NUTRIENT BALANCE ON COMMERCIAL DAIRIES IN IDAHO

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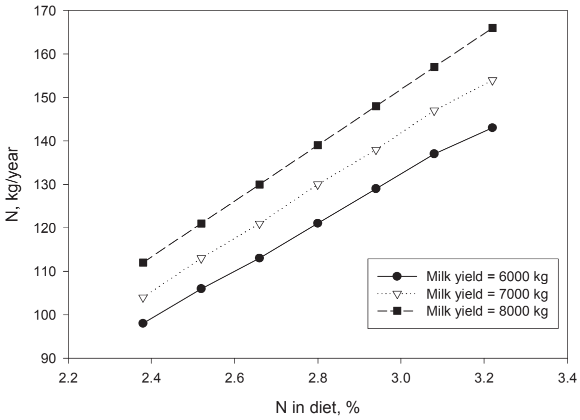
Increased milk yield and herd size are the basis of intensive dairying in the United States. Concentrating large numbers of dairy cows requires the import of nutrients from outside the production system. Thus, nutrient balancing on a dairy farm has to be approached within the context of the entire production system. Imbalanced import/export of nutrients can result in accumulation of environmentally important nutrients, such as nitrogen (N) and phosphorus (P) on the farm. Ratios of P:N in manure are twice as high as P:N required for plant growth, and excessive application of manure may exceed the assimilatory capacity of the soil and planted crops leading to eutrophication of aquatic systems (Satter and Wu, 1999). Phosphorus export to surface waters can be a significant problem in manure-amended soils. When manure is used as a fertilizer, it is commonly added to meet the N requirement of the crop (Heathwaite et al. 2000). Since manure typically has high P:N ratios, application of manure based on N availability and plant requirements results in overloading of P. While in the Eastern U.S., where concentration of dairy cows per unit of arable land is relatively low, surpluses of N and P are in most cases manageable (Dou et al., 2001), large dairies in Southern Idaho (and in the Western U.S., in general) are under economic pressure to push the upper bounds on land application of manures and other waste effluents in order to reduce costs for trucking and land-leasing.

In dairy cows, output of nutrients is closely related to nutrient inputs and level of production. The rate of nutrient losses, however, depends largely on nutrient input and is little affected by level of production. As illustrated in Fig. 1, increasing level of N intake linearly increases N output irrespectively of the level of production. Increased milk production on a dairy will require increased input of nutrients and will results in increased output of N and P with manure, elevated soil P levels, and perhaps impaired ground water quality (Wang et al., 1999). In this respect, diet modification can be a powerful tool in reducing N and P emissions from livestock operations (Klopfenstein et al., 2002; Satter et al., 2002; Børsting et al., 2003). Controlled animal experiments and mathematical modeling have demonstrated that nutrition can significantly reduce nutrient surpluses from dairy operations (Van Bruchem et al., 1999; Rotz et al., 1999). Thus, controlling nutrient inputs is critical for reducing nutrient losses and achieving nutrient balance on a whole-farm scale.

Figure 1. Nitrogen excretion in relation to N concentration in the diet and milk production of the cow (Oenema et al., 2001)



We conducted a study with commercial dairies from South Central Idaho with the following objectives: (1) examine dietary concentrations of N, P, potassium (K), and several other minerals; (2) propose dietary changes that will reduce P output in feces; (3) investigate the relationship between dietary crude protein (CP) level and solubility and concentration of milk urea N (MUN); and (4) conduct whole-farm nutrient balance of N, P, K, and other minerals on the participating dairies.

Materials and Methods

The duration of this project was 2 years. Twenty dairies participated in Year 1 and eight in Year 2. Data on nutrient inputs and outputs were collected from each participating dairy at monthly visits from January through December. Data included beginning and ending inventories of livestock and feed along with monthly purchases of feeds, minerals, bedding (straw) and fertilizer. In addition, records of loads of waste products shipped, kind and weight of livestock purchased and sold and the weight of milk sold were recorded. Milk, feed, urine, fecal, and manure samples were analyzed for concentration of nutrients.

