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Nitrogen, Ammonia Emissions and the Dairy Cow

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NITROGEN FROM THE FARM TO THE ENVIRONMENT

Ruminant animals do not efficiently utilize dietary nitrogen. Excess nitrogen fed in the form of feed proteins is excreted in manure (urine + feces). Dairy cows on average secrete in milk 25 to 35 percent of the nitrogen they consume and almost all the remaining nitrogen is excreted in urine and feces with about half of the nitrogen excreted in urine. Approximately 60 to 80 percent of the nitrogen in urine is in the form of urea.

Nitrogen in manure can be converted to ammonia through bacterial degradation, primarily the conversion of urinary urea to ammonia. Urease, an enzyme produced by microorganisms in feces, reacts with urinary urea to form ammonia. Urease activity in feces is high and rapidly converts urea to ammonia after excretion.

Urinary urea concentration is an important predictor of ammonia emission from dairy cows. It is possible through dietary strategies to manipulate urine volume and urinary urea concentration as well as total manure output. It should be noted that urine and fecal material, individually, emit minimal amounts of ammonia; it is the physical process of combining urine and feces after deposition on a floor surface, which results in ammonia volatilization in dairy housing.

There are additional factors that influence ammonia volatilization in dairy housing. They include temperature, air velocity, pH, floor surface area, manure moisture content, and storage time. For example, high pH and temperature favor increased ammonia emissions. Dairy manure pH typically ranges from 7.0 to 8.5, which allows for fairly rapid emission of ammonia into the atmosphere.

The Environmental Protection Agency considers ammonia a threat to air quality because of contribution to surface water eutrophication, nitrate contamination of ground water and impaired air quality. Ammonia gas released into the atmosphere can react with combustion gases, i.e. nitric acid and sulfuric acid, to form ammonium nitrate or ammonium sulfate. These later forms are the precursors for the development of fine particulate matter ($PM_{2.5}$). These fine particulates have been shown to cause respiratory problems in humans and contribute to haze and poor visibility.

Ammonia emissions typically have a short life in the atmosphere, several hours to a few days. The length of time depends if it is in a gaseous form vs. a particulate. Deposition of atmospheric ammonia and chemical compounds resulting from atmospheric chemical reactions with ammonia (i.e. ammonium aerosol) is believed to contribute to acidification and eutrophication of water and soil. Problems related to visibility and deposition can occur in the immediate vicinity of the ammonia release or affect landscapes hundred of miles from the emission source. Figure 1 illustrates the nitrogen cycle and the impact to both water and air quality.

RATION BALANCING TO MINIMIZE NITROGEN EXCRETION

Balancing carbohydrate and protein fractions

Ruminant nutrition is complex and involves concepts related to balancing the requirements of the microbial population in the rumen as well as the animal itself. Figure 2 illustrates a simplistic overview of protein and carbohydrate (CHO) nutrition. Table 1 defines terminology related to protein and carbohydrates.

The key to improving nitrogen (N) efficiency of the cow is to balance the various protein fractions along with providing adequate CHOs and their fractions. Nutritional imbalances arise when nitrogen is fed in excess of requirements, excessive rumen degradable protein (RDP) or soluble protein are fed relative to fermentable CHOs, diets are improperly balanced for rumen undegradable protein (RUP), or there are inadequate amounts or an imbalance of amino acids. Sound ration balancing of proteins and CHOs that promotes increases in milk production should decrease nitrogen excretion in feces and urine per unit of milk produced.

Challenges associated with CHO and protein nutrition

Challenges in ration formulation for dairy cows are the numerous factors affecting how protein and CHOs are utilized in the rumen. Feeds can vary in their rate and extent of degradation in the rumen. The objective to balancing rations is to compliment the forages used in the ration with feed proteins and CHOs that will meet the cow's requirement for RDP and RUP. However, other factors affect nutrient utilization in addition to the type or source of protein. They include the animal's physiological state, dry matter intake, fiber level and type in the diet, the percent of the ration composed of concentrate ingredients, moisture content of ensiled forages and grains, and amount of heat treated feeds used. Production and N efficiency can be improved when the level of dietary protein is reduced and cows are fed the proper balance of protein and CHO fractions (Table 2).

