Use of Milk or Blood Urea Nitrogen to Identify Feed Management Inefficiencies and Estimate Nitrogen Excretion by Dairy Cattle and Other Animals

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Summary

The objective of this review is to describe recent research findings related to the use of milk or blood urea nitrogen to identify inefficiencies in protein nutrition and estimate nitrogen excretion. A mathematical model was developed to integrate milk urea nitrogen (MUN) and milk composition to predict urinary and fecal excretion, intake, and utilization efficiency for nitrogen in lactating dairy cows. This model was subsequently used to develop target MUN concentrations for lactating dairy cattle fed according to National Research Council recommendations. Further research identified a change in measurement of MUN by Dairy Herd Improvement Associations, and subsequently resulted in adjustments to the model. Target MUN concentrations for most dairy herds bulk tank samples are between 8 to 12 mg/dl. Urinary nitrogen (g/d) can be estimated as 0.026 times MUN (mg/dl) times body weight (kg) for dairy cattle. A similar approach can be used with blood or plasma urea nitrogen. Because blood or plasma urea is higher than MUN, the coefficient relating blood urea to urinary N is lower than for MUN. Urinary nitrogen (g/d) can be estimated as 0.013 times MUN (mg/dl) times body weight (kg) for cattle, sheep, goats and horses. However, pigs and rats were found to be more efficient at clearing urea from the blood, and therefore, higher coefficients are used to relate blood urea concentration to N excretion rate for these species. Several extension and field research projects using MUN have been implemented. Bulk tank samples are used to identify herds with either chronic or occasional herd nutrition problems. Herds with high MUN have been found to be at risk for over feeding protein and herds with low MUN have been found to be at risk for under feeding protein.

Introduction

Reducing N excretion by dairy cattle is the most effective means to reduce N losses (runoff, volatilization and leaching) from dairy farms. The objective of this review is to describe recent research findings related to the use of milk or blood urea nitrogen to identify inefficiencies in protein nutrition and estimate nitrogen excretion.

See Figure 1 for a brief model of N metabolism in a dairy cow. Absorbed N in the blood stream of a dairy cow results from the diffusion of ammonia across the rumen wall and transport of amino acids and peptides from the small intestine. Ammonia is toxic to

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the cow and is rapidly converted to urea in the liver. Absorbed amino acids and peptides that are not utilized for milk synthesis are deaminated in the liver for energy, and the N converted to urea. This urea becomes part of the blood urea N pool. The blood urea N pool has three ultimate fates: recycling, secretion in milk, or excretion in urine. Recycling of urea via saliva, and across the rumen wall, can be an important source of N for microbial protein synthesis in ruminants. Urea also is filtered from the blood by the kidney and is excreted from the body in urine. Blood flow through the kidney is constant within an animal, which ensures a constant blood filtration rate (milliliters of blood filtered per minute) regardless of urine volume (Swensen and Reece, 1993).

As milk is secreted in the mammary gland, urea diffuses into and out of the mammary gland, equilibrating with urea in the blood. Because of this process, MUN is proportional to blood urea N (Roseler et al., 1993; Broderick and Clayton, 1997)), and total urinary N excretion is linearly related to MUN (Ciszuk and Gebregziabher, 1994; Jonker et al., 1998).

MUN may be used as a management tool to monitor nutritional status of lactating dairy cows and improve dairy herd nutrition. Several researchers have explored the relationship of MUN to dietary protein and energy. Variation in MUN has been suggested to be related to the protein to energy ratio of the diet consumed (Roseler et al., 1993). The concentration of MUN was only slightly affected by N intake when the protein to energy ratio was held constant, but increased with an increase in this ratio. Broderick and Clayton (1997) analyzing data from 35 conventional lactation trials found no effect of total energy (Mcal/d), non-protein N intake (g/d), dietary concentration of energy (Mcal/kg), or neutral detergent fiber (%), in single factor regression analysis. The protein to energy ratio affected MUN in the study.