Concentrate feeds were sampled trice/year. Composite samples were oven dried and analyzed for nutrients. Hay bales were sampled with a core sampler (approx. 5 to 7 bales per dairy and sampling). A composite sample was oven dried and analyzed for nutrients. Silage samples were taken from several locations in the silo, mixed, and stored on ice. A subsample was preserved frozen and the rest of the silage was oven dried and analyzed for nutrient composition. Diet (TMR, total mixed ration) samples were taken from six locations, mixed, and kept on ice until processed. Diets for each group of cows (fresh, lactating, dry) was sampled separately. Only freshly prepared TMR were sampled. Part of the sample was oven dried and part was stored frozen. Diets were subjected to a variety of chemical analyses (see diet composition tables).

Fecal samples were taken from 15 randomly selected lactating cows fed the same diet. Sample cows were distributed evenly across pens fed the same diets. Fresh fecal samples were obtained from the rectum or from the ground. One composite sample per diet fed was stored frozen. After thawing, fecal samples were oven dried and analyzed for acid-insoluble ash (AIA, used as an internal digestibility marker) and mineral composition. Urine samples were taken from 15 randomly selected lactating cows fed the same diet. As with the feces, cows fed different diets were sampled separately. Sample cows were distributed evenly across pens fed the same diets. Composite samples were analyzed for pH, acidified, and stored frozen for further chemical analysis.

Dry manure samples were taken from several locations from each manure pile after the surface layer was removed. A composite sample was oven dried and analyzed for minerals. Depending on the manure management system, separator solids samples were taken from different locations. Composite samples were oven dried and analyzed for minerals. Lagoon samples were obtained with a sampling device from 6 to 8 different locations and at a depth of approx. 1-2 feet. Composite samples were analyzed for pH and the samples were acidified and stored frozen for chemical analysis.

Bulk milk samples were collected from the milk tank. Samples were preserved and analyzed for milk protein, milk fat, milk urea N (MUN), lactose, and solid non-fat (SNF) residues.

Two fields from each of the participating dairies were selected for monitoring soil mineral composition. The fields were selected based on consistency of dairy waste application over the past few years. The fields received either lagoon water via sprinkler irrigation or dry waste via spreader trucks in the fall and spring. Each field was sampled in two areas, each area representing the soil and landscape features of a large portion of the field. Samples were taken over a 0.5 ha area in each location to a depth of 60 cm at 30 cm intervals. The positions of the sampling points were recorded with a GPS and resampled in the fall. Soils were analyzed for minerals, pH, organic matter and electrical conductivity using accepted soil sampling methods at a certified soil analysis laboratory.

Results and Discussion

Diet composition and reducing fecal P. Average CP content of the diets from the participating dairies was 17.7% (Table 1), which is within the range of CP routinely fed to high producing dairy cows, but somewhat above current recommendations (NRC, 2001). Reduction in the efficiency of utilization of dietary N for milk protein synthesis with increasing CP content of the diet has been well documented (Broderick, 2003; Hristov et al., 2004). Thus, despite of the increased milk yield, feeding more CP will inevitably result in greater losses of N with excreta, primarily urine. Crude protein concentration in the diets from some of the dairies was high (max of 18.2%). Another important observation was that in some diets, solubility of dietary CP was reaching 40%. Soluble protein is very rapidly degraded in the rumen and contributes significantly to urinary N excretion. Diets analyzed high in fiber (NDF and ADF, neutral- and acid-detergent fiber, respectively) and relatively low in non-fiber carbohydrates (NFC). As a result, estimated TDN content of the diets was 66%, on average. Dietary DM digestibility was on average 67.6±1.55%. In all participating dairies, cows were fed separate diets in the early and late stages of lactation. We did not observe any significant differences between the two category diets; crude and soluble protein, fiber, carbohydrate fractions, and DM digestibility were similar.

Concentration of dietary P was on average 0.49%, but some diets had P concentration of above 0.50% (Table 2). Phosphorus concentration in lactating dairy cow diets should not exceed 0.38% in order to minimize the environmental impact of the industry. Concentration of P was similar between the fresh and lactating cow diets.

