MINNESOTA EXTENSION SERVICE

UNIVERSITY OF MINNESOTA
ANIMAL SCIENCE EXTENSION

Department of Animal Science
101 Haecker Hall
1364 Eckles Avenue
St. Paul, Minnesota 55108
(612) 624-4995 FAX: (612) 625-1283

Dairy Update

Issue 111
August 1992

PROTEIN NUTRITION IN DAIRY ANIMALS

Brad Nosbush and Jim Linn
Department of Animal Science

In contrast to many other species, the ruminant animal's diet is not its only source of protein. Microbial protein synthesized from non-protein nitrogen (NPN) in the rumen can supply the dairy animal with a large portion of the required protein for growth and production. Adequate ammonia, amino acids (AA) and peptides are essential for efficient microbial growth. If these factors are deficient, digestion of feed, feed intake and microbial protein synthesis are reduced due to diminished microbial activity.

In high producing dairy cows, microbial protein alone is not sufficient to meet the protein requirements of milk production. Both microbial and dietary protein must be of proper quantity and quality to supply a correct balance of AA into the small intestine for absorption and use by the animal. If the supply of AA presented to the intestine is inadequate, the yield of milk and milk components, especially milk protein, is reduced. Manipulating the balance of amino acids available for absorption from the intestine is a complex nutritional problem.

PROTEIN TERMINOLOGY

<u>Amino acids (AA)</u>: Amino acids are the nitrogen (N) containing building blocks of proteins. All 20 common AA share the same basic carbon skeleton but each has a different side chain giving it specific properties.

<u>True protein</u>: A compound which contains several AA linked together. The order in which the individual AA are linked together determine the physical and chemical characteristics of a protein.

<u>Crude protein (CP)</u>: The amount of CP in a feedstuff is estimated by multiplying the measured nitrogen (N) content by a factor derived from the average N content of protein (CP = N x 6.25). If a large portion of the N is derived from NPN material, CP will not represent the true protein content.

Microbial crude protein (MCP): The CP contained in the bacteria and protozoa which inhabit the rumen. The microbes which leave the rumen along with feed are used as a source of protein by the animal.

Non-protein nitrogen (NPN): Any N containing compound that is not a true protein. Examples of NPN are ammonia, urea, and various N containing biological compounds such as deoxyribonucleic acid (DNA). Rumen bacteria use these compounds as sources of N for the synthesis of amino acids.

Degradable protein: Crude protein which is broken down (degraded) into individual AA or NPN compounds while in the rumen. Rumen bacteria can use either the AA directly or they can further degrade the AA by removing the N portion (deamination). The N released by deamination can then be used for synthesis of new AA or be absorbed into the blood. Degradable intake protein (DIP) is another term for degradable protein.

Undegradable protein: Crude protein which is not degraded into individual AA or NPN while in the rumen. Undegradable protein leaves the rumen in the same form in which it was fed. Beyond the rumen, digestion continues much like it would in a nonruminant animal. Bypass protein, escape protein and undegradable intake protein (UIP) are other terms used for undegradable protein.

Soluble protein: Crude protein which is easily dissolved in rumen fluid. Soluble protein can be rapidly degraded because the linkages between AA are easily accessible to rumen microbes.

Nitrogen recycling: Nitrogen returned to the rumen either through the rumen wall or via saliva. Recycled N comes from three possible sources: excess rumen ammonia absorbed into the blood stream following a meal high in degradable protein; ammonia absorbed from the intestine; and ammonia released from the breakdown of AA in body tissues. Nitrogen is recycled as urea since urea is much less toxic to the animal than ammonia.

Essential amino acids: Amino acids that must be absorbed from the intestine because animal tissues cannot synthesize them. Since rumen microbes can synthesize the essential AA, ruminant animals do not have a specific dietary essential AA requirement. The ruminant's requirement for essential AA occurs at the intestinal level while the nonruminant's requirement occurs at the dietary level.

Nonessential amino acids: Amino acids which animal tissues can synthesize from N and a carbohydrate energy source.