With adequate energy in the diet, MUN is indicative of protein status. Roseler et al. (1997) observed an increase in MUN concentration for dairy cows when different forms of protein were fed in excess of National Research Council recommendations with no difference in milk production. Conversely when protein was fed below recommendations, MUN concentration and milk production were reduced because N was limiting in the diet. High levels of readily degraded protein were reported to increase MUN concentrations (Baker et al., 1995).

Predicting Urinary and Fecal N, Intake and Utilization Efficiency

Jonker et al. (1998) developed and evaluated a model to estimate urinary and fecal N excretion, N intake, and N utilization efficiency for lactating dairy cows (Table 1). The model requires knowledge of milk production per cow, milk protein percentage, and MUN. Urinary N is predicted as a function of MUN. Originally, urinary N (g/d) was predicted as 12.54 times MUN (mg/dl) for typical Holstein cows (Jonker et al., 1998). These researchers recognized that urinary N was under predicted for smaller breeds when using the model, but were unable to account for these effects using the data available. In September 1998, Dairy Herd Improvement Association laboratories changed the way standards were derived in the US. As a result, reported MUN values decreased by an average of 4 mg/dl (Kohn et al., 2002). Kauffman and St-Pierre (2001) and Kohn et al., (2002) were able to account for body weight effects and the change in MUN analysis. Currently, urinary N (g/d) can best be predicted as .026 times body weight (kg) times MUN (mg/dl) for any breed of dairy cow.

Jonker et al. (1998) also showed that the proportion of N absorbed in the body, as opposed to excreted in feces, is consistent across various types of feedstuffs. Therefore, assuming that most N is either secreted in milk or urine by mature dairy cows, N intake (g/d) can be predicted as: (urinary N (g/d) + milk N + 97) / 0.83. The endogenous losses are represented as 97 g/d and the fraction of feed N digested is assumed to be 0.83. Since all intake N by mature (not growing) cows must eventually leave the animal, fecal N can be predicted as intake N – urinary N – milk N. Finally, N utilization efficiency for mature cows is equal to milk N times 100 and divided by N intake. This model was evaluated using data from several published research studies.

Target MUN Concentrations

Target MUN concentrations were determined for cows fed according to NRC (1989) recommendations (Jonker et al., 1999). Required N intake was calculated throughout a standard 305-d lactation for cows fed diets balanced for different forms of protein according to the NRC. Driving variables used to calculate N intake requirements were milk production (kilograms per day), milk fat (percentage), body weight (kilograms), live weight change (kilograms per day), parity (1, 2, or 3+), and days pregnant. Typical lactation curves for daily milk production, milk fat percentage, milk protein percentage, and body weight change were developed. Target MUN concentrations were determined for a 600-kg second lactation cow (Figure 2). The data represented in the current paper is adjusted for the modification in the procedure recommended by Kauffman and St-Pierre (2001) and Kohn et al. (2002). For a 10,000 kg per year lactation, peak MUN concentration of 11.6 mg/dl occurred at 78 days in milk (DIM).

With higher average milk production, target MUN levels increased (Figure 2). Mean MUN weighted by milk production for a 12,000-kg lactation was 12.7 mg/dl with a peak MUN concentration of 14.5 mg/dl occurring on day 76. Milk production drives the requirement for N in lactating dairy cows fed according to NRC. As milk production increases, when cows are fed according to NRC recommendations, predicted MUN concentrations increase linearly because of higher N intake and N excretion. Subsequently, target MUN concentrations are extremely sensitive to changes in milk production.

Target MUN concentrations were much less sensitive to changes in milk fat and protein percentages, body weight, and parity (Jonker et al., 1998). Rodriguez et al. (1997) reported lower MUN content in milk from Jersey cows compared with the MUN content of milk from Holstein cows. These differences were likely due to five factors: body weight, milk production, milk fat and protein percentage, and N intake. Renal clearance rates and blood volume may increase as animal size increases (Swenson and Reece, 1993) and could affect differences observed between breeds as well. These target values apply only to lactating cows weighing 600 kg. Integrating effect of bodyweight on protein requirements (Kohn et al., 2002) with effect of body weight on the relationship between MUN and urinary N excretion enables calculation of the target MUN for smaller or larger cattle. A Jersey cow with a body weight of 400 kg would be expected to have a mean MUN that is 3 mg/dl higher than a Holstein with a bodyweight of 600 kg for the same production level.