Feeding excess dietary N not only has a consequence to the environment, but also to the animal. There is a metabolic energy cost associated with excreting excess N in the urine, which can result in lower production and overall performance. If the liver is overloaded with ammonia, elevated blood urea N will occur as well as an increase in milk urea nitrogen (MUN). This can have adverse affects on health and reproduction.

There are several situations when excessive protein or an imbalance of RDP and RUP can occur. A forage ration consisting primarily of excellent quality haylage typically has excessive levels of protein, RDP and soluble protein. The problem can be compounded when high moisture grains are fed. This type of diet can result in excessive urinary urea excretion as well as an increase in urine volume.

Feed sources, such as wheat midds, corn gluten feed and urea, are ingredients usually priced lower than some other commonly used feedstuffs. This causes them to be used heavily in diets to keep feed costs under control. They are also sources of highly degradable and soluble protein, which may not properly compliment the ration for protein balance.

Another situation where protein levels in the diet may not be balanced is feeding a one group total mixed ration for all lactating cows. Formulating rations with higher than required protein levels as a safety factor often compounds the problem. Depending on the actual level of milk produced, this can result in excessive levels of N being fed and excreted.

Some producers treat their corn silage with nonprotein nitrogen (NPN) to increase the protein level in this forage. Excess N in the diet will occur when extremely high moisture haylage or excellent quality legume silage are fed along with NPN treated corn silage.

FEEDING STRATEGIES TO MINIMIZE NITROGEN EXCRETION

Implementing a ration formulated on paper to cows can be difficult. It is not unusual for lactating dairy rations to consist of 10 to 20 feed ingredients with 2 to 5 being the forage component. This adds a tremendous amount of variability among and within feed sources. Because of this added source of variability, some basic practices should be implemented. They include:

1. Routine schedule of analyzing forages and grains for their nutrient content. Adjustments to rations would occur with the updated analyses.
2. Herds feeding a TMR should periodically analyze the ration for nutrient content. This is appropriate when major ration adjustments have been made or animal performance does not meet expectations.
3. Use the Penn State Particle Separator to examine particle size distribution of the ration. Problems can occur during mixing or from animals sorting the feed. This can result in major imbalances in protein and CHO nutrition and intakes.
4. Monitor dry matters on all high moisture ingredients weekly. There can be a tremendous amount of variation in moisture contents without the nutrient content varying to any great extent. This simple procedure can help ensure that animals are receiving the proper levels of forages and concentrates.

New area receiving attention

An area that is receiving attention is dry matter intake (DMI) efficiency. This relates to efficiency of feed use related to milk produced. There is an economic incentive to the producer to maintain a high feed efficiency as well as the potential for reduced manure excretion. It is necessary to have the fat corrected milk (FCM) for the herd or various groups as well as accurate dry matter intakes. The calculation for DMI efficiency is the FCM pounds divided by dry matter intake pounds. (Example: 80 lbs of 3.5% FCM / 55 lbs. dry matter intake = 1.45) This measurement is difficult to use in non-TMR fed herds.

A benchmark for dry matter intake efficiency is 1.30 to 1.50 for herds producing between 60 and 80 pounds of FCM. Some herds have been able to maintain efficiencies around 1.70. More work is needed to evaluate DMI efficiency related to affects on feed costs, animal performance and manure output.

To achieve these higher efficiencies requires attention to optimizing nutrient use and microbial protein synthesis in the rumen, selection of N and CHO sources, high quality forages, and a highly digestible ration. It should be noted that high dry intake efficiency does not necessarily equate into less manure excretion. More research is needed to evaluate feeding strategies and their effect on nutrients excreted, their distribution between urine and feces, and quantity.

On-farm example of lowering ration protein

Table 2 provides an example strategy used at the Penn State Dairy Complex making the change from a high protein diet to a lower protein diet. The change in ingredients and their nutrient analysis using the NRC 2001 model are provided. The production data and N efficiency calculation were used to evaluate animal performance to the change. Fat corrected milk production (3.5%) and N efficiency improved substantially compared to the high protein diet. This example illustrates that proper attention to ration formulation and feeding management practices can result in animals being fed closer to their requirements and can maintain or improve performance. Further research is continuing at Penn State to investigate dietary strategies for lactating cows and heifers, as well as monitor and measure N and ammonia emissions from mechanically and naturally ventilated facilities.