Fat and protein content of milk was within the range typically reported for high-producing dairy cows. Milk urea N is an indirect indicator of the efficiency of utilization of dietary N and is used as a tool to monitor protein feeding of dairy cows (Carlsson and Pehrson, 1994; Jonker et al., 1999). Milk from some of the dairies participating in the study had high MUN concentrations most likely indicating overfeeding of ruminally degradable protein. The relationships between dietary CP concentration and solubility and MUN, however, did not exist in this dataset (Fig. 2). Concentration of MUN can vary greatly between cows and time

Table 1. Average chemical composition of diets from participating dairies

Variable	Average	SD	Min	Max
CP, %	17.7	0.59	16.3	18.2
NDF, %	39.2	2.59	34.3	42.5
ADF, %	26.1	1.94	22.6	29.2
AD-ICP*, %	1.54	0.30	1.25	2.23
Protein solubility, %	39.1	3.28	32.7	43.7
Starch, %	16.2	2.64	11.6	19.6
NFC, %	31.4	2.79	28.4	37.4
NEL, Mcal/cwt	68.1	1.65	64.7	70.5
TDN, %	66.0	1.48	63.0	68.2

*ADF-ICP = CP insoluble in ADF reagent; NFC = non-fiber carbohydrates

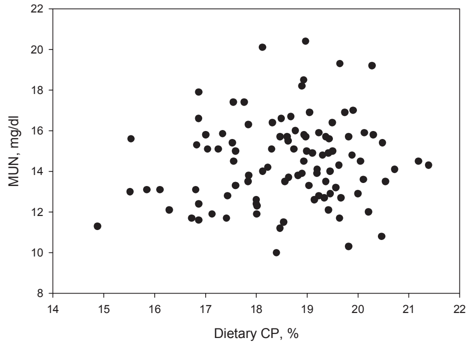
Table 2. Average mineral composition of diets from participating dairies

Variable	Average	SD	Min	Max	NRC*
P, %	0.49	0.05	0.41	0.59	0.35
K, %	1.90	0.20	1.61	2.16	1.07
Ca, %	0.98	0.08	0.90	1.17	0.63
Mg, %	0.37	0.03	0.34	0.41	0.20
Na, %	0.40	0.18	0.14	0.65	0.23
S, %	0.25	0.02	0.24	0.30	0.20
Cu, mg/kg	21.2	4.79	15.09	29.03	15.7
Zn, mg/kg	109.1	35.16	54.3	151.3	63

*NRC (2001) recommendations for a 90 DIM, 680 kg BW cow consuming 25 kg DMI and producing 40 kg milk.

of sampling (Hristov and Ropp, 2003) and our data suggest that, in commercial dairies, the relationship between MUN and protein feeding of the cows may not be as strong as in controlled research trials.

Figure 2. Relationship between dietary CP and MUN concentration (n = 107)



Sample taken from the dairies were also analyzed for macro and micro minerals (Table 2). For most of the minerals, dietary concentrations were above recommended levels (NRC, 2001). Although not considered environmentally important at the present (except maybe K), there is a lack of information on the movement of these minerals on a dairy farm. These elements may be accumulating on the farm, similar to N and P, and may present a concern for the producers and the public in the future.

In Year 2, eight dairies (with a total of approx. 12,700 cows) continued with the project. Based on the results from the diet analyses, our priority was to convince the participating dairymen and their nutritionists that a reduction in P concentration of their lactating cow diets would significantly reduce P excretion with feces and consequently P concentration in manure. All participating dairies accepted our recommendations for reduced dietary P. As a result, dietary P concentrations were significantly decreased (Fig. 3). Following implementation of the reduced P feeding, all dairies had dietary P concentrations of less than 0.4%, which was within the range recommended by NRC (2001). As a result of the decreased levels of P in the diets, fecal P was also significantly reduced in all but one dairy (Fig. 4). In ruminants, excretion of P is mainly with feces and reduction of fecal P is expected to significantly reduce P concentration in manure and consequently, in soil.

