Why Use Metabolizable Protein for Ration Balancing?

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Introduction

For many years, crude protein (CP) content has been used in formulating diets for lactating dairy cows because little was known regarding the response to dietary protein of varying quality. In addition, many researchers postulated that the high quality microbial protein (MCP) synthesized in the rumen would complement deficiencies in the quality of dietary protein that escaped ruminal fermentation. Research conducted in the 1960s showed that the rumen was capable of supplying all of the protein required by the cow producing up to 10,000 lb of milk. However, milk yield per cow in the US has more than doubled during the last 30 yr, and the general concern currently is for cows yielding 20,000 to 30,000 lbs of milk annually. For these high yielding cows, microbial protein synthesis supplies a decreasing proportion of the required protein, and significant amounts of dietary protein must escape ruminal degradation in order to meet protein needs. However, we now have information that demonstrates that we have to be careful not to over feed rumen undegradable protein (RUP) as it lowers the efficiency of use of metabolizable protein (MP) for milk protein production. The protein balance for the lactating cow is a challenge. Degradable protein needs to be balanced for the microorganisms in the rumen and MP and amino acids (AA) are needed to meet the requirements of the cow for lactation, pregnancy, and growth.

Importance and Goals of Protein and Amino Acid Nutrition

Ruminally synthesized MCP, RUP and to a much lesser extent, endogenous CP (ECP) contribute to the passage of MP to the small intestine. Metabolizable protein is defined as the true protein that is digested postruminally and the component AA absorbed by the intestine. Amino acids and not protein are the required nutrients. Absorbed AA, used for the synthesis of proteins are vital to the maintenance, growth, reproduction, and lactation of dairy cattle.

The goals of ruminant protein nutrition are to provide adequate amounts of rumen degradable protein (RDP) for optimal ruminal efficiency and to obtain the desired animal productivity with a minimum amount of dietary CP. Optimizing the efficiency of dietary CP requires selection of complementary feed proteins and nonprotein nitrogen (NPN) supplements that will provide the types and amounts of: 1) RDP that will meet, but not exceed, the N needs of ruminal microorganisms for maximal synthesis of MCP and 2) digestible RUP that will optimize the profile and amounts of absorbed AA. The nutritive value of MP for dairy cows is determined by its profile of essential AA (EAA). Improving the efficiency of protein and nitrogen (N) usage while striving for optimal productivity is a matter of practical concern. Incentives include reduced feed costs per unit of lean tissue gain or milk produced, a desire for greater and more efficient yield of milk protein, creation of space in the diet for other nutrients that will enhance production, and concerns for waste N disposal. Research studies have shown that milk protein content and yield can be increased by improving the profile of AA in MP, by reducing the amount of surplus protein in the diet, and by increasing the amount of fermentable carbohydrate in the diet.

Types of Proteins

Feedstuffs contain many different proteins and several types of NPN compounds. Proteins have been classified on the basis of their 3-dimensional structure and solubility characteristics. Proteins in feeds are composed primarily of four types: albumins, globulins, prolamines, and glutelins. Albumins and globulins are usually more soluble than prolamines and glutelins (Sniffen, 1974). Cereal grains contain more glutelins and prolamines whereas leaves and stems are rich in albumins (Sniffen, 1974). Generally about 65% of the protein fractions in feeds are made up from these four protein types plus NPN. The remaining insoluble N would include protein bound in intact granules of cereal grains, most of the cell wall-associated proteins and heat denatured proteins that are associated with NDF. Feeds with the highest percentage of insoluble protein (>40%) measured were forages, beet pulp, soy hulls, sorghum, dried brewers grains, dried distillers grains, fish meal, and meat and bone meal (Blethen et al, 1990).

Feedstuffs also contain variable amounts of low molecular weight NPN compounds. These compounds include peptides, free AA, nucleic acids, amides, amines, and ammonia. Grasses and legumes contain the highest and most variable concentrations of NPN. Hays and especially silages contain higher amounts of NPN than the same feed when fresh because of proteolysis that occurs during wilting and fermentation. Reported concentrations of NPN in CP of grasses and legume forages are within the following ranges: fresh material: 15%, hay 25%, and silage 65% (Van Soest, 1994). The NPN content of most non-forage feeds is 12% or less of CP (Van Soest, 1994).

