J. Dairy Sci. 85:1218–1226

Dairy Herd Management Practices that Impact Nitrogen Utilization Efficiency[1]

J. S. Jonker,*,[2] R. A. Kohn,* and J. High†
*Department of Animal and Avian Sciences
University of Maryland, College Park, 20742
†Lancaster Dairy Herd Improvement Association
Manheim, Pennsylvania, PA 17545

ABSTRACT

Improving the efficiency of feed N utilization by dairy cattle is the most effective means to reduce nutrient losses from dairy farms. The objectives of this study were to quantify the impact of different management strategies on the efficiency of feed N utilization for dairy farms in the Chesapeake Bay Drainage Basin. A confidential mail survey was completed in December 1998 by 454 dairy farmers in PA, MD, VA, WV, and DE. Nitrogen intake, urinary and fecal N, and efficiency of feed N utilization was estimated from survey data and milk analysis for each herd. Average efficiency of feed N utilization for milk production by lactating dairy cows (N in milk/N in feed × 100) was 28.4% (SD = 3.9). On average, farmers fed 6.6% more N than recommended by the National Research Council, resulting in a 16% increase in urinary N and a 2.7% increase in fecal N. Use of monthly milk yield and component testing, administration of bovine somatotropin (bST), and extending photoperiod with artificial light each increased efficiency of feed N utilization by 4.2 to 6.9%, while use of a complete feed decreased efficiency by 5.6%. Increased frequency of ration balancing and more frequent forage nutrient testing were associated with higher milk production, but not increased N utilization efficiency. Feeding protein closer to recommendations and increasing production per cow both contributed to improving efficiency of feed N utilization.
(**Key words:** nitrogen pollution, milk urea nitrogen, dairy cattle protein requirements)

Abbreviation key: MUN = milk urea N, **3× milking** = three-times daily milking.

Received July 3, 2001.
Accepted November 6, 2001.
Corresponding author: R. A. Kohn; e-mail: rkohn@wam.umd.edu.
[1]A contribution from the Maryland Agricultural Experiment Station.
[2]Present address: National Research Council, Suite HA 394, 2001 Wisconsin Ave., N.W., Washington, DC 20007.

INTRODUCTION

Nitrogen losses from agriculture to water resources present a major environmental challenge for the Chesapeake Bay Drainage Basin (Thomann et al., 1994). Dairy farming is a large agricultural enterprise in the region, making dairy farms a major contributor to the nonpoint N loading of the bay. Kohn et al. (1997) used a simple mathematical model to evaluate which management practices had the greatest impact on reducing N losses from the farm: dairy herd feeding and management, soil and crop management, or manure storage and handling. This model suggests that improving herd management is the most effective means to reduce nutrient losses to the environment. Improving herd nutrient utilization efficiency by 50% was calculated to reduce nitrogen losses to water by up to 40%, but improving manure utilization efficiency by 100% only reduced N losses to water by 10 to 14%. Other authors determined the effect of several management practices, such as animal grouping (St-Pierre and Thraen, 2001), use of bST, milking three times daily (**3× milking**) or artificial lighting (Dunlap et al., 2000), on nutrient utilization efficiency and nutrient excretion in research dairy herds. However, the variation in herd nutrient utilization efficiency on commercial dairy farms is not known.

Jonker et al. (1998) developed and evaluated a model to estimate N excretion, N intake, and N utilization efficiency for lactating dairy cows. The model requires knowledge of milk production per cow, milk protein percentage, and milk urea N (**MUN**). The first objective of this study was to determine current N utilization efficiency of dairy herds in the Chesapeake Bay Drainage Basin. The second objective was to identify factors that contribute to variation from herd to herd in nitrogen utilization efficiency. With a better understanding of current management practices and their effect on potential N loading to the environment, opportunities to improve overall management may be identified.

MATERIALS AND METHODS

Dairy Farm Survey

A confidential mail survey was conducted in December 1998 with the Maryland and Virginia Milk Producers Cooperative (West Reston, VA). An introductory letter was mailed 1 wk prior to the survey, and a reminder letter was sent 1 wk after the survey. The cooperative had 1156 members located throughout most of the Chesapeake Bay Drainage Basin, including Delaware (n = 23), Maryland (n = 432), Pennsylvania (n = 519), Virginia (n = 172), and West Virginia (n = 18). Participants were offered monthly bulk tank milk analysis of MUN for 6 mo as an incentive to return the survey.

The survey included information on dairy herd characteristics, milk production, crop production, feed inputs, management characteristics, and MUN knowledge and use. Herd characteristics included information regarding breed, number and distribution by parity of milking animals, and number and age distribution of replacement heifers. Milk production included volume and compositional data. Crop production and management included types and acreage of crops grown and use of a nutrient management plan (**NMP**). Feed inputs included types of feeds routinely fed and frequency of ration balancing and nutrient composition testing. Management characteristics indicated the use of various technologies (bST, increased milking frequency, etc.).