Figure 3. Dietary P before and after recommended P reduction (8 dairies)

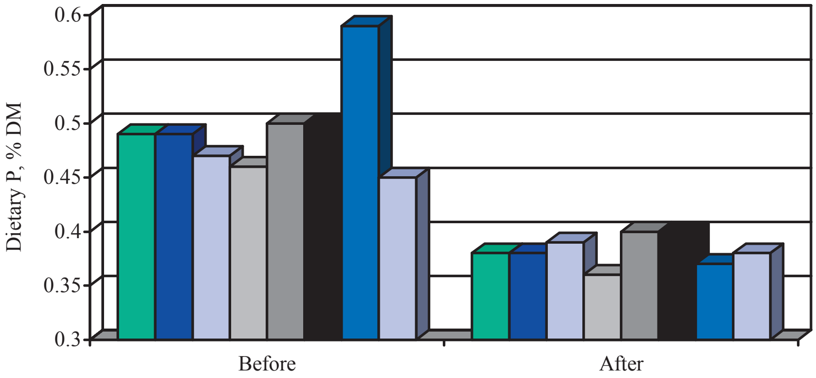
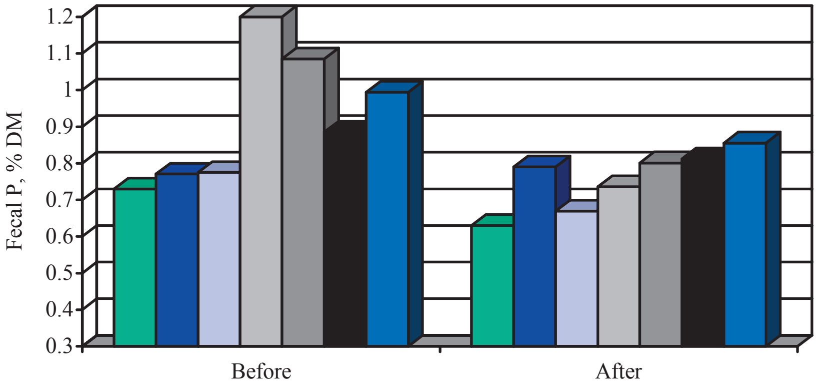


Figure 4. Fecal P before and after recommended dietary P reduction (7 dairies)



Whole-farm N and P balance. The whole-farm N and P balance data (Tables 3 and 4) indicated that, in most cases, feed was the largest source of imported N on the dairies (92 to 96% of all N imported). One dairy was an exception with only 38% of the imported N as feed; this particular dairy was producing a large amount of forage on its own land. The largest import of N on this dairy was through N fixation (42% of the import). Dairies exported from 19 to 70% of the N exported from the dairy as milk N. The lowest value was for a dairy, which exported a large proportion of its N export as feed N (77% of the total N exported). On average, 50% of the exported N was with milk. Typical for the large dairies in South Central Idaho, only a small proportion of the N export was with feed (except one dairy). Four of the dairies did not export any feed. Some dairies used all the manure produced on the farm, but most exported various proportions of manure N. On average, 29% of the N export was as manure N. Average balance (or efficiency of use of imported N) of N was 40%, which is similar to the 35% reported by Spears et al. (2003) for western dairies. Among the participating dairies, the most efficient use of N was on the dairy, which produced its own forages, milk yield was relatively high, and all manure was used on the dairy. The least efficient dairies exported little N with feeds and manure and had lower milk yield per cow.

Table 3. Summary of whole-farm N balance in participating dairies (as proportion of total imported or exported N)

Dairy	Imported with feed, % of total	Exported with milk, % of total	Exported with feed, % of total	Exported with manure, % of total	Balance (exported/ imported)
1	94	54	7	33	42
2&3	95	70	6	16	25
4	38	20	80	0	67
5	95	51	0	44	30
6	92	38	0	55	37
7&8	96	68	0	23	41
Overall	**85**	**50**	**15**	**29**	**40**

Similar to N, in all dairies the major import of P was with feed; from 88 to 98% of all P imported (Table 4). One dairy imported very little P due to its own forage production. From 25 to 62% of the P leaving the dairies was as milk P.

Except one dairy, there was little or no export of P with feeds. All dairies (except one), were exporting a significant amount of P with manure; from 25 to 68% of the total P export. The efficiency of P use on the farm was higher than the efficiency of use of N (due to the fact that there are no volatilization losses of manure P). The most efficient dairy exported large amounts of P with forages produced on the farm. In most dairies, however, there was a net accumulation of P on the farm, as a result of which soil P levels were considerably higher than the maximum recommended P threshold concentration of 40 ppm for surface water concerns and the 20 ppm maximum for ground water concerns (Idaho NRCS Nutrient Management Standard) in the 0-30 cm sample (data not shown).