Ruminal Protein Degradation

The CP content of a feedstuff merely reflects its total N content. ***By itself, CP is of little value in assessing protein value as it reveals nothing of the types of compounds either in their value to the rumen microbes or to the animal if they escape the rumen undegraded.***

Ruminal degradation of dietary feed CP is an important factor influencing ruminal fermentation and AA supply to dairy cattle. RDP and RUP are two components of dietary feed CP that have separate and distinct functions. Ruminally degraded feed CP provides mixtures of peptides, free AA, and ammonia for microbial growth and synthesis of MCP. Ruminally synthesized MCP generally supplies most of the AA passing to the small intestine. Ruminally undegraded protein is the second most important source of absorbable AA to the animal. Knowledge of the kinetics of ruminal degradation of feed proteins is fundamental to formulating diets for adequate amounts of RDP for rumen microorganisms and adequate amounts of RUP for the host animal.

Because of the availability of in situ data for ~ 1300 individual feedstuffs, the 2001 NRC chose to use in situ derived data for computing RDP and RUP values. The most used model to describe in situ ruminal protein degradation divides CP into three fractions: 1) Fraction A is the percentage of CP that escapes from the bag during initial pre-soak period. This is completely degraded and is considered similar to the soluble protein fraction; 2) Fraction B is the percentage of CP that disappears from the bag with unlimited exposure to fermentation and is potentially degradable; 3) Fraction C is that percentage of CP remaining in the bag at a defined end-point of degradation and is undegradable in the rumen environment. The RDP fraction contains the A fraction which is considered all degraded and an amount of the B fraction that is degraded in the rumen; the amount degraded is affected by fractional rates of digestion and passage. RUP contains potentially digestible material only degraded post ruminally (fraction B) and an indigestible fraction (fraction C). The B fraction is affected by variable fractional digestion and passage rates.

In addition to the three CP fractions and the digestion rate of fraction B (this is determined by removing bags after varying times of ruminal exposure), the estimated passage rate is also needed for undigested feed. Three equations are used for predicting passage rates of undigested feeds; one for wet forages, one for dry forages, and one for concentrates. The rate of passage considers effects of DM intake, concentrate in DM, and content of NDF in forage DM on passage rates. In the previous version of the NRC (1989) RUP digestibility was assumed to be a constant at 80%. However, RDP and RUP are not constant, and RUP digestibility varies with feed type (Bach and Stern, 2000). Digestibility values unique to each feedstuff were included in the 2001 NRC.

Numerous factors affect the amount of CP in feeds that will be degraded in the rumen. The chemistry of feed CP is the single most important factor. The two most important considerations of feed CP chemistry are: 1) the proportional concentrations of NPN and true protein, and 2) the physical and chemical characteristics of the proteins that comprise the true protein fraction of the feedstuff. Other factors affecting ruminal degradability of feed protein include ruminal retention of the protein, microbial proteolytic activity, and ruminal pH.

Metabolizable protein requirements

Three primary differences existed between NRC 2001 and NRC 1989 in regard to calculating MP requirements.

1) New equations were introduced for predicting MP requirements for endogenous urinary protein (EUP), scurf protein, metabolic fecal protein, growth, and pregnancy. The changes were the subtraction of conceptus weight from BW in predicting EUP and scurf protein, subtraction of that portion of intestinally undigested, ruminally synthesized MCP believed not to be digested in the hindgut (assumed to be 50%) from predicted metabolic fecal protein, adoption of the 1996 Beef NRC equations for predicting MP requirements for growth, and a modified and improved equation for predicting the MP requirement for pregnancy.

2) The efficiency of conversion of MP to milk protein was changed from 70% to 67%. A conversion of 67% is more in keeping with the value of 65% used in the French system and the value of 69% obtained by Fraser et al (1987) with gastric infusion studies.

3) An MP requirement for endogenous MP was introduced. In view of a lack of published data, the efficiency of use of absorbed MP for endogenous MP was assumed to be 67%.