First limiting amino acid: The production or synthesis of products containing AA is regulated by the amount of AA available. When the amount of one AA becomes limiting or depleted so as to decrease or halt product production, that AA is defined as the first limiting AA. While precise AA requirements for dairy animals are unknown, methionine and lysine are suggested as the potential first limiting AA in dairy cows. Histidine, phenylalanine and threonine may be limiting in some cases. Arginine, isoleucine, leucine, tryptophan and valine are generally not considered limiting for milk production (4, 9, 16).

NITROGEN PATHWAYS

The two common sources of N entering the rumen from the diet are NPN and true protein (Figure 1). Upon entering the rumen, NPN is quickly degraded to ammonia and used as a N source by rumen microbes for protein synthesis. Dietary true protein is separated into degradable and undegradable fractions in the rumen. Degradable protein is broken down into AA and/or ammonia for use in the formation of microbial protein. Undegradable protein passes through the rumen intact and unaltered from its dietary form.

Two protein sources, undegradable and microbial, reach the intestine for digestion and absorption. Amino acids absorbed into the bloodstream are used for synthesis of milk protein, tissue protein, enzymes and hormones. Amino acids also can be used to supply carbon for glucose synthesis. Thus, AA consumed in excess of requirements are used as a source of energy. The undigestible portion of intestinal protein is lost in the feces.

Ammonia in excess of what bacteria can incorporate into protein is absorbed into the blood through the rumen wall and is converted to urea by the liver. This urea can be recycled by diffusion across the rumen wall from the blood when rumen concentrations of ammonia are low as may be the case between meals or when the animal is on a low protein diet. Urea is a normal component of saliva which is another N recycling pathway. When feeding diets containing less than 13% CP, the amount of protein leaving the rumen exceeds that consumed in the diet because of N recycling. Diets exceeding 15% CP may result in less protein leaving the rumen than consumed because of excessive degradation in the rumen to ammonia and the loss of N in urine. This constitutes a major nitrogen loss for animals fed highly degradable high protein diets.

AMINO ACID DELIVERANCE TO THE SMALL INTESTINE

A high concentration of a specific AA in the feed does not ensure that a large amount of this AA will reach the intestine. The factors which affect deliverance of AA to the small intestine are the amount and composition of microbial protein and the amount and composition of protein which escapes degradation in the rumen. These complex factors make it difficult to precisely manipulate the quantity of a specific AA reaching the small intestine in the ruminant animal.

Factors affecting microbial protein synthesis

Microbes require a N source and energy for protein synthesis but incorporating these two factors into an equation for accurate estimation of microbial protein synthesis is difficult. NRC (13) estimates microbial protein synthesis from energy intake without taking into account energy source or nitrogen intake, thus all diets equivalent in energy are estimated to support the same microbial protein synthesis. Diets which contain a larger proportion of energy derived from fat result in less microbial growth than a diet of equal energy containing predominately carbohydrates. This occurs because rumen microbes utilize carbohydrates as an energy source but cannot utilize dietary fat as an energy source. Hoover and Stokes (7) found that insufficient levels of DIP decreases carbohydrate digestion and lowers microbial growth. Bacteria also are known to have preference, if not a requirement, for some peptides or combinations of AA