Protein feeding level with regard to NRC protein requirements affects target MUN concentrations the most. Feeding above NRC recommendations for N intake by 10% results in an increase in lactational MUN concentration of 26% (Jonker et al., 1999). This excess N intake results in elevated feed costs and excess urinary N excreted to the environment. This response clearly demonstrates that MUN is very sensitive to overfeeding protein and can be useful in field applications.

While this method provides a precise number for target MUN concentrations, an acceptable range around the target exists. For a 25-cow management group, a group's MUN concentration could be 2 mg/dl and still be considered within the target range. Overall under typical production conditions, most dairy farms should have MUN concentrations between 8 to 12 mg/dl.

MUN Pilot Project

A confidential mail survey (Jonker et al., 2002B) was conducted in December 1998 with members of the Maryland and Virginia Milk Producers Cooperative (West Reston, VA; n = 1156). Participants returning the survey were offered monthly bulk tank milk analysis of MUN for 6 months. Bulk tank MUN analyses were performed monthly for six months for all dairy farms from December 1998 through May 1999, regardless of survey completion. Dairy farms that completed the survey were provided their MUN concentration and interpretive information monthly, while others remained anonymous.

The mean and standard deviation in N feeding parameters were calculated based on model predictions 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 .026 times body weight times MUN as recommended by Kauffman and St-Pierre (2001) and Kohn et al. (2002). Crude protein requirements were determined using the NRC (1989) recommendations for dairy cattle assuming a one-group TMR was fed (Stallings and McGilliard, 1984). The protein required was assumed to be that needed by the 83th percentile cow with respect to protein requirements for the entire milking herd. This approach prevents under feeding of most cows. Excess N feeding was determined as the difference between observed N intake and that predicted to be required.

A total of 472 dairy farmers responded to the survey for a 40.8% rate of return. Over 60% of the responding dairy farms indicated prior knowledge of MUN. However prior to the survey, over 89.5% of the dairy farms did not routinely test for MUN. A total of 33 dairy nutrition consultants responded to the survey for a 50.0% return rate. Conversely to the lack of use among dairy farmers, 88% of consultants recommended routine use of MUN.

Observed MUN was 12.7 mg/dl but feeding according to NRC (1989) and allowing for variation within the herd by feeding the 83nd percentile cow would have resulted in a MUN of 11.0 mg/dl. Farmers appeared to feed 6.6% more N than recommended by NRC and this overfeeding resulted in a 16% increase in urinary N and a 2.7% increase in fecal N compared to feeding to requirements. Most (71.5%) of farmers appeared to feed more than recommended amounts of protein by an average of 61 g/d or 11% of required N. 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 efficiency were not associated with herd size ($P > 0.1$).

Participants in the program initially had higher MUN values than non-participants, perhaps reflecting higher producing herds among participants. For both groups of farms, MUN increased in the spring when lush pastures high in protein were available and when milk production is higher. However, MUN did not increase as much among participants in the study as for non-participants. Thus, it appears the study encouraged some farmers to reduce protein feeding levels.

As was hoped, farmers that appeared to be underfeeding protein appeared to increase protein feeding during the course of the program, and farmers that appeared to be overfeeding protein appeared to decrease dietary protein relative to non participants. For farms that indicated they increased dietary crude protein (% DM), MUN was lower compared to target during the first three months of the program, and MUN increased during the last three months suggesting an increase in dietary crude protein. For dairy farmers that indicated they decreased dietary crude protein (% DM), MUN was higher than target values, but MUN appeared to decrease in the spring. Nonetheless, the magnitude of the spring increase was 1 mg/dl lower than for non-participating farms.

Economic and Environmental Impact of Over Feeding Protein

The environmental and economic impact of overfeeding dairy herds in the Chesapeake Bay drainage basin were estimated on summarized results from December 1998 MUN analyses according to the method of Jonker et al. (2002A). Estimates of the environmental and economic impact of overfeeding N in the watershed are presented in Table 2. 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 have been lost to water resources due to overfeeding of N by farmers. This figure represents 7.9% of the total non-point source N loaded to the Chesapeake Bay each year. In addition, crops would be grown to produce this excess feed N, and N losses would result from the fields where these crops were produced. The cost of feeding excess soybean meal in place of corn grain was $32.94 per cow per year, or $17.86 million per year.