Table 4. Summary of whole-farm P balance in participating dairies (as proportion of total imported or exported P)

Dairy	Imported with feed, % of total	Exported with milk, % of total	Exported with feed, % of total	Exported with manure, % of total	Balance (exported/ imported)
1	95	39	3	53	75
2&3	98	62	4	25	46
4	88	27	73	0	95
5	96	35	0	60	63
6	93	25	0	68	71
7&8	95	55	0	35	49
Overall	**94**	**41**	**13**	**40**	**67**

We estimated the reduction in annual P imports for five of the participating dairies (which participated in both phases of the study). As seen in Fig. 5, a reduction in dietary P concentration to the levels recommended by NRC (2001) could result in significant reduction in P imported into the dairy with the purchased feeds. Depending on the amount of feeds produced on the dairy, the estimated P imports could be reduced by up to 61.44 t/year. This would result in improved whole-farm P balance (Fig. 6). The estimated balance in three of the dairies would be greater than 80% and one dairy would be a net exported of P, which would allow reduction of soil P levels. These data provide a clear example of the possibilities of improving whole-farm nutrient balance and sustainability of the dairy industry through manipulating dietary nutrient content.

Figure 5. Estimated net reduction in P imports as a result of reduced dietary P

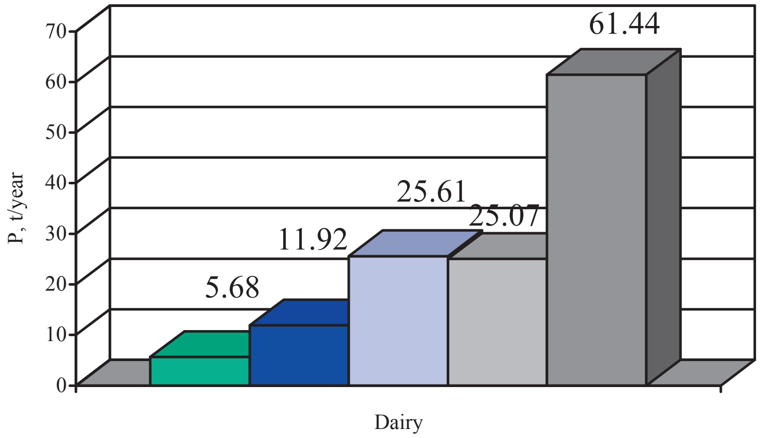
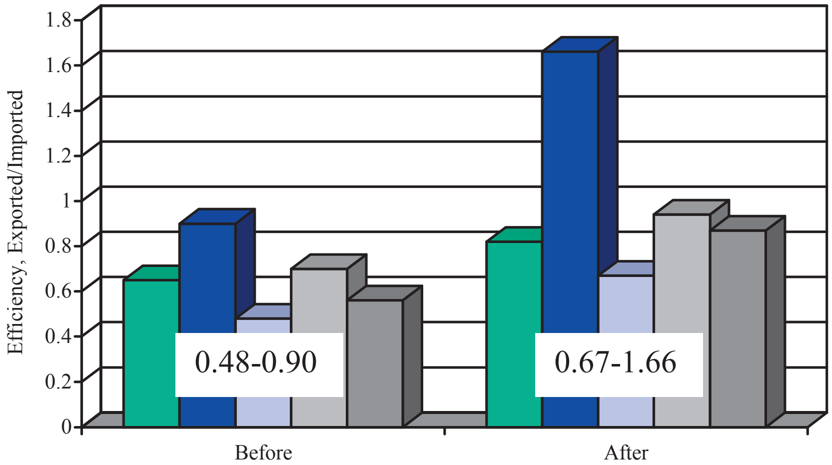


Figure 6. Estimated efficiency of whole-farm P use before and after dietary P reduction



Implications

This study generated important information on mineral composition of dairy samples and whole-farm balance of several environmentally important nutrients. Our overall conclusions are:

- Levels of most minerals studied in Idaho dairy diets exceed NRC (2001) recommendations;
- Reduction of dietary P resulted in reduced fecal P;
- The efficiency of whole-farm nutrient use varies greatly among dairies;
- Exporting nutrients as manure or crops, in addition to milk, is the key for achieving whole-farm balance and sustainability of the dairy operation.