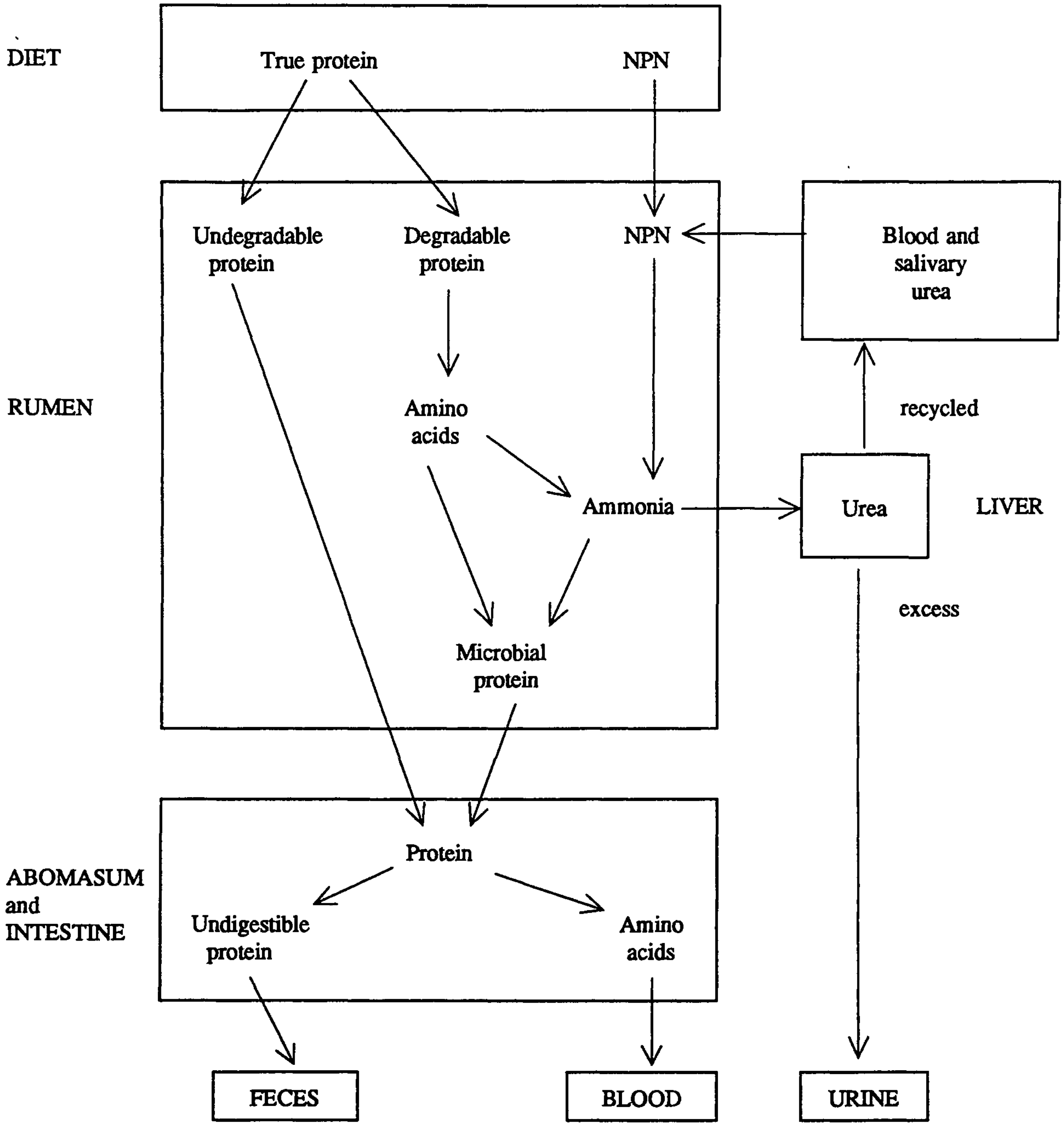

Figure 1. Protein and NPN digestion in the ruminant animal.

released during protein degradation in the rumen (19). Hence the amount and type of both DIP and energy in the rumen determines microbial growth and microbial protein production.

Precise requirements of microbes for DIP and carbohydrate are unknown but general recommendations can be made. Increasing non-structural carbohydrates (NSC) in the diet increases the total amount of carbohydrate digested which increases energy available to microbes. Diets for high producing dairy animals often contain greater than 40% NSC which is adequate under most conditions. Diets high in NSC may need to contain as much as 14% to 15% DIP (DM basis) to maximize microbial growth (7). Sustained release of peptides and AA, from feeds like soybean meal and alfalfa, is more stimulatory to microbial growth than rapid degradation of protein. Practices which increase the rate of feed passage through the rumen reduce the time microbes spend in the rumen increasing the overall microbial synthesis and decreasing energy expenditure for maintenance of microbes.

Amino acid composition of microbial protein

The AA composition of microbial protein is comparable to animal byproducts such as meat meal and blood meal (Tables 3 and 4). This is advantageous when diets containing small amounts of true protein are fed since the protein synthesized by the microbes will improve the quality of the protein delivered to the small intestine.