MUN can be used both as a nutritional tool by dairy farmers to identify when cows are consuming excess protein and to quantify non-point source N emanating from dairy farms. A potential exists to both increase dairy farm profitability and decrease non-point N loading to the environment. However, many dairy farms maintain high production with lower MUN concentrations than the target, indicating a potential for feeding below NRC recommendations and further reducing N loading.

Using MUN for Diet Evaluation

High MUN levels are often attributed to specific causes, including too much RDP, too little energy, imbalance of carbohydrate and protein ratios, and too much RUP. None of these reasons alone tells the complete story; high (or low) MUN concentrations depend on a combination of factors. In simplest terms, high MUN concentrations indicate a general excess of N in the cow based on the animal's level of milk production. Excess N might be the result of excess protein. The wasted protein is excreted in the cow's urine resulting in lost income to the dairy farmer. With an imbalance of available protein to fermentable carbohydrate, energy may be limiting in the diet and milk production lost by the cow. Because of this reduced production, the protein cannot be used, and high MUN results.

Under typical production conditions, most dairy herds should have MUN concentrations between 8 to 12 mg/dl. When the average MUN concentration is outside the target range, the cause needs to be determined. A minimum of 10 cows should be sampled from a management group to determine an average MUN value for that group. Bulk tank samples may save money, but will not show differences among different management groups of cows.

The first area to consider when MUN concentrations are outside the target range is milk production (Table 3). Are the cows producing what they are expected to produce and what the ration is balanced for? If the cows are producing less than expected, excess protein consumption results in elevated MUN levels. The reason for lower milk production needs to be examined. Lower than expected milk production can be caused by management (e.g. too high expectation) or ration formulation (e.g. not enough energy).

A next logical step, if milk production is as expected, is to examine the ration formulation. Is the ration formulated to meet the nutrient requirements of the cow? While computer programs have made ration formulation easier, results are only as good as the expertise of the person performing the formulation and the accuracy of the program used. If, for example, a ration is only balanced for crude protein level and not protein fractions, a situation could arise where degradable protein level is too high causing elevated MUN levels.

When ration formulation appears correct, differences may exist in nutrient composition of actual feed ingredients and nutrient composition used in ration balancing. Are the forages analyzed routinely and are the samples representative of the forage being fed? Nutrient composition of forages can change dramatically from field to field and cutting to cutting, so occasional forage testing may not show the true variability of the forage nutrient composition.

When accounting for these factors, high MUN concentrations may still not be explained. The actual process of feeding the cows may need to be examined. Is the TMR mixed thoroughly? An improperly mixed TMR can result in inadequate distribution of nutrients with some cows getting more than their share. Is the ration being fed according to how it was balanced? Careful attention must be made in order not to over- or under-feed any particular diet ingredient. If, for example, soybean meal is overfed and corn meal underfed, there will be an excess of protein in the diet relative to available energy and high MUN will result.

If the cause of high MUN level is still not isolated, diet consumption by the cow needs to be examined. Are the cows consuming what they are being fed? There are really two rations to consider. The first is the ration as it is fed to the animal (assuming it is already properly balanced and mixed). The second is what the cow actually consumes. The feed left in the bunk by the cows should look like the ration which was fed to the cows earlier. If the cows are able to sort through the ration, concentrate may be consumed preferentially over forage and high MUN levels may occur.

Conditions can exist where MUN levels may actually be low indicating a protein deficiency in the diet and potentially lost milk production. Low MUN levels suggest the cows' diet does not contain adequate available protein. Do any of the feed ingredients have heat damage reducing its digestibility? If a dried brewers grain (or other dried by-product feed) being fed is dark brown, it may have a significant portion of bound protein which the animal is unable to use. If forages were heat damaged during the ensiling or hay preservation process, the protein digestibility may be reduced. This may cause the diet to be low in absorbed protein and may result in a low MUN level. When MUN levels are extremely low, production may be limited because of a protein deficient diet. Suspicious feeds should be analyzed for acid detergent insoluble nitrogen or bound protein.