MUN Sampling and Analysis

Bulk tank MUN analyses were performed monthly for 6 mo for dairy farms from the Maryland and Virginia Milk Producers Cooperative (n = 1156) from December 1998 through May 1999. Only the December samples are used in the current paper because other results were affected by our correspondence with farmers. Milk samples were collected weekly from Environmental Systems Services (College Park, MD) after routine milk component analyses were performed for cooperative members. One sample for MUN analysis was analyzed per herd per month. The fresh milk samples were treated with an antimicrobial preservative (Broad Spectrum Microtabs II, D & F Control Systems, San Ramon, CA). The milk samples were then shipped to Lancaster DHIA (Manheim, PA) for MUN analysis using the Bently Chemspec autoanalyzer (Chaska, MN).

Modeling and Data Analysis

The mean and standard deviation in N feeding parameters were calculated based on model predictions (Table 1) from the survey data and December milk analysis. Nitrogen intake, urinary and fecal N, and N utilization efficiency were determined for each herd using the model of Jonker et al. (1998), except prediction of urinary N was equal to 0.0259 times body weight times MUN, as recommended by Kauffman and St-Pierre (2001). Average BW for the cows in each herd was predicted as the weighted mean for all cows, where each cow's body weight was assigned according to breed as follows: Holstein and Brown Swiss, 600 kg; Ayrshire and Guernsey, 500 kg; and Jersey, Milking Shorthorn, and Dutch Belted, 400 kg. Estimates of body weights were made based on DHIA data summarized by Dunlap et al. (2000). Crossbred animals were assumed to weigh the average of the breeds crossed. Crude protein requirements were determined using the National Research Council (NRC, 1989) recommendations for dairy cattle, assuming a one-group TMR was fed (Jonker et al., 1999). The protein required was assumed to be that needed by the 83rd percentile cow with respect to protein requirements for the entire milking herd (Stallings and McGilliard, 1983). Excess N feeding was determined as the difference between observed N intake, estimated using the model described previously (Table 1), and that predicted to be required. Thus, negative values represented underfeeding and decreased the average estimate of overfeeding. The accuracy of N feeding was calculated by taking the absolute value of observed minus required N, so that the average represents both overfeeding and underfeeding.

Statistical analyses were performed using the software package JMP (SAS, 1995). Herds were excluded from the analysis whenever incomplete survey answers resulted in missing data for a variable in the model to predict N intake or utilization efficiency. Treatment means for each observed or calculated value were compared using ANOVA for discrete variables or regression for continuous variables. Observations were excluded when either X or Y values were missing (i.e., missing data were not estimated by the model). When more than two discrete variables were compared (e.g., frequency of diet formulation), the Tukey-Kramer t-test was used to compare each pair.

The environmental and economic impact of overfeeding dairy herds was estimated based on summarized results. Excess N fed in the watershed was calculated by multiplying the number of cows in the watershed during the study (n = 758,347 [United States Department of Agriculture, 1998]) by the fraction of farms overfeeding N and the average excess N per overfed cow. The N losses to water resources that result from overfeeding were calculated by accounting for losses from manure during storage and application. The total excess N fed was assumed to be excreted into manure. Assuming that 25% of manure N excreted eventually becomes available to crops, excess feed N was multiplied by 0.75 to estimate manure N losses (Kohn et al., 1997). There would be additional losses of N from the production of crops. However, imported soybean

Table 1. Prediction equations.

Variable	Equation
Urinary N (UN), g/d	0.0259 × milk urea N (mg/dl) × BW (kg)
N Intake (NI), g/d	(Predicted UN + milk N + 97)/0.83
Fecal N, g/d	Predicted NI + predicted UN − milk N
N utilization efficiency, %	(Milk N × 100)/predicted NI
DMI, kg/d	(Predicted NI × 6.25)/dietary CP percentage

meal was assumed to provide the excess feed N, so the N losses would not have occurred in this watershed. The cost of feeding excess N was estimated assuming that soybean meal (44%) could be replaced by corn grain to decrease N content. The 5-yr average prices (1996 to 2000) for soybean meal ($0.210/kg) and corn grain ($0.097/kg) were used (Bridge Information Systems, Inc., 2000).

RESULTS AND DISCUSSION

A total of 472 dairy farmers responded to the survey, for a 40.8% rate of return. However, nine farms stopped shipping milk shortly after completing the survey and were therefore excluded, and 91 farms were excluded because of incomplete data (usually rolling herd average or milk protein percentage was missing). For the final data, the largest number of surveys were from Pennsylvania (n = 165), followed by Maryland (n = 139), Virginia (n = 56), West Virginia (n = 6), and Delaware (n = 6). A large range in farm size and production was represented in the survey (Table 2). Average FCM was 28.3 kg/d per cow (SD = 4.2) with 3.74% (SD = 0.24) fat and 3.25% (SD = 0.15) true protein. The average farm surveyed had 109 cows (93 milking and 16 dry cows) and 86 replacement heifers (Table 2). Several farms reported not raising any replacements. Nearly every farm (>98%) reported having Holstein cows. Jersey cattle were the second most predominant breed—reported on 11.7% of the farms—and made up 3.7% of all dairy cattle. Other breeds represented less than 1% of total dairy cattle.

Table 2. Milk production and distribution of cows from surveyed farms.