TABLES AND FIGURES

Figure 1. A simplistic illustration representing the nitrogen cycle in a dairy operation.

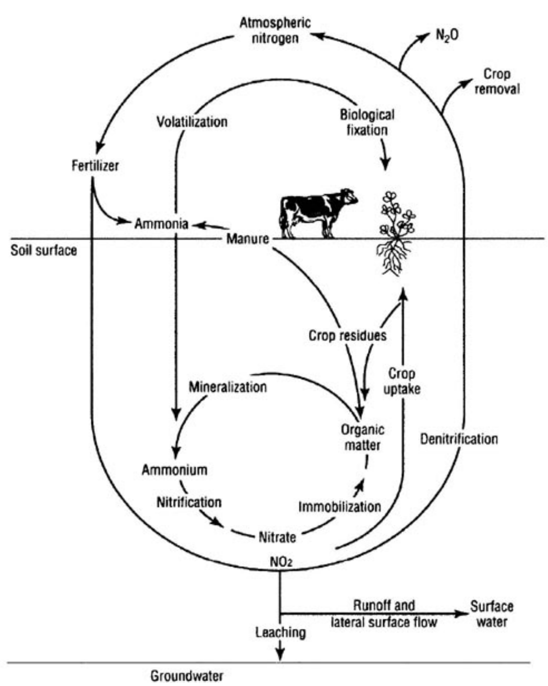

Figure 2. Prot Source: Adapted from National Research Council 1993.

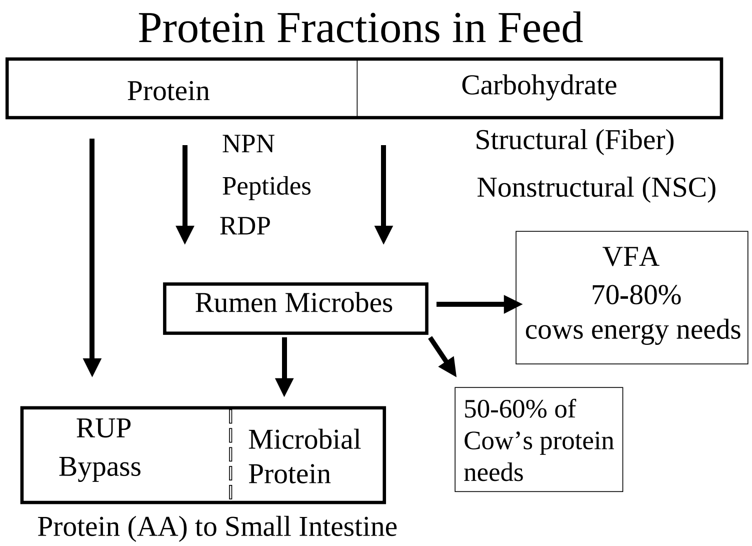

Table 1. Protein and carbohydrate terminology

1. Amino Acids (AA)
   – The building blocks of protein.
   – There are twenty primary AA that occur in proteins, ten are usually classified as being essential or indispensable for the animal.
2. Metabolizable protein (MP)
   – The true protein that is digested post ruminally and the component amino acids that are absorbed by the small intestine. MP is used for milk protein synthesis.
3. RDP: rumen degradable protein
   – Protein that is degraded in the rumen and converted into microbial protein.
4. RUP: rumen undegradable protein
   – Protein that 'escapes' rumen degradation.
5. Soluble protein
   – Soluble in a liquid (lab test used to estimate).
   – Comprised of nonprotein nitrogen (i.e. urea), peptides, and other protein compounds.
   – Readily available nitrogen source for rumen microbes, which readily dissolves and is rapidly degraded in the rumen to ammonia and other simple compounds.
6. Nonstructural carbohydrates (NSC)
   – Comprised of starch and sugars.
   – Measured in the lab by enzymatic methods.
7. Nonfibrous carbohydrates (NFC)
   – Starch, sugar, pectin, plant reserve CHOs and organic acids are included in NFC.
   – A calculated value.
   100 –[(%NDF-NDFCP) + % crude protein + % fat + % ash)
8. Structural carbohydrates
   – The most common measure is neutral detergent fiber, which is comprised of hemicellulose, cellulose and lignin.
   – Acid detergent fiber (ADF) measures only cellulose and lignin.
9. Volatile fatty acids (VFA)
   – Produced when CHOs undergo microbial fermentation.
   – The primary VFAs in descending order of abundance in the rumen are acetic, propionic, butyric, isobutyric, valeric, isovaleric and traces of various other acids

Table 2. Dietary strategies and production results changing from a high protein diet to a low protein diet.