Individual Farm Case Study

Over the past several years, we have intermittently offered milk bulk tank MUN analysis for free to a wide range of dairy producers. The farms with very high or very low MUN are offered further assistance. Results from one farm are shown in Figure 3. The farm was one of 150 that were offered free MUN analysis for three months. After the second month of high MUN, the farm was contacted and offered assistance with feed management. In this case, the manager was offering a diet with more soybean meal than needed to meet protein requirements. The nitrogen intake was estimated as formulated assuming feed intake was as expected from NRC, 1989. When the diet was reformulated after the second month by substituting corn grain for soybean meal, N intake and MUN declined, the ration became less expensive, and milk production increased (not necessarily due to the treatment). This case was especially rewarding.

Often farms are identified as having high or low MUN but when the reason is identified, the manager chooses not to change feed management practices. For example, a farmer may not want to change protein in the diet because it would require buying feed to replace a feed produced on farm. Farms that feed a large percentage of the diet as legume forage or pasture may also have high MUN, due to excessive RDP, but may not benefit economically from reformulating diets.

The high or low MUN may not be caused by diet formulation, but rather by feed delivery. One case of high MUN resulted from the manager substituting alfalfa haylage for corn silage without consulting the nutritionist. One puzzling case of very high MUN (25 mg/dl) could not be attributed to protein intake. The diet was low in salt, and cattle did not have adequate access to clean water. Both effects could decrease water intake and result in reduced clearance of urea from the body, increasing MUN.

Current Program

We are currently implementing an extension program to institutionalize MUN analysis on dairy farms. The program was funded by the USDA Natural Resource Conservation Service (NRCS) with a Conservation Innovation Grant. All milk producer cooperatives in Maryland and Virginia are participating in the project. The objectives are: 1) to institutionalize the routine measurement of MUN on bulk-tank milk samples from three of the major milk cooperatives in the region, 2) to educate dairy farmers, educators (e.g. agricultural extension agents), technical assistance personnel (e.g. NRCS, SCD, private crop consultants) and representatives of allied industries (e.g. feed companies) about the use and interpretation of MUN results, 3) to identify dairy farms that have problems with herd nutrition, and provide them with needed assistance, 4) to demonstrate an incentive program to encourage nutritional consultants and dairy farmers to reduce nitrogen lost to the environment by decreasing nitrogen feeding, and 5) to integrate herd nutrition into comprehensive nutrient management plans.

Previously, most milk was analyzed for MUN by DHIA laboratories. However, bulk-tank MUN can be analyzed more frequently, and provide valuable information about acute or chronic nutritional problems on farms. This project provides an incentive to laboratories analyzing bulk-tank milk for farmer cooperatives to also analyze for milk urea nitrogen. We are assisting the cooperatives in Maryland and Virginia with upgrading equipment so they can accurately measure MUN on a routine basis. We will insure accuracy of sample analyses by randomly testing milk from farms and comparing our results with those reported. We will provide 5000 farmers serviced by the cooperatives with information on interpreting MUN analyses and farms that have high

MUN will be offered direct technical assistance. A one-time incentive program will be tested to encourage farmers to try reducing nitrogen in feed. Among 600 farmers that participate in the incentive program, those who are able to keep MUN below 11 mg/dl for 3 consecutive monthly averages will be awarded $150, and those who keep MUN monthly average below 12 mg/dl will be awarded $100. These levels would indicate low nitrogen excretion and proper levels of protein in diets. After the program, cooperatives will be positioned to analyze MUN routinely on farms, and farmers and nutritional consultants will understand how to interpret the results.