			Range[1]	
	Mean	SD	10th percentile	90th percentile
Production				
FCM, kg $cow^{-1}d^{-1}$	28.3	4.2	22.4	33.6
Fat, %	3.74	0.24	3.50	4.00
Protein, %	3.25	0.15	3.10	3.40
Cows				
Total	109	103	40	200
Milking	93	88	34	173
Dry	16	16	4	30
1st lactation	35	35	9	70
2nd lactation	31	29	7	56
Mature	42	46	14	76
Heifers				
Total	86	80	24	173
<1 yr	42	41	11	85
>1 yr	44	41	11	90

[1]Reported range of surveyed dairy farms (n = 372).

The farmers participating in the program generally appeared to represent the range of farmers in the Chesapeake Bay Drainage Basin. The average milk production reported by participants was 28.3 kg/d per cow, compared to the average of 29 kg/d per cow reported for Lancaster DHIA members between July 1996 and April 1998 (Dunlap et al., 2000). Herd distribution (Table 2) was also similar to results reported for those records. The mean MUN for participating farms was 12.8 mg/dl (Table 3), compared to 12.4 mg/dl for all farms in the cooperative (Jonker et al., 2002). Higher MUN may have resulted from a tendency of participants to have higher milk production or to feed higher CP diets than nonparticipants, but the error imposed by nonrandom participation of farmers compared to all cooperative members would be 3.2% of MUN.

The model of Jonker et al. (1998) enables calculation of the variance in N utilization efficiency for a large number of herds in the field. The mean and standard deviation in N utilization parameters for lactating cows across all herds are given in Table 3. These calculations do not include dry cows or heifers, which would otherwise add to excreted N and decrease N utilization efficiency for the herd. Observed parameters differed significantly from recommended levels for all parameters. Observed MUN was 12.7 mg/dl, but feeding according to NRC (1989) and allowing for variation within the herd by feeding the 83rd percentile cow would have resulted in a MUN of 11.0 mg/dl.

As with any measurement, the variance can be attributed to both errors in measurement and true variance within the population. The root mean square prediction error (RMSPE) for the model used in this analysis was 16.9% of mean urinary N prediction (Jonker et al., 1998). A similar prediction error for the current study would result in prediction error accounting for 40% ($100 \times RMSPE^2/SD^2$) of the total variance (SD^2) among farms reported in Table 3. The RMSPE for prediction of N

Table 3. Mean and SD in milk urea nitrogen (MUN) and N intake, fecal N, urinary N, and N utilization efficiency for lactating herds on 372 commercial dairy farms.

	Observed[1]		Recommended[2]		Observed–recommended	
	Mean	SD	Mean	SD	Mean	SE[3]
MUN, mg/dl	12.7	3.4	11.0	0.7	1.8	0.17
N intake, g $cow^{-1}d^{-1}$	532	72	499	40	33	3.16
Fecal N, g $cow^{-1}d^{-1}$	187	12	182	7	6	0.52
Urinary N, g $cow^{-1}d^{-1}$	195	52	168	12	27	2.59
N efficiency, g/100 g	28.4	3.9	29.8	2.2	–1.47	0.17

[1]Observed MUN or predicted parameter using model of Jonker et al., 1998, with modification of Kaufman and St-Pierre, 1999.

[2]Recommended values for cows fed according to NRC (1989) recommendations using lead factors for a one-group TMR.

[3]Calculated as SD/√n.

utilization efficiency was 11% of prediction (Jonker et al., 1998). A similar prediction error in the present study would explain 64% of total variance in utilization efficiency among farms. Most of the model prediction error used for these calculations was associated with lab and cow variation (Jonker et al., 1998), and these would be reduced by using a single lab that uses wet chemistry and bulk tank samples representing an average of 109 cows. Therefore, we do not have adequate data to accurately estimate model prediction error under the circumstances in which the model was used in the present study. Nonetheless, the model prediction errors reported previously provide an upper limit of model prediction error.

On average, farmers appeared to feed 6.6% more N than recommended by NRC (1989), and this overfeeding resulted in a 16% increase in urinary N and a 2.7% increase in fecal N, compared to feeding to requirements. The average feeding level masks the extent of overfeeding because many farmers feed well below recommendations, which decreases the average estimate of overfeeding. Most (71.5%) of the farmers appeared to feed more than recommended amounts of protein by an average of 61 g/d or 11% of required N (data not shown). The standard deviation in N intake (Table 3) shows the high variation in N utilization on farms. The values for the 17th percentile farm equal the mean-minus-1 standard deviation, while those for the 83rd percentile farm equal the mean-plus-1 standard deviation. Urinary N excretion ranged from 143 g/d for the 17th percentile herd to 247 g/d for the 83rd percentile herd. Similarly, herd efficiency ranged between the same percentiles from 24.5 to 32.3. The tendency to overfeed and herd N utilization efficiency were not associated with herd size ($P > 0.10$).