	PSU Herd 2001-2002 18%-High	PSU Herd 2002-2003 16%-Low
Ration, % DM		
Corn silage	25.6	26.5
Alfalfa silage	14.8	14.6
Hay	9.6	3.2
Cottonseed hulls	-	***6.7***
Shelled corn	14.2	20.3
Bakery product	6.8	6.8
Sugar	4.0	4.0
Distillers grain	5.0	1.7
Wheat midds	4.9	-
Heat treated SBM	4.9	1.6
Canola meal	4.0	6.7
Fish meal	0.4	-
Roasted soybeans	4.6	6.0
Min-vitamin mix	1.2	1.9

	MUN	Milk	Pro%	N util eff %	3.5%FCM
Oct-01	12.4	72.4	3.1	30.6	72.8
Nov-01	13	78.5	3.05	31.3	79.0
Dec-01	11	79.6	2.99	33.3	79.5
Jan-02	10.6	81.9	3.03	34.6	83.1
Feb-02	9.4	84.2	3.05	36.8	84.0
Mar-02	10.3	83	3.18	36.3	81.8
Apr-02	9.4	83.6	3.18	37.6	82.9
May-02	8.7	80	2.95	36.1	79.2
Jun-02	12.7	80	2.99	31.5	77.4
Jul-02	9.8	70.9	2.91	31.9	69.5
	10.73			**34.0**	**78.9**

Animal performance results from DHIA when cows were fed the high protein diet from October 2001 to July 2002.
MUN is the measure of milk urea nitrogen.
N efficiency was calculated using the equation from Jonker et. al., J. Dairy Sci. 2001.

	2001-2002 18%	2002-2003 16%
PROTEIN PROFILE		
MP required (lbs./day)	5.71	5.72
MP supplied (lbs./day)	6.18	5.65
RDP (lbs./day)	6.02	5.64
RUP (lbs./day)	3.74	3.11
Balance RDP (lbs./day)	+0.66	+0.25
Balance RUP (lbs./day)	+0.59	-0.09
MP-Bacterial (lbs./day)	2.915	2.926
MP-RUP (lbs./day)	3.008	2.467
MP-Endogenous	0.256	0.258
CP- RDP %DM	11.1	10.3
CP-RUP %DM	6.9	5.7
Lysine	6.17	6.42
Methionine	1.81	1.89
Ratio	3.41	3.40
CHO PROFILE, % DM		
A fraction (sugar)	8.8	7.8
B1 CHO (starch/pectin)	34.4	34.9
NDF	31.0	32.8
NFC	43.2	42.7

Source: Protein profile from NRC, 2001 and CHO profile from CNCPS models.

	MUN	Milk	Pro%	N util eff %	3.5%FCM
Oct-02	6	76.8	3.1	40.4	77.1
Nov-02	7.4	76.5	3.08	37.9	78.8
Dec-02	5.4	83.7	3.07	43.0	88.0
Jan-03	6.4	81.5	3.07	40.8	86.2
Feb-03	6.8	82.6	3.05	40.2	87.4
Mar-03	9	86.3	3.03	37.8	90.3
Apr-03	7.6	82.3	3.05	38.9	84.6
May-03	7.2	80	3.11	39.3	81.9
Jun-03	10	78.1	3.02	34.3	80.6
Jul-03	10	78.4	2.97	34.1	80.6
	7.58			**38.7**	**83.5**

Animal performance results from DHIA when cows were fed the low protein diet from October 2002 to July 2003.
MUN is the measure of milk urea nitrogen.
N efficiency was calculated using the equation from Jonker et. al., J. Dairy Sci.