 9 solid samples at farm 2, and 1 liquid and 3 solid samples at farm 3.

We measured forage yields on farms 1 and 2, by determining the wet weight per load harvested and the number of loads per field. At farm 3, we measured forage yield by weighing 3 random field areas (30 ft^2) immediately after the farmer cut the field. A composite sample was taken for each field after each cutting. We estimated pasture yield and nutrient content for each grazing from a sample collected from a 4.5-ft^2 area by the farmer just before turning the animals out to graze. Each field was sampled before each grazing cycle. Grass fields were harvested up to 6 times per year, and pastures grazed up to 10 times per year. Samples of the harvested material were dried at 130^{o}F to determine moisture content and dry matter yield. Dried samples were analyzed for total N, P, and K, to determine nutrient content and uptake. Plant, soil, and manure samples were analyzed using standard methods.

RESULTS AND DISCUSSION

This paper is focused on overall nutrient balance results, soil nitrate residual, and manure nutrient content. Most of the data presented is from 1996. Results from 1997 were similar, but final data analysis is not complete.

Nutrient balance summary. Overall nutrient balance summaries for each farm are shown in Tables 2 – 5. These are based on measured imports and exports and do not account for losses. To put these balances in perspective, we can compare them to surplus targets used in new regulations in The Netherlands (Muller, 1998). For example, the Dutch regulations allow a maximum N surplus of 270 lb/acre in 1998, declining to 160 lb/acre by 2008.

Table 2. Nutrient balance sheet for Farm 1 in 1996

		Nitrogen (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
Imports				
Fertilizer		2	2	5
Feed		714	135	361
Bedding		3	0	0
	Total	720	138	366
Exports				
Milk		203	40	61
Animals (net)		2	1	0
	Total	205	41	61
Net		514	97	305

The two larger farms have a large surplus of imported nutrients. Most of the surplus will be stored in the soil or lost to the environment. The nutrients stored in the soil will contribute to future nutrient cycling, further increasing the amount of nutrients available. Studies of soil N mineralization rates in western Washington soils showed that about 65% more N mineralization occurred on soils with a history of intensive dairy manure application compared to soils without recent application (Cogger et al., 1997).

Table 3. Nutrient balance sheet for Farm 2 in 1996

		Nitrogen (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
Imports				
Fertilizer		89	17	34
Feed		588	121	212
Bedding		4	0	6
	Total	682	138	253
Exports				
Milk		214	44	66
Animals		-9	-3	-1
Manure		46	10	46
	Total	252	51	111
Net		430	88	142

Table 4. Nutrient balance sheet for Farm 3 in 1996

		Nitrogen (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
Imports				
Fertilizer		99	21	18
Feed		78	14	41
Bedding		2	0	2
	Total	179	35	61
Exports				
Milk		57	10	15
Animals		-1	0	0
	Total	56	9	14
Net		123	26	47

Table 5. Nutrient balance sheet for New York dairy.

		Nitrogen (lb/acre)	Phosphorus (lb/acre)	Potassium (lb/acre)
Imports				
Fertilizer		44	7	24
Feed		143	27	40
N fixation		48	0	0
	Total	234	34	64
Exports				
Milk		61	12	18
Animals		6	2	0
	Total	66	14	19
Net		168	20	45

The pasture-based farm has N levels below the Dutch maximum values. Based on a preliminary evaluation of our data, N application rates to the pastures on this farm average about 225 lb/acre for manure and fertilizer combined, which is less than that needed for peak grass production. It appears that this farm could benefit from increased N inputs. The third farm is by far the smallest farm, and has the lowest herd average milk production. This type of management is becoming less common in western Washington, as farms become larger and more dependent on imported feed.

The New York dairy is similar to the larger Washington dairies in management and milk production, but similar to the pasture-based dairy in animal density and nutrient balance. The large land area available on the New York dairy provides greater opportunity to use manure nutrients in growing feed.