Using Blood Urea Nitrogen

Blood or plasma urea nitrogen (BUN) can be used in much the same way as MUN. Within a study, BUN concentration was an excellent predictor of urine N excretion per day (Kohn et al., 2005). However, there was considerable variation from study to study. On average for herbivores, urine N could be predicted as 0.013 x BW x BUN. This lower coefficient compared to the one used for MUN results from the higher concentration of BUN as compared to MUN even though both are highly correlated (Roseler et al., 1993; Kauffmann and St-Pierre, 2001). A higher coefficient is needed for pigs or rats because the kidneys of these animals are better adapted to clearing urea from the blood (Kohn et al., 2005).

Conclusions

Milk or blood urea nitrogen is indicator of diet adequacy and nitrogen utilization efficiency in lactating dairy cattle. As a management tool for dairy farmers, MUN offers a simple and noninvasive approach to examine protein status of rations fed to dairy cattle. Through routine monitoring of MUN, dairy farmers can adjust dietary protein levels to better match protein requirements of their cows and potentially increase profitability by reducing feed costs. Milk urea nitrogen also is an effective means to estimate nitrogen excretion from lactating dairy cattle. MUN can be used to assess the impacts of excess nitrogen feeding to dairy cows in a watershed.

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Table 1. Equations for predicting nitrogen utilization in dairy cattle.

Prediction	Equation
Urinary N, g/d	0.026 x BW (kg) x MUN (mg/dl)
N Intake, g/d	(Predicted UN + milk N + 97)/0.83[1]
Fecal N, g/d	Predicted NI – predicted UN – milk N
N Utilization Efficiency, g in milk / g intake	(Milk N x 100) / predicted NI
Dry matter intake, kg/d	(Predicted NI x 6.25) / Diet CP %

[1]Metabolic N and true digestibility coefficent obtained from regesson of N utilization versus N intake.

Table 2. Economic and environmental impact of overfeeding protein to dairy cows in the Chesapeake Bay Drainage Basin.

Item	Estimate
Farms feedings 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.

Table 3. Checklist to identify causes of high (or low) MUN concentrations.

MUN Analysis	Was the MUN analysis accurate? You may take another sample and try a different laboratory.
Milk Production	Are the cows producing as much milk as expected?
Diet Formulation	Is the diet formulated to meet the cows' nutrient requirements?
Feed Analysis	Are all forages analyzed routinely?
Feed Digestibility	Do any of the feeds have heat damage? Damaged feeds have not protein digestibility.
Feeding Management	Are the cows fed the diet as formulated or is something lost in the translation from nutritionist to manager to feeder?
Animal Consumption	Are the cows eating what is offered or are they selecting part of the ration?
Water and salt	Did the cows have adequate salt and water? Low water intake increases MUN.