Dietary RDP and RUP Requirements

RDP requirement is based on TDN-predicted microbial crude protein. As TDN intake increases RDP requirement increases. When the requirement is not met the requirement for RUP increases. When the requirement for RDP is not met energy deficit in the rumen becomes a possible reason for impairment of ruminal digestion. RUP requirement = (MP required - MP bacteria - MP endogenous) / diet RUP digestibility. RUP requirement is basically the difference between the cow's requirement and bacterial protein. If the RUP requirement is not met production will decrease. If RUP is in excess the urinary loss of nitrogen increases. So how does one calculate the crude protein requirement? ***Cows do not have a CP requirement.*** If RDP and RUP exactly meet requirements then RDP +RUP = CP. It is necessary to pay attention to RDP and RUP supply, because the dietary need for RUP is independent of the dietary need for RDP and is expressed on a DM basis and not as a percent of dietary CP.

Protein requirements are a function of dry matter intake, body weight, milk yield, and milk protein, and as these variables increase the protein requirements increase. Protein requirements also depend on TDN intake, RUP source and amount of RDP fed.

Animal Responses to CP, RDP and RUP

Crude protein. A data set of 393 means from 82 protein studies was used to evaluate the relationship between milk and milk protein responses to changes in the concentrations of dietary CP. The regression equation obtained was: Milk yield (kg/d) = 0.8 × DMI (kg/d) + 2.3 × CP (%) – 0.05 × CP^2 (%) – 9.8 (r^2 = 0.29). Assuming a fixed DMI (there was no correlation between DMI intake and CP% in this data set), the maximum milk production was obtained at 23% CP. This resulted in a response where increasing dietary CP one percentage unit from 15 to 16% would be expected to increase milk yield an average of 0.75 kg/d and increasing CP percentage one unit from 19 to 20% would be expected to increase milk yield by 0.35 kg/d. Although milk production may be increased by feeding diets with extremely high concentrations of CP, the economic and environmental costs must be compared with lower CP diets. Dietary CP was not correlated ($P > 0.25$) with milk protein percent, but was weakly correlated (r = 0.14: $P < 0.01$) with milk protein yield.

Rumen degradable and undegradable protein. A data set of 206 treatments from 38 studies was selected to evaluate lactation responses to concentrations of RDP and RUP in diet DM. The regression equation was Milk (kg/d) = -55.61 + 1.15 × DMI (kg/d) + 8.79 × RDP (%) – 0.36 × RDP^2 (%) + 1.85 × RUP (%) (r^2 = 0.52). Based on the equation maximum milk yield occurred (DMI and RUP held constant) when RDP equaled 12.2% of diet DM. Milk yield increased linearly to RUP at the rate of 1.85 kg for each percentage increase in RUP.

Santos et al (1998) published a comprehensive review of the effects of replacing SBM with various sources of RUP on protein metabolism (29 published comparisons) and production (127 published comparisons). Santos et al (1998) reported that in 76% of the metabolism studies, higher RUP decreased MCP flows to the small intestine. This was reflective of inadequate RDP to meet the needs for microbial protein synthesis. Supplementation with RUP usually did not affect flow of total EAA, and RUP supplementation usually did not increase or actually decreased flow of lysine to the duodenum. If RUP is too high and RDP low this again reflects a negative impact on microbial protein production. Supplementation of RUP increased milk production in only 17% of the studies and heat treated or chemically treated SBM or fish meal were the most likely RUP supplements to cause increased milk production. When studies were combined, cows fed diets with treated SBM ($P < 0.03$) or fishmeal ($P < 0.01$) produced more milk than cows fed SBM. These protein supplements also ranked highest in the EAA index when compared with milk protein. Cows fed other animal proteins (blood, feather, meat meals) or corn gluten meal produced similar or numerically less milk than those cows fed SBM. The adequacy of RUP and RDP in diets for lactating dairy cows should be considered independently, and it is illogical to increase RUP at the expense of RDP unless RDP is excessive.