Soil nitrate residual. Fall soil nitrate tests can be used to indicate potential N surpluses on farm fields. Nitrate levels were higher on farms 1 and 2 than on farm 3, a likely result of N surpluses and cropping patterns. Nitrate-N in the 0-24 in. soil depth in 1996-1997 averaged 146 lb/acre beneath corn and 75 lb/acre beneath grass on farm 1 compared with 41 lb/acre beneath grass on farm 3. Farm 2 had the highest post-harvest nitrate-N levels, averaging 326 lb/acre beneath corn and 107 lb/acre beneath grass. The higher levels on farm 2 may be in part because of uneven distribution of manure. Some fields on farm 2 received more than 1300 lb N/acre in manure applications in 1996. Farm 1 had a more even distribution of manure.

Manure nutrient content. Table 6 shows the nutrient content of the manure from farms 1 and 2 (calculated on a per cow basis) compared with standard book values (Hermanson and Kaitla, 1994). The manure at farms 1 and 2 was collected in the field at application, and would be expected to have significantly lower N values (because of storage and application losses) than the book values, which are for fresh manure. The table shows that manure from farms 1 and 2 had only slightly lower mean N content than fresh manure book values, and higher K content. This suggests that book values underestimate manure nutrient loading at high-producing dairies, a result found by others in detailed nutrition studies (Wilkerson et al., 1997).

Table 6. Nutrient content of manure (per cow basis)

	N (lb/cow/year)	P (lb/cow/year)	K (lb/cow/year)
Farm 1 (stored manure)	218	45	228
Farm 2 (stored manure)	183	41	168
Hermanson and Kaitla (fresh)	230	48	149

SUMMARY AND CONCLUSIONS

Our results show that farms using a large proportion of imported nutrients are likely loading the soil with surplus nutrients. These surpluses may affect crop quality and water quality, as the nutrients become available for plant uptake or leaching. In the long term, best management practices will not be enough to reduce the nutrient imbalances, and major changes in nutrient management will be needed. Potential management changes must meet the twin goals of improving the long-term sustainability of nutrient management, while maintaining the economic health of the dairy business.

Management changes involve at least three phases. The first two can be done individually and in the short term, but the third will require time and cooperation among a number of parties. The first phase is estimating nutrient balances on individual farms. Imports of feed and fertilizers and exports of milk will account for nearly all of the nutrient flows into and out of most dairies. You can estimate imports of N, P, and K from feed and fertilizer purchase records, estimate exports from milk sales and standard milk nutrient values, and compare the balances with those reported here. Manure testing gives you farm-specific manure nutrient data. *Which Test is Best*, PNW 505, (Sullivan et al., 1997a) is a Cooperative Extension publication that provides guidelines for setting up a manure testing program. Testing soil for nitrate in the fall is a tool for determining if nutrient (specifically N) applications have been excessive in certain fields or across the farm.

The second phase is improving manure nutrient management under existing conditions. Keeping records of manure applications will let you determine if manure can be apportioned better among fields. *Date, rate, and place*, PNW 506, (Sullivan et al., 1997 b) is a booklet for recording manure applications in the field. It can be used to start a record-keeping program.

If nutrient flow measurements, manure testing, and soil testing indicate that you have excess manure nutrients, some short-term steps can begin to reduce the excesses. Some gains may be possible by adjusting feed programs; check with a nutritionist to see what is feasible. Reducing excess feed nutrient inputs can save money and reduce nutrient surpluses. Selling separated solids is often the simplest way to export some of the surplus nutrients. Most purchasers will prefer solids that have been composted. Since the proportion of total manure nutrients in the separated solids is small, exporting solids is not the complete solution to nutrient surpluses. In some cases it may be possible to supply liquid manure to neighbors who can use the nutrients.

The third phase is developing ways to export large amounts of manure nutrients off farm (and sometimes out of the watershed) to land where the nutrients will benefit plant growth. But, large-scale nutrient export will not be feasible until manure handling methods change. The potential demand for manure nutrients exceeds the supply, but the demand will depend on a product that is economical to ship and convenient to use. The specific technologies for future manure handling are not clear, but may involve initial handling in a drier form, improved solids separation to capture more nutrients, digestion with energy capture for drying, or many other possibilities. Many groups have much to contribute to the future of manure handling, including private sector innovation and marketing skills, public financial support, university research and education, and regulatory support for changes. Although the challenge is difficult, finding economic ways to reduce dairy nutrient imbalances is essential to the long-term sustainability of dairy farming in Washington.

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