Microbial protein's AA profile is consistent over a wide variety of diets and has a positive effect when low protein or low protein quality diets are fed. Microbial protein can enhance the AA composition of intestinal contents in comparison to dietary AA intake when 15% CP diets are fed. (See Table 1.) These data indicate that the potential first limiting AA, lysine and methionine, are supplemented the most via microbial protein synthesis.

Table 1. Comparison of dietary amino acid intake and amount delivered to the small intestine. Average of eight diets.[a]

	AA presented to the rumen (grams/day)	AA presented to the intestine (grams/day)	Difference (%)
Arginine	84	90	7
Histidine	44	43	-2
Isoleucine	93	108	16
Leucine	249	213	-14
Lysine	79	133	68
Methionine	31	38	23
Phenylalanine	108	106	-2
Threonine	86	105	22
Valine	108	106	-2

[a]Adapted from Klusmeyer (10), McCarthy (11), and Merchen (12).

FACTORS WHICH AFFECT RUMEN DEGRADATION OF PROTEIN

Protein structure

The characteristics of protein present in a feed has a direct affect on the degradability of protein in the rumen.

Soluble fractions of proteins are nearly 100% degraded. A protein of which a large proportion is soluble will generally be more degradable than a protein with low solubility. However, soluble protein is only a small fraction of the total protein degraded in the rumen. Thus, the difference in degradation of the insoluble fraction accounts for more variation than solubility alone.

Four basic protein types are found in cereal grains and protein supplements. Albumins and globulins are small proteins which are soluble and highly degradable in rumen fluid and have a good AA balance. A high lysine and arginine content increases degradability because enzymes are able to easily cleave protein bonds at these AA. A large proportion of the proteins in soybean meal and alfalfa are albumins and globulins which result in a high rate of degradation over a sustained period. Prolamins and glutelins are large proteins with poor solubility in rumen fluid. Low solubility and the presence of disulfide bonds diminishes microbial access which slows degradation. Proteins in distillers grains, brewers grains and corn consist mainly of prolamins and glutelins resulting in a higher proportion of slowly degraded protein types (5).

Plant maturity

In an immature plant, a larger percentage of total N is in the NPN form which is highly degradable. As the plant matures, more N is incorporated into true protein or is bound by lignin, both of which decrease degradability.

Storage and processing effects

Ensiling at less than 45% DM generally causes protein to be converted to NPN which increases degradability. Ensiling at greater than 60% DM can decrease both rumen degradation and post-ruminal digestion of protein. In high DM silages, reactions between free AA and carbohydrates in the presence of heat cause formation of N containing compounds which are resistant to rumen degradation and may be unavailable to the animal. Hay is less degradable than high moisture haylage but more degradable than low moisture haylage (12).

Heat applied during drying of by-product feeds, which causes chemical reactions similar to heat damage in forages, decreases rumen available crude protein (Table 3). Also, shrinkage of the protein molecule upon cooling results in reduced surface area for the microbes to act upon (5).

Dietary effects

The degradability of protein can be quite variable in a given feedstuff under different feeding situations. As DM intake increases, degradability decreases due to reduced time spent in the rumen. As forage levels increase, degradability increases because of increased rumen pH.

Rumen pH in the range of 6.5 to 7.0 results in higher protein solubility and a more favorable environment for bacterial enzymes (proteases and deaminases) to break down protein. The opposite is true for high concentrate diets which tend to decrease pH and enzyme activity.

Amino acid composition of undegraded protein

Estimating the actual AA composition of undegraded protein is difficult since differential degradation modifies the AA profile of the dietary protein. For example, lysine and threonine are preferentially degraded in the rumen. King, et al. (9) estimated the percentage of ingested lysine and threonine reaching the small intestine to be 70% and 39% respectively. Using total protein degradability estimates and AA composition values, the quantity of AA delivered to the small intestine can be calculated for various diets (Tables 2, 3, 4 and 5). These calculations indicate that animal by-products and soybean meal deliver the most lysine to the intestine per pound of ingredient fed. Blood meal, corn gluten meal, fish meal and meat meal deliver the most methionine to the intestine per pound of ingredient fed.