Over three-quarters of the farms surveyed reported managing their milking cows as one feeding group (Table 4). Of those farmers that reported more than one feeding group, factors considered for grouping included milk production (69%), DIM (44%), reproductive status (41%), parity (23%), or other factors such as body condition (3%). Intuitively, an advantage of dividing cows into different feeding groups is to reduce variation within each group in order to better match nutrient requirements with feed nutrient concentrations. Having more feeding groups was not associated with higher milk production or reduced urinary N. Recommended N intake was calculated with the assumption that all lactating cows were fed, as they would be when grouped together, but in practice the recommendations could be decreased with multiple feeding groups. Nonetheless, having more feeding groups did not result in feeding

Table 4. Effect of the number of feeding groups for lactating cows on 4% FCM and N utilization.

	Number of feeding groups[1]		
Item[1]	One	Two to four	Individuals
Number of farms	282	69	21
FCM, kg $cow^{-1}d^{-1}$	28.3	28.6	27.7
Urinary N, g/d	193	206	186
Fecal N, g/d	187	190	185
N efficiency, g/100 g	28.5	28.0	28.3
N intake, g $cow^{-1}d^{-1}$			
Observed[2] (O)	529	549	516
Recommended[3] (R)	499	504	492
Excess[4] ($1/n\ \Sigma$ {O – R})	31	45	24
Difference[5] ($1/n\ \Sigma$ |O – R|)	54	56	47

[1]No significant differences due to number of feeding groups, were detected ($P > 0.1$).

[2]Observed 4% FCM or predicted parameter using model of Jonker et al., 1998, with modification of Kaufman and St-Pierre, 1999.

[3]Recommended N intake for cows fed according to NRC (1989) requirements for production and BW.

[4]Represents the average amount of N fed above recommendations.

[5]Represents the average difference in N intake compared with recommendations.

Table 5. Effect of frequency of forage DM determination on 4% FCM and N utilization.

Item[1]	Frequency			
	Weekly	Monthly	Quarterly	Other
Number of farms	40	146	113	59
FCM, kg $cow^{-1}d^{-1}$	30.8[a]	29.1[a]	27.1[b]	27.2[b]
Urinary N, g/d	206	200	188	193
Fecal N, g/d	192[a]	189[ab]	185[c]	186[bc]
N efficiency, g/100 g	29.3	28.6	28.2	27.7
N intake, g $cow^{-1}d^{-1}$				
Observed[2] (O)	561[a]	543[ab]	518[c]	523[bc]
Recommended[3] (R)	523[a]	506[a]	490[b]	488[b]
Excess[4] (1/n Σ {O − R})	38	36	28	35
Difference[5] (1/n Σ |O − R|)	54	53	54	59

[a,b]Difference superscripts within the same row indicate significant differences ($P < 0.05$).

[1]Observed 4% FCM or predicted parameter using model of Jonker et al., 1988, with modification of Kaufman and St-Pierre, 1999. Recommended N intake for cows fed according to NRC (1989) requirements for production and BW. Represents the average amount of N fed above recommendations. Represents the average difference in N intake compared to recommendations.

closer to requirements or feeding less protein. These results contradict the predictions of St-Pierre and Thraen (2001). They estimated an 8% decrease in N excretion due to feeding cows in six groups compared to a one-group TMR. The results in Table 4 shows that despite the theoretical possibility, herds fed as one group consumed no more N than those divided into two to four groups, and there was no difference in how accurately cows were fed on average.

The frequency of forage DM (Table 5) or nutrient (Table 6) determination was associated with 4% FCM, but not accuracy of diet formulation (represented as "difference" in tables). Reformulation of rations monthly was associated with higher FCM compared to doing so quarterly (Table 7). However, monthly diet reformulation was not more accurate (i.e., "difference" of observed and recommended intake was not different). More frequent DM and nutrient (e.g., CP, NDF) determination for forages was associated with higher FCM, but did not affect the potential for overfeeding of protein or the accuracy of diet formulation (Table 5). More frequent ration formulation was also associated with higher FCM, but not with more accurately formulating diets. These management strategies to improve diet formulation were associated with improved feed N utilization efficiency, but they were not associated with the accuracy of diet formulation relative to NRC recommendations.

Nearly 70% of surveyed farms reported feeding a TMR, with a similar percentage testing milk through DHIA (Table 8). Approximately 34% of the farms reported use of bST. The use of other herd management technologies (3× milking, extended photoperiod, and seasonal calving) represented less than 10% of farms. Thirty-eight percent had tested for MUN at least once. Only 33% of farms had a nutrient management plan,

Table 6. Effect of frequency of forage nutrient analysis on 4% FCM and N utilization.

Item[1]	Frequency			
	Weekly	Monthly	Quarterly	Other
Number of farms	9	152	131	64
FCM, kg $cow^{-1}d^{-1}$	30.8[ab]	29.3[a]	27.5[b]	27.5[ab]
Urinary N, g/d	207	202	190	190
Fecal N, g/d	193[ab]	190[a]	186[b]	186[b]
N efficiency, g/100 g	29.3	28.5	28.3	28.1
N intake, g $cow^{-1}d^{-1}$				
Observed[2] (O)	565[ab]	546[a]	523[b]	521[ab]
Recommended[3] (R)	526[ab]	507[a]	494[b]	491[b]
Excess[4] (1/n Σ {O − R})	38	38	29	30
Difference[5] (1/n Σ |O − R|)	51	57	53	55

[a,b]Different superscripts within the same row indicate significant differences ($P < 0.05$).