Literature Cited

Børsting, C. F., T. Kristensen, L. Misciattelli, T. Hvelplund, and M. R. Weisbjerg. 2003. Reducing nitrogen surplus from dairy farms. Effects of feeding and management. Livest. Prod. Sci. 83:165-178.

Broderick, G. A. 2003. Effects of varying dietary protein and energy levels on the production of lactating dairy cows. J. Dairy Sci. 86:1370-1381.

Carlsson, J. and B. Pehrson. 1994. The influence of the dietary balance between energy and protein on milk urea concentration. Experimental trials assesses by two different protein evaluation systems. Acta Vet. Scand. 35:193-205.

Dou, Z., D. T. Galligan, C. F. Ramberg, Jr., C. Meadows, and J. D. Ferguson. 2001. A survey of dairy farming in Pennsylvania: nutrient management practices and implications. J. Dairy Sci. 84:966–973.

Heathwaite, L., A. Sharpley, W. Gburek. 2000. A conceptual approach for integrating phosphorus and nitrogen management at watershed scales. J. Envron. Qual. 29:159-166.

Hristov, A. N. and J. K. Ropp. 2003. Effect of dietary carbohydrate composition and availability on utilization of ruminal ammonia nitrogen for milk protein synthesis in dairy cows. J. Dairy Sci. 86: 2416-2427.

Hristov, A. N., R. P. Etter, J. K. Ropp, and K. L. Grandeen. 2004. Effect of dietary crude protein level and degradability on ruminal fermentation and nitrogen utilization in lactating dairy cows. J. Anim. Sci. 82: 3219-3229.

Jonker, J. S., R. A. Kohn and R. E. Erdman. 1999. Milk urea nitrogen target concentrations for lactating dairy cows fed according to National Research Council recommendations. J. Dairy Sci. 82:1261-1273.

Klopfenstein, T., R. Angel, G. L. Cromwell, G. L. Erickson, D. G. Fox, C. Parsons, L. D. Satter, A. L. Sutton. 2002. Animal diet modification to decrease the potential for nitrogen and phosphorus pollution. Council for Agricultural Science and Technology (CAST) Issue Paper, no. 21:1-16.

NRC. 2001. National Research Council. Nutrient requirements of dairy cattle. Seventh Revised Edition. National Academy Press, Washington, D.C.

Oenema, O., A. Bannink, S. G. Sommer, and G. L. Velthof. 2001. Gaseous nitrogen emissions from livestock farming systems. *In* Nitrogen in the Environment: Sources, Problems, and Management (R. F. Follett and J. L. Hatfield, Eds.), Elsevier Science B. V.

Rotz, C. A., L. D. Satter, D. R. Mertens, and R. E. Muck. 1999. Feeding strategy, nitrogen cycling, and profitability of dairy farms. J. Dairy Sci. 82:2841-2855.

Satter, L. D. and Z. Wu. 1999. Phosphorus nutrition of dairy cattle – What's new. Proceedings of the 61st Cornell Nutrition Conference. Rochester, N.Y. 72-81.

Satter, L. D., T. J. Klopfenstein, and G. E. Erickson. 2002. The role of nutrition in reducing nutrient output from ruminants. J. Anim. Sci. 80 (E. Suppl. 2):E143-E156.

Spears, R. A., R. A. Kohn, and A. J. Young. 2003. Whole-farm nitrogen balance on Western dairies. J. Dairy Sci. 86:4178-4186.

Van Bruchem, J., H. Schiere, and H. van Keulen. 1999. Dairy farming in the Netherlands in transition towards more efficient nutrient use. Livest. Prod. Sci. 61:145-153.

Wang, S. J., D. G. Fox, D. J. R. Cherney, S. D. Klausner, and D. R. Bouldin. 1999. Impact of dairy farming on well water nitrate level and soil content of phosphorus and potassium. J. Dairy Sci. 82:2164-2169.