RUMINALLY PROTECTED AMINO ACIDS

Ruminally protected amino acids (RPAA) are formed by encasing AA in a pH-sensitive coating. The coating prevents degradation while in the rumen, but allows for release of the AA post-ruminally. Application of this technology may allow AA supplementation of diets which deliver an insufficient level of essential AA to the small intestine. Rumen protected forms of lysine and methionine have been tested most extensively. The results generally have been variable and have shown little or no advantage to feeding of RPAA.

Chow et al. (3) observed an increase in milk protein when RPAA was fed in combination with added fat but no effect was observed with diets without added fat. Adding RPAA had no effect on milk fat percent or lactose percent in either diet.

A similar study conducted by Canale, et al. (1), found the addition of RPAA and fat increased milk fat .25 percentage units. Sole addition of RPAA decreased fat corrected milk by 3.7 pounds and fat yield .2 pounds.

In another trial, a soybean meal based diet out-performed a corn gluten meal based diet supplemented with rumen protected methionine and lysine. Much of the soybean meal based diet's performance advantage was attributed to its higher DM intake (18).

DIETS AND MICROBIAL PROTEIN EXAMPLES

Diets A, B and C illustrate how rumen microbial protein production and dietary protein contribute to the supply of AA presented to the lower digestive tract for digestion and absorption. All diets are balanced for a 1300 pound cow producing 80 pounds of 3.8% fat milk and have equivalent energy and CP contents, DM basis. Equations used to calculate the information shown in the diets are included in Appendix A. An approximate AA balance [(Dietary rumen undegradable AA + Microbial AA) - AA required for maintenance and production] is shown for each diet (2,16).

Diet A is an all corn based diet with urea as a rumen available N source. The high carbohydrate content of this diet is conducive to good rumen fermentation and production of microbial protein. However, Diet A has the lowest DIP level of the three diets which may limit microbial growth. Depressed microbial growth limits MCP production and dry matter intake. This diet is low in lysine (LYS) but is a good source of methionine (MET). However, because rumen bacteria are an excellent source of LYS, the actual amount of LYS in the intestine for digestion and absorption is almost 6 times the amount of dietary LYS undegraded. Other AA like MET, histidine (HIS), phenylalanine (PHE) and threonine (THR) are not produced by rumen microbes protozoa to the extent LYS is and therefore, the amounts found in the intestine are only 2 to 3 times the dietary amounts undegraded. Lysine and HIS appear to be limiting in this diet.

Diet B contains alfalfa haylage, barley, corn and a non traditional protein supplement, sunflower meal. The grams of undegraded AA entering the intestine are about 25% of the original amount fed in diet B. Lysine, MET, HIS, PHE and THR all appear to be limiting in this diet. Except for LYS, the dietary contribution of AA in the intestine is considerably less for diet B than A because of Diet B's low UIP content. However, Diet B which contains more DIP than either Diet A or C, may perform better than the equations would suggest because MCP synthesis may be underestimated. The equation used to calculate MCP is based on the energy level of the ration, as energy is generally the first limiting nutrient for microbial growth. The MCP equation does not include a factor for DIP which positively influences microbial growth when adequate levels of rumen available carbohydrate are included in the diet. If microbial growth is enhanced, dry matter intake will also increase. The combined effects of increased MCP production and dry matter intake may overcome the apparent AA shortages.

Diet C is a mixture of alfalfa and corn products with a good source of DIP (soybean meal) and two high UIP supplements (fish and blood meals). Grams of dietary AA presented to the intestine are considerably higher than for diet B and considerably higher for LYS than diet A. Diet C is a good example of balancing AA for both dietary and microbial source. The estimated grams of AA presented to the intestine when diet C is fed should be adequate for this particular animal. However, the low palatability of fish and blood meal may lower dry matter intake which has a negative impact on nutrient intake.