[1]Observed 4% FCM or predicted parameter using model of Jonker et al., 1998, with modification of Kaufman and St-Pierre, 1999. Recommended N intake for cows fed according to NRC (1989) requirements for production and BW. Represents the average amount of N fed above recommendations. Represents the average difference in N intake compared to recommendations.

Table 7. Effect of frequency of diet formulation on 4% FCM and N utilization.

	Frequency			
Item[1]	Weekly	Monthly	Quarterly	Other
Number of farms	23	165	100	71
FCM, kg $cow^{-1}d^{-1}$	28.6^{ab}	29.2^{a}	27.2^{b}	27.9^{ab}
Urinary N, g/d	207	201	185	191
Fecal N, g/d	190^{ab}	190^{a}	184^{c}	186^{bc}
N efficiency, g/100 g	27.9	28.6	28.4	28.3
N intake, g $cow^{-1}d^{-1}$				
Observed (O)	549^{ab}	546^{a}	514^{b}	523^{ab}
Recommended (R)	504^{ab}	508^{a}	490^{b}	495^{ab}
Excess (1/n Σ {O − R})	45	38	24	29
Difference (1/n Σ |O − R|)	56	55	53	52

[a,b]Different superscripts within the same row indicate significant differences ($P < .05$).

[1]Observed 4% FCM or predicted parameter using model of Jonker et al., 1998, with modification of Kaufman and St-Pierre, 1999. Recommended N intake for cows fed according to NRC (1989) requirements for production and BW. Represents the average amount of N fed above recommendations. Represents the average difference in N intake compared to recommendations.

and 28% used cover crops. The amount of FCM produced was higher for farms using TMR, DHIA, bST, 3× milking, or MUN testing and was lower for farms using seasonal calving and complete feeds. Whereas most farms use more than one of these technologies at the same time, a multivariate analysis was conducted starting with all management factors in Table 8 and eliminating the least significant with each run until all remaining variables were significant. Use of DHIA and bST were associated with increased FCM ($P < 0.05$), whereas seasonal calving was associated with a decrease in FCM. There was a tendency ($P < 0.07$) for an effect of 3× milking and testing for MUN. The model accounted for 27% of the variation in reported FCM, and use of bST explained the most variation in FCM ($r^2 = 0.17$). The management factors predicted FCM as follows:

$$\text{FCM (kg/cow per d)} = 27.6 + 0.91\ (\text{DHIA} = \text{yes};\ r^2 = .05) + 1.6\ (\text{bST} = \text{yes};\ r^2 = 0.17) + 0.8\ (3\times \text{ milking} = \text{yes};\ r^2 = 0.01) + 0.4\ (\text{MUN} = \text{yes};\ r^2 = 0.01) - 1.50\ (\text{seasonal calving} = \text{yes};\ r^2 = 0.03).$$

Daily milk production has been reported to increase between 3.8 to 5.5 kg/d for cows receiving bST (Thomas et al., 1991; Johnson et al., 1992; Speicher et al., 1994), and increased milking frequency (3× vs. 2× milking) was reported to increase FCM by 3.5 kg/d (Erdman and Varner, 1995). Dahl et al. (1997) reported use of an artificial photoperiod to increase milk production by 8 to 10%. Dairy farms reporting use of DHIA, bST, and 3× milking were observed to have higher FCM. Multivariate analysis revealed that most of the other management factors investigated had no effect on FCM ($P > 0.05$). Use of either bST or 3× milking was associated with an increase of about 2 kg/d, being somewhat lower

Table 8. Relationship of farm management to 4% FCM (kg $cow^{-1}d^{-1}$), N in urine (g/d), N in feces (g/d), and N utilization efficiency (NUE [g/100 g]).

	Number		FCM		Urine N		Fecal N		NUE	
Management factor	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
TMR	260	112	28.8**	27.0	202**	178	190**	183	28.3	28.7
DHIA member	278	94	29.0**	26.2	197	190	189*	184	28.7*	27.5
bST	126	246	30.8**	27.0	199	193	191**	186	29.6**	27.7
3× milking	18	354	31.0**	28.2	203	195	193†	187	29.8	28.3
Photoperiod	13	359	31.4**	28.2	200	195	191	187	29.5*	28.3
Seasonal calving	17	355	24.2**	28.5	158**	197	176**	188	28.0	28.4
Cover crops	105	241	28.5	28.4	188	197	186	188	28.9	28.3
N management plan	124	235	28.2	28.4	193	196	187	188	28.4	28.4
MUN testing	142	230	29.5**	27.6	198	193	189*	186	28.8†	28.1
Complete feed	46	326	26.7**	28.5	204	194	188	187	27.0*	28.6

**$P < 0.01$.

*$P < 0.05$.

†$P < 0.1$.