Amino Acid Requirements

Absorbed AA provided by ruminally synthesized MCP, RUP, and ECP are essential as the building blocks for the synthesis of tissue and milk proteins. Lysine (Lys) and methionine (Met) have been identified most frequently as first-limiting EAA in MP of dairy cattle. Production responses of lactating dairy cattle to increased supplies of Lys and Met in MP include variable increases in milk, milk yield, and feed intake. Recent studies from Piepenbrink et al (1999), Nocek et al (1999), Sniffen et al (1999), Wu et al (1999), Rulquin and Delaby et al, (1997) indicate: 1) that content of protein in milk is more responsive than milk yield to supplemental Lys and Met, particularly in post-peak cows, 2) that increases in milk protein percentage are independent of milk yield, 3) that casein is the most influenced milk protein fraction, 4) that increases in milk protein production to increased supplies of either Lys or Met in MP are the most predictable when the resulting predicted supply of the other AA in MP is near or at estimated requirements, 5) that milk yield responses to Lys and Met are more common in cows during early lactation than in mid or late lactation, and 6) production responses to increased supplies of Lys and Met in MP typically are greater when CP in diet DM approximates normal levels (14 to 18%) than when it is lower or higher.

The breakpoint estimate for the required concentration of Lys in MP for maximal content of milk protein is 7.2% and milk protein yield was 7.1% Lys in MP. Estimation of the dose plots indicated little or no expected loss in content or yield of protein when Lys in MP was 6.9%. From a practical standpoint it was concluded that 6.6% be considered as the requirement for Lys in MP. The breakpoint estimate for the required concentration of Met in MP for maximal milk protein content was 2.2% and for milk protein yield was also 2.2% Met in MP. The optimum ratio of Lys to Met in MP is therefore 3/1 (6.6/2.2%) for optimal use of MP for maintenance plus milk protein production. Attempts to identify EAA that may become limiting after Lys and Met in dairy cattle are limited.

Schwab et al (2004) presented an update, which compared MP, Lys, and Met supplies as predictors of milk volume and milk protein yield. Metabolizable protein supply does a good job (r^2 of 0.65) of predicting milk volume and a slightly better job of predicting milk protein yield (r^2 of 0.74). Compared to MP, Met supply was a better predictor of both milk volume (r^2 of 0.76) and milk protein yield (r^2 of 0.81). However, when studies were limited to those in which the Lys:Met ratio in MP was less than 3.25:1.00, Lys supply proved to be the best predictor of both milk volume and milk protein yield with r^2 of over 0.90. This analysis shows that predictability of milk performance is improved by paying attention to at least the first two limiting AA. However this requires an amino acid profile for all feedstuffs used on the farm and may present a limitation in obtaining this information due to cost and analyses.

An On-farm Example of Using RDP, RUP, and MP in Ration Formulation

A more precise measure of protein nutrition is formulating for MP, RDP and RUP. Metabolizable protein is the true protein that is digested post ruminally and the component amino acids are absorbed by the small intestine. RDP is the protein broken down in the rumen to microbial protein, and the protein that escapes the rumen is the RUP. In addition to protein, the source and types of carbohydrates are just as important. The balance between sugar, starch and soluble fiber is essential for a healthy rumen. Table 1 shows an actual farm ration formulation for diets formulated for 18% and 16% CP and Table 2 presents the nutrient specifications for the same diets.

Nitrogen efficiency was improved by 4.6% when comparing the average values for the herd on the 18% to the 16% protein diets. In addition energy corrected milk increased from 78 to 84 lb of milk/d. The key to achieving improved N efficiencies are feeding cows closer to their requirement for metabolizable protein requirements. The lower protein diet resulted in improved components, and eight out of ten months showed improved milk income based on volume, fat and protein response to the lower protein ration.

Recommendations for Feeding Protein to Dairy Cows

Make sure you meet the cow's RDP requirement. A deficiency will suppress the growth and activity of the microorganisms, decrease feed intake, and decrease the efficiency of MCP. Decreased MCP almost always has the net effect of decreasing Lys in MP. This occurs because of the resulting decreased contribution of MCP and thus, increased contribution of RUP to MP. Do not feed excessive amounts of RDP. Clearly, there is no benefit to this, and at the very least it decreases the efficiency of use of dietary protein for milk protein production. Do not over-feed RUP as it lowers the efficiency of use of MP for milk protein production. Overfeeding RUP decreases efficiency of use of MP for two reasons: 1) supply of MP exceeds MP requirements, 2) because on average, RUP has lower concentrations of Lys and Met than microbial protein.

References

Bach, A. and M. D. Stern. 2000. Measuring resistance to ruminal degradation and bioavailability of ruminally protected methionine. Anim. Feed Sci. Tech. 84:23-32.