SUMMARY

Rumen microbes can synthesize high quality, highly digestible protein from low cost NPN and highly degradable low quality protein sources. Microbial protein tends to be high in lysine and threonine and marginal in methionine relative to requirements. If microbial protein is adequate to meet the animal's requirements, feeding supplemental rumen undegradable protein is not economical. Rumen undegradable protein tends to be lower in total tract digestibility, more expensive and will not increase production in cases where microbial protein is adequate.

Maximization of microbial protein synthesis is important since microbial protein accounts for 40-70% of the total amino acids reaching the small intestine of a lactating dairy cow. Microbial protein may constitute a larger portion of the total protein and may have a greater influence on the quality of the amino acids reaching the small intestine than does supplemental rumen undegradable protein.

Ingested N which is excreted in feces or urine is wasted. Feeding an excessive amount of rumen undegradable protein increases fecal N loss as feeds low in rumen degradability generally have low post-ruminal degradability. If NPN and degradable protein are in excess, high rumen ammonia concentrations cause an increase in the amount of N excreted in the urine. Providing an energy source for the rumen microbes at the same time highly degradable protein feeds are fed allows more N to be incorporated into MCP.

If microbial protein is inadequate, complementing its amino acid composition with rumen undegradable protein may increase production. Increasing dietary undegradable protein is only useful if the animal has a amino acid deficiency and the protein source delivers the limiting amino acids to the intestine in a form which can be absorbed.

Factors to take into consideration when selecting protein supplements include:

1) Feeding excess UIP and insufficient DIP results in reduced microbial growth. This has a negative impact on MCP production and dry matter intake.

2) Excess DIP and insufficient UIP limits the amount of AA reaching the intestine. Diets should be balanced to provide for both good rumen fermentation and high quality UIP to obtain optimal production.

3) An unpalatable ingredient with a good AA profile is not beneficial if production declines due to decreased dry matter intake. Many byproduct feeds need to be fed in limited amounts because of palatability problems.

Diet A. Corn products with urea.

Ingredient	Dry Matter (lbs)	Net Energy (Mcal)	Crude Protein (lbs)	Undegrad-ability (%)	UIP (lbs)	DIP (lbs)
Corn silage	19.63	14.19	1.63	31	.51	1.12
Ear corn	19.63	16.39	1.77	55	.97	.80
Corn gluten meal	6.12	5.38	4.11	55	2.26	1.85
Urea	.20	.00	.54	0	.00	.54
Dical	.42	.00	.00	0	.00	.00
Limestone	.49	.00	.00	0	.00	.00
Total	46.49	35.96	8.05		3.74	4.31

Total MCP = [6.25 (-30.93 + 11.45 × 35.96)] = 2380 grams (g)

	Dietary AA presented to the rumen				
	LYS (g)	MET (g)	HIS (g)	PHE (g)	THR (g)
Corn silage	38	39	19	32	32
Ear corn	18	14	17	40	29
Corn gluten meal	31	55	43	124	68
Urea	0	0	0	0	0
Dical	0	0	0	0	0
Limestone	0	0	0	0	0
Total AA intake	87	108	79	196	129

	Dietary AA undegraded in the rumen				
	LYS (g)	MET (g)	HIS (g)	PHE (g)	THR (g)
Corn silage	12	12	6	10	10
Ear corn	10	8	9	22	16
Corn gluten meal	17	30	24	68	38
Urea	0	0	0	0	0
Limestone	0	0	0	0	0
Total	39	50	39	100	64
A-MCP	200	40	39	109	115
Estimated AA presented to the intestine	239	90	78	209	179
Estimated AA requirements	250	73	80	158	159
Difference	-11	17	-2	51	20

Diet B. Alfalfa, barley and corn with sunflower meal.