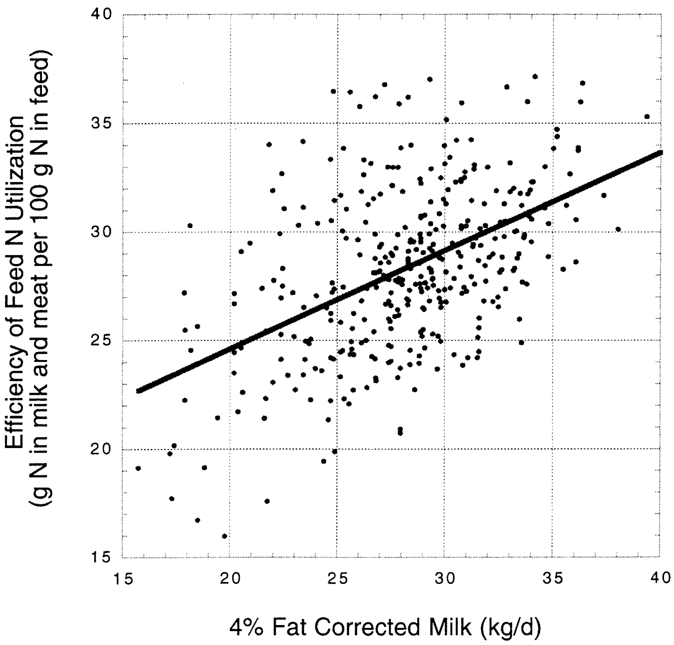

Figure 1. Effect of 4% FCM yield on efficiency of feed N utilization by dairy herds (n = 372). Line of best fit is Y = 0.45 (SE = 0.05) X + 15.6 (SE = 1.2); r^2 = 0.25.

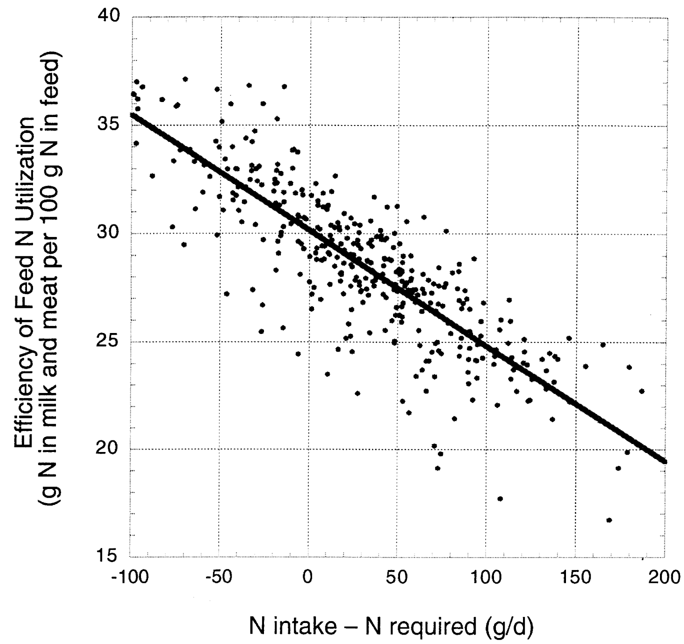

Figure 2. Effect of N feeding level relative to NRC recommendations (1989) on feed N utilization by dairy herds (n = 372). Line of best fit is Y = 0.053 (SE = 0.002) X + 30 (SE = 0.1); r^2 = 0.71.

than studies previously mentioned. While many management and herd factors have been reported to contribute to higher milk production in research trials, the current study shows that use of some of these technologies is associated with higher milk production in the field.

Factors that increased herd N utilization efficiency were DHIA membership, use of bST and photoperiod manipulation, whereas use of a complete feed was associated with decreased efficiency (Table 8). The same factors remained after stepwise multivariate analysis, which explained 7.3% of the variation according to the model:

$$\text{N utilization efficiency (\%)} = 28.0 + 0.4 \text{ (DHIA = yes; } r^2 = 0.01) + 0.8 \text{ (bST = yes; } r^2 = 0.05) - 0.6 \text{ (complete feed = yes; } r^2 = 0.01).$$

Figure 1 shows the effect of increasing FCM on feed N utilization efficiency of each herd. For each kilogram increase in FCM, the N utilization efficiency increased by 0.45 percentage units (SE = 0.05). This relationship explained 25% of the variation in N utilization efficiency and did not differ from the change in N utilization efficiency that would be predicted for this change in milk when feeding according to NRC recommendations (slope = 0.47; data not shown). Since N utilization efficiency is a function of FCM, the relationship shown in Figure 1 is not surprising. The dispersion of data about the line results because herds are predicted to be fed more or less than NRC recommendations. In addition to increasing FCM, N utilization efficiency can be improved by feeding closer to requirements. Figure 2 shows that N utilization efficiency decreased by 0.05 percentage units for every additional gram of N in the diet. This relationship explained 71% of the variation in N utilization efficiency. There was no effect of protein feeding level on FCM for the farms included in this study (Figure 3), suggesting that many herds appeared to maintain milk production even as protein intake fell far below NRC recommendations.

As FCM per cow increases, dietary protein requirements increase at a slower rate (NRC, 1989), thereby improving N efficiency for milk production. Management factors that may increase FCM (bST, 3× milking, increased photoperiod) should increase N efficiency and reduce urinary and fecal N excretion per unit of milk produced. Due to increased milk production and N efficiency, a decrease in N excretion per unit of milk production of 8, 7, and 5% is predicted from using bST, 3× milking, and increased photoperiod, respectively (Dunlap et al., 1999). Cumulatively, if all three technologies were used, N excretion per unit of milk production would decrease by 16% (Dunlap et al., 1999). Therefore, cows on surveyed dairy farms utilizing these or other management factors that are associated with increased

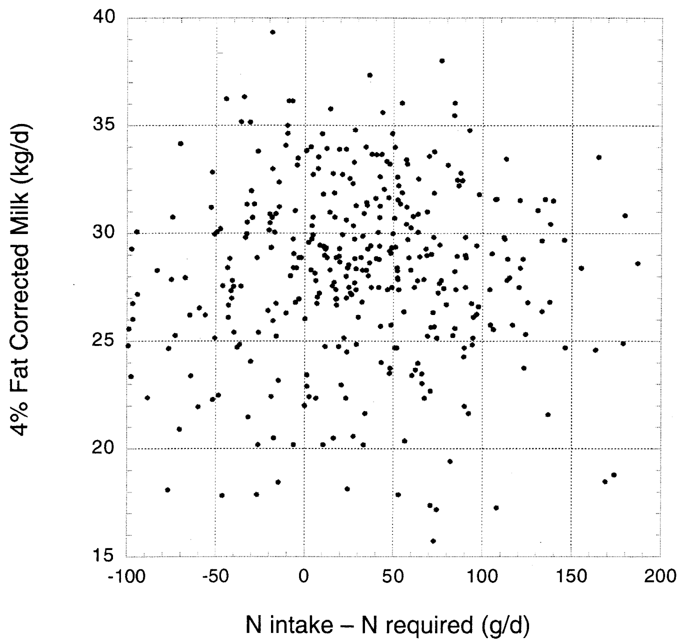

Figure 3. Effect of N feeding level relative to NRC recommendations (1989) on 4% FCM (n = 372). Mean milk yield was 28.3 kg/d (SE = 0.22).

FCM (Table 9) have reduced N excretion per unit of milk produced. Conversely, some management factors reduce FCM (seasonal calving, complete feeds), decrease N efficiency for milk production, and increase N excretion per unit of milk production.

Estimates of the environmental and economic impact of overfeeding N in the watershed are presented in Table 10. Seventy-one percent of farms fed N above NRC (1989) recommendations for the 83rd percentile cow. This excess N would be excreted in urine. Since less than 25% of excreted N is typically available to be recycled to crops, 75% of the manure N is likely to be lost to the environment. Thus, 7.6 million kg of N would be lost to the environment due to overfeeding of N by farmers. This figure represents 7.9% of the total nonpoint source N loaded to the Chesapeake Bay each year (Thoman, 1994), but it includes some N that returns as atmospheric deposition taken up by natural or agricultural plants and N converted to N_2. The cost of feeding excess soybean meal in place of corn grain was $32.94/cow per yr, or $17.86 million/yr. Theoretically, some of that cost could be recovered with increased milk production from the highest-producing cows (St-Pierre and Thraen, 2000).

Kohn et al. (1997) showed that a 50% improvement in N utilization efficiency by a dairy herd could reduce N losses from the farm by up to 40%. The current study suggests that such improvements are feasible for some farms. It would be practical to attempt to improve the typical herd by 10% to reduce N losses to the environment by 8%. New technology that isn't currently being used (e.g., amino acid supplements) will be needed to further reduce nutrient losses. For the most part, all of the technologies discussed are targeted toward increasing the profitability of milk production on farms. Under current regulatory practices, it would be impractical to expect farmers to risk loss in profitability in order to adopt technologies to reduce environmental damage. However, incentive programs or regulations can change how profitable a given management strategy is. The current study shows that most variation (71%) in feed N utilization by dairy herds is due to CP feeding levels. On average, farmers only overfeed protein by a small margin, but some overfeed substantially while others underfeed protein. There was no improvement from using various techniques to formulate diets more accurately. Thus, rather than emphasiz-

Table 9. Relationship of farm management to N intake (g/d) as mean observed, recommended (NRC, 1989), excess (observed – recommended), and difference (absolute value of [observed – recommended]).

	Observed		Recommended		Excess		Difference	
Management factor	Yes	No	Yes	No	Yes	No	Yes	No
TMR	545**	503	505**	487	40**	16	57	49
DHIA member	539**	514	505**	482	33	32	55	54
bST	553**	522	523**	487	30	35	46*	58
3× milking	564†	531	531**	497	33	33	45	55
Photoperiod	556	532	523**	499	33	33	41	55
Seasonal calving	462**	536	455**	501	7†	34	43	55
Cover crops	529	535	498	500	24	35	46*	57
N management plan	527	532	498	501	30	34	51	56
MUN testing	543*	526	510**	493	33	33	53	55
Complete feed	534	530	485**	501	49*	31	68*	52

**$P < 0.01$.

*$P < 0.05$.

†$P < 0.1$.

Table 10. Economic and environmental impact of overfeeding protein to dairy cows in the Chesapeake Bay Drainage Basin.