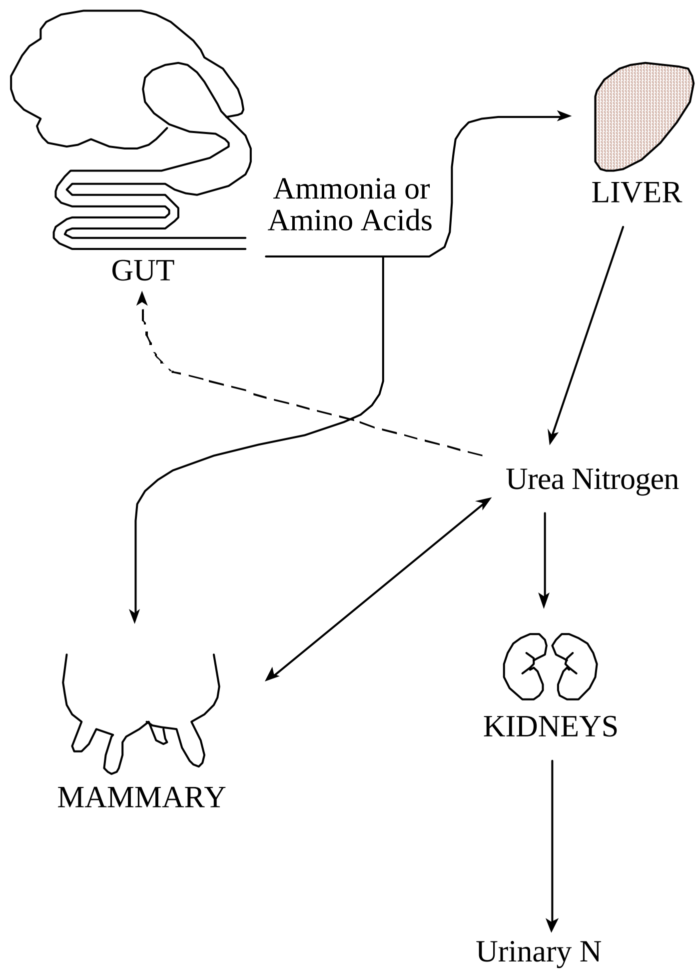

Figure 1. Nitrogen metabolism in the ruminant.
Reprinted from Kohn et al. (1997).

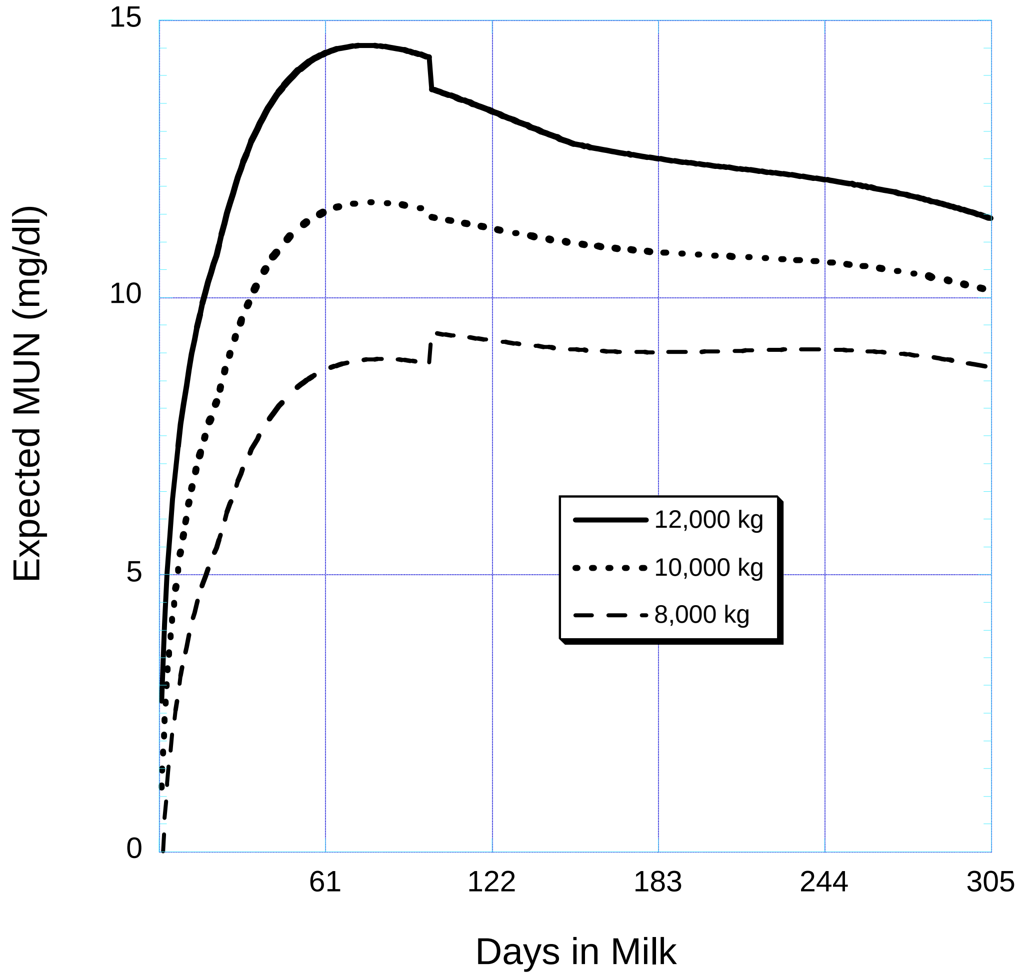

Figure 2. Predicted milk urea N (MUN, mg/dl) throughout a 305-d lactation for milk production of 12,000 kg (———), 10,000 kg/yr (········) and 8,000 kg/yr (- - - -).