Ingredient	Dry Matter (lbs)	Net Energy (Mcal)	Crude Protein (lbs)	Undegrad-ability (%)	UIP (lbs)	DIP (lbs)
Haylage 40% DM	18.73	12.30	3.80	15	.57	3.23
Barley	4.40	18.36	2.86	60	1.72	1.14
Corn	21.15	4.07	.44	27	.12	.32
Sunflower meal	1.90	1.23	.95	26	.25	.70
Dical	.31	.00	.00	0	.00	.00
Total	46.48	35.96	8.05		2.66	5.39

Total MCP = [6.25 (-30.93 + 11.45 × 35.96)] = 2380 grams (g)

	Dietary AA presented to the rumen				
	LYS (g)	MET (g)	HIS (g)	PHE (g)	THR (g)
Haylage 40% DM	77	17	18	54	48
Barley	5	4	5	10	8
Corn	42	16	27	63	40
Sunflower meal	18	11	11	22	18
Dical	0	0	0	0	0
Total AA intake	142	48	61	149	114

	Dietary AA undegraded in the rumen				
	LYS (g)	MET (g)	HIS (g)	PHE (g)	THR (g)
Haylage 40% DM	12	3	3	8	7
Barley	3	3	3	6	5
Corn	11	4	7	17	11
Sunflower meal	5	3	3	6	5
Dical	0	0	0	0	0
Total	31	13	16	37	28
AA-MCP	200	40	39	109	115
Estimated AA presented to the intestine	231	53	55	146	143
Estimated AA requirements	250	73	80	158	159
Difference	-19	-20	-25	-12	-16

Diet C. Alfalfa and corn products with DIP and UIP supplements.

Ingredient	Dry Matter (lbs)	Net Energy (Mcal)	Crude Protein (lbs)	Undegrad-ability (%)	UIP (lbs)	DIP (lbs)
Alfalfa	13.09	8.60	2.36	28	.66	1.70
Corn	16.10	14.87	1.61	60	.96	.65
Corn silage	11.72	8.47	.97	31	.30	.67
Soybean meal	2.77	2.35	1.38	35	.48	.90
Fish meal	1.40	1.05	.92	60	.55	.37
Blood meal	.92	.62	.80	82	.66	.14
Dical	.48	.00	.00	0	.00	.00
Total	46.48	35.96	8.04		3.61	4.43

Total MCP = [6.25 (-30.93 + 11.45 × 35.96)] = 2380 grams (g)

	Dietary AA presented to the rumen				
	LYS (g)	MET (g)	HIS (g)	PHE (g)	THR (g)
Alfalfa	53	13	23	46	39
Corn	18	16	19	36	29
Corn silage	23	23	11	19	19
Soybean meal	38	8	14	30	24
Fish meal	34	12	11	17	17
Blood meal	28	4	18	26	16
Dical	0	0	0	0	0
Total AA intake	194	75	96	174	144

	Dietary AA undegraded in the rumen				
	LYS (g)	MET (g)	HIS (g)	PHE (g)	THR (g)
Alfalfa	15	4	6	13	11
Corn	11	9	11	22	17
Corn silage	7	7	4	6	6
Soybean meal	13	3	5	10	8
Fish meal	20	7	6	10	10
Blood meal	24	3	15	21	13
Dical	0	0	0	0	0
Total	89	33	47	82	65
AA-MCP	200	40	39	109	115
Estimated AA presented to the intestine	289	73	86	191	180
Estimated AA requirements	250	73	80	158	159
Difference	39	0	6	33	21

Appendix A: Equations used for protein and AA calculations.

Grams of Microbial Crude Protein (MCP):

$$MCP = 6.25 \times (-30.93 + 11.45 \times \text{Mcal NEL})$$

Degradability:

$$\text{Degradability} = 100 - \text{percent undegradability}$$

Degradable Intake Protein (DIP):

$$DIP = \frac{\text{lb feedstuff CP} \times \text{\% degradability of feedstuff}}{100}$$

Undegradable Intake Protein (UIP):

$$UIP = \frac{\text{lb feedstuff CP} \times \text{\% undegradability of feedstuff}}{100}$$

Percent Degradable Intake Protein (%DIP):

$$\%DIP = \frac{\text{lb DIP}}{\text{lb UIP} + \text{lb DIP}} \times 100$$

Percent Undegradable Intake Protein (%UIP):

$$\%UIP = \frac{\text{lb UIP}}{\text{lb UIP} + \text{lb DIP}} \times 100$$

Grams of individual Amino Acids in Diet (AAD):

$$AAD = \frac{\text{lb feedstuff DM} \times \text{amino acid composition (\% of DM)}}{4.54}$$