Item	Estimate
Farms feeding N above recommendations,[1] %	71.5
Excess N per overfed cow,[1] kg/yr	18.6
Excess N fed in watershed, 10^6 kg/yr	10.1
N loss to Bay from overfeeding,[2] 10^6 kg/yr	7.6
Additional feed cost per overfed cow,[3] $/yr	$32.94
Cost of overfeeding in watershed, 10^6 $/yr	$17.86

[1]N intake – N recommended.

[2]N losses from manure application and crop production minus estimated denitrification.

[3]Cost of excess soybean meal to exceed CP requirement.

ing forage analysis or diet reformulation, it may be more important to encourage certain nutritionists to keep protein levels in diets at recommended levels. Given the environmental and economic costs of protein overfeeding in an industry with a very low profit margin, an educational program to address overfeeding of protein is justified. Although feeding less protein has an important impact on reducing N losses to water resources, current government programs to provide incentives for better management of the environment do not address the issues of feeding and herd management.

CONCLUSIONS

The efficiency of N utilization by dairy herds was highly variable from farm to farm and most of this variation could be explained by the level of N feeding relative to recommendations. Twenty-five percent of the variation in N utilization efficiency could be explained by the variation in milk production per cow. Ironically, the management strategies employed to improve the accuracy of N feeding (forage analysis, ration formulation) appeared to have little impact, while strategies to increase production per cow (use of bST, 3× milking, photoperiod, manipulation) appeared to increase N utilization efficiency the most.

ACKNOWLEDGMENTS

The authors thank Alan Grove and the participating member farmers of the Maryland and Virginia Milk Producers Cooperative, Lancaster DHIA laboratory staff, and Susan Newman of Environmental Systems Services, for participating and assisting in the study.

REFERENCES

Bridge Information Systems, Inc. 2000. The CRB Commodity Yearbook. John Wiley and Sons, Inc., New York.

Dahl, G. E., T. H. Elsassar, A. V. Capuco, R. A. Erdman, and R. R. Peters. 1997. Effect of a long daily photoperiod on milk yield and circulating concentrations of insulin-like growth factor-1. J. Dairy Sci. 80:2784–2789.

Dunlap, T. F., R. A. Kohn, G. E. Dahl, R. A. Erdman, and M. Varner. 2000. The impact of bovine somatotropin, three times daily milking or extended photoperiod on nitrogen flows from dairy farms. J. Dairy Sci. 83:968–976.

Erdman, R. A., and M. Varner. 1995. Fixed yield responses to increased milking frequency. J. Dairy Sci. 78:1199–1203.

Johnson, D. E., G. M. Ward, and J. Torrent. 1992. The environmental impact of bovine somatotropin use in dairy cattle. J. Environ. Qual. 21:157–162.

Jonker, J. S., R. A. Kohn, and R. A. Erdman. 1998. Using milk urea nitrogen to predict nitrogen excretion and utilization efficiency in lactating dairy cattle. J. Dairy Sci. 81:2681–2692.

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

Jonker, J. S., R. A. Kohn, J. High, and A. Grove. 2002. Use of milk urea nitrogen to improve dairy cow diets. J. Dairy Sci. 85:939–946.

Kauffman, A. J., and N. St-Pierre. 2001. The relationship of milk urea nitrogen excretion in Holstein and Jersey cows. J. Dairy Sci. 84:2284–2294.

Kohn, R. A., Z. Dou, J. D. Ferguson, and R. C. Boston. 1997. A sensitivity analysis of nitrogen losses from dairy farms. J. Environmental Management 50:417–428.

National Research Council (NRC). 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. Natl. Acad. Sci., Washington, DC.

SAS User's Guide: JMP, Version 3.1.5 Edition. 1995. SAS Inst. Inc., Cary, NC.

Speicher, J. A., H. A. Tucker, R. W. Ashley, E. P. Stanisiewski, J. F., Boucher, and C. J. Sniffen. 1994. Production responses of cows to recombinantly derived bovine somatotropin and to milking frequency. J. Dairy Sci. 77:2509–2417.

Stallings, C. C., and M. L. McGilliard. 1984. Lead factors for total mixed ration formulation. J. Dairy Sci. 67:902–907.

St-Pierre, N. R., and C. S. Thraen. 2001. Animal grouping strategies, sources of variation, and economic factors affecting nutrient balance on dairy farms. J. Dairy Sci. 77(Suppl. 2):72–83.

Thomann, R. V., J. R. Collier, A. Butt, E. Casman, and L. C. Linker. 1994. Response of the Chesapeake Bay Water Quality Model to Loading Scenarios. Environmental Protection Agency, Washington, DC.

Thomas, J. W., R. A. Erdman, D. M. Galton, R. C. Lamb, M. J. Arambel, J. D. Olson, K. S. Madsen, W. A. Samuels, C. J. Peel, and G. A. Green. 1991. Responses by lactating cows in commercial herds to recombinant bovine somatotropin. J. Dairy Sci. 74:945–964.

United States Department of Agriculture. 1998. 1997 U.S. Census of Agriculture. USDA, Washington, DC.