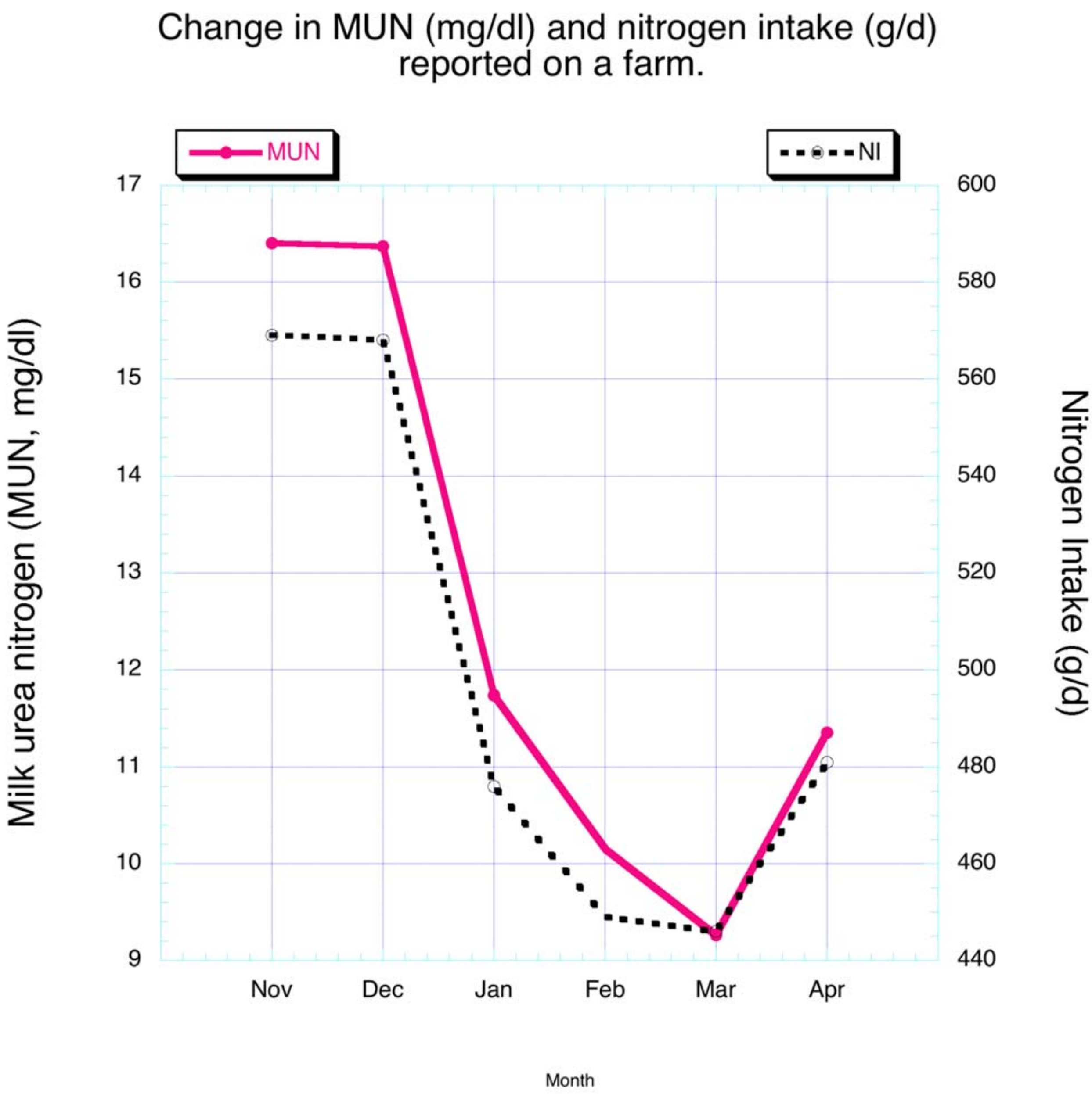

Figure 3. Change in milk urea N (MUN) and N intake for a dairy farm that reformulated the diet after the second month of analysis.