Grams of Undegradable AA (UAA):

$$UAA = \text{lb feedstuff DM} \times \text{grams AA reaching intestine per lb of ingredient fed.}$$

Grams of individual AA in Microbial Crude Protein (AA-MCP):

$$AA\text{-}MCP = \frac{\text{grams MCP} \times \text{amino acid composition (\% of CP)}}{100}$$

Table 2. Protein analysis of common feeds.[1]

Feed[2]	Dry Matter (%)	Crude Protein (%)	Soluble Protein (% of CP)	Undegradability Mean (%)	Undegradability S.D. (%)
Blood meal	92	87.20	3	82	1
Brewers DG	92	29.40	6	49	13
Corn gluten feed	90	25.60	55	22	11
Corn gluten meal	90	67.20	4	55	8
Cottonseed meal	91	45.60	12	43	11
Cottonseed, whole	92	23.00	40	29	
Distillers DG	94	29.80	6	54	
DDG w/ solubles	92	29.50	19	47	18
Feather meal	93	89.00	4	82	
Fish meal	92	66.70		60	16
Linseed meal	90	38.30		35	10
Meat & bone meal	93	54.10	18	49	18
Meat meal	94	54.80		76	
Soybean meal	90	49.90	24	35	12
Soybeans, raw	92	42.80		26	11
Soybeans, roasted	92	43.00	17	51	
Sunflower meal	93	49.80		26	5
Barley	88	13.50		27	10
Corn, dry	88	10.00	15	60	7
Corn, high moisture	72	10.00	40	34	7
Ear corn	87	9.00		55	
Oats	89	13.30		17	3
Wheat	89	16.00		22	6
Alfalfa	90	18.00	30	28	7
Haylage (66% DM)	66	19.50	42	36	8
Haylage (40% DM)	40	20.30	64	15	8
Corn silage	30	8.30	52	31	6
Rumen microbes		44.30		100	0

[1]Adapted from Clark (5), Merchen (12), and NRC (13, 14).

[2]Brewers DG = Brewers dried grains; Distillers DG = Distillers dried grains; DDG w/ solubles = Distillers dried grains with solubles.

Table 3. Amino acid composition of common feeds[1].

	Percent of Dry Matter (%)									
Feed[2]	Lys	Met	His	Phe	Thr	Arg	Ile	Leu	Trp	Val
Blood meal	6.92	.97	4.34	6.00	3.89	3.55	.95	10.86	1.07	7.12
Brewers DG	.95	.50	.56	1.56	1.01	1.38	1.68	2.70	.40	1.75
Corn gluten feed	.71	.41	.68	.90	.87	.87	.98	2.44	.17	1.22
Corn gluten meal	1.12	1.98	1.55	4.45	2.46	2.31	2.82	11.33	.33	3.43
Cottonseed meal	2.01	.62	1.27	2.21	1.48	4.71	1.59	2.67	.56	2.20
Distillers DG	.84	.43	.67	1.00	.52	1.04	1.06	3.22	.21	1.26
DDG w/ solubles	.77	.54	.70	1.64	1.01	1.05	1.52	2.43	.19	1.63
Feather meal	2.49	.59	1.06	3.28	4.27	7.58	4.37	7.46	.56	6.97
Fish	5.15	1.91	1.58	2.69	2.73	4.09	3.15	4.89	.71	3.52
Linseed meal	1.28	.60	.77	1.62	1.35	3.25	1.87	2.24	.56	1.93
Meat & bone meal	3.11	.70	1.04	1.83	1.77	3.75	1.76	3.29	.32	2.63
Meat meal	3.45	.75	1.02	1.94	1.75	3.84	1.86	3.40	.37	2.68
Soybean meal	2.99	.58	1.17	2.36	1.85	3.38	2.27	3.65	.71	2.25
Soybeans, raw	2.67	.59	1.06	2.22	1.81	3.11	2.32	3.28	.59	2.25
Sunflower meal	2