Blethen, D. B., J. E. Wohlt, D. K. Jasaitis, and J. L. Evans.

1990. Feed protein fractions: relationships to nitrogen solubility and degradability. J. Dairy Sci. 73:1544-1998.

Blum, J. W., R. M. Bruckmaier, and F. Jans. 1999. Rumen-protected methionine fed to dairy cows: bioavailability and effects on plasma amino acid pattern and plasma metabolite and insulin concentrations. J. Dairy Sci. 82:1991-1998.

Fraser, D. L., E. R. Orskov, F. G. Whitelaw, and M. F. Franklin. 1991. Limiting amino acids in dairy cows given casein as the sole source of protein. Livestock Prod. Sci. 28:235-252.

Johnson, H. E., N. L. Whitehouse, B. D. Garthwaite, M. S. Piepenbrink, and C.G. Schwab. 1999. Supplementation of corn and barley based diets of late gestation and early lactation cows with liquid methionine hydroxyl analog (HMB). J Dairy Sci. 82(Suppl. 1):65.

Nocek, J. E., G. D. Young, W. Chalupa, C. J. Sniffen, W.E. Julien, T. Ueda, T. Fujieda, I. Shinzato, H. Sato, and H. Suzuki. 1999. The effect of rumen protected lysine on production performance of lactating dairy cows. J. Dairy Sci. 82 (Suppl. 1):94.

Piepenbrink, M. S., C.G. Schwab, B. K. Sloan, and N. L. Whitehouse. 1999. Importance of dietary concentrations of absorbable lysine on maximizing milk protein production of mid-lactation cows. J. Dairy Sci. 82 (Suppl. 1):93.

Roe, M. B., C. J. Sniffen, and L. E. Chase. 1990. Techniques for measuring protein fractions in feedstuffs. Proc. Cornell Nutr. Conf., p 81, Ithaca, NY.

Rulquin, H. P., P. M. Pisulewski, R. Verite, and J. Guinard. 1993. Milk production and composition as a function of postruminal lysine and methionine supple: a nutrient response approach. Livestock Prod. Sci. 37:69-90.

Santos, F. A. P., J. E. P. Santos, C. B. Theurer, and J. T. Huber. 1998. Effects of rumen-degradable protein on dairy cow performance: A 12 year literature review. J. Dairy Sci. 81:3182-3213.

Sniffen, C. J. 1974. Nitrogen utilization as related to solubility and NPN and protein in feeds. Proc. Cornell Nutr. Conf. p 12, Ithaca, NY.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. Second Edition. Cornell University Press, Ithaca, NY.

Wu, Z., C. Le Guilloux, and L. D. Satter. 1999. Supplementing rumen protected methionine to lactating cows fed different amounts of protein. J. Dairy Sci. (Suppl.1):65.

Table 1. Diets formulated for 18% and 16% CP

Ingredient	18%	16%
	% DM	
Corn silage	25.6	26.5
Alfalfa silage	14.8	14.6
Hay	9.6	3.2
Cottonseed hulls	.	6.7
Shelled corn, coarse ground	14.2	20.3
Cookie meal	6.8	6.8
Liquid sugar (dextrose)	4.0	4.0
Distillers grain	5.0	1.7
Wheat midds	4.9	.
Heat treated soybean meal	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

Table 2. Nutrient profile of the 18% and 16% protein diets

Item	18%	16%
	% DM	
Protein profile[1]		
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
CP- RDP, % dry matter	11.1	10.3
CP-RUP, % dry matter	6.9	5.7
Lysine, % of MP	6.17	6.42
Methionine, % of MP	1.81	1.89
Ratio	3.41	3.40
Carbohydrate profile[2]		
Sugar, %	7.4	6.8
Starch, %	26.5	27.2
Soluble fiber, %	6.6	4.7
Silage acids, %	3.2	3.1
NDF, %	31.0	31.4
NFC, %	43.8	44.3

[1]Protein profile based on the 2001 NRC. MP=metabolizable protein; RDP=rumen degradable protein; RUP=rumen undegradable protein; CP=crude protein.
[2]Carbohydrate profile based on CPM dairy ration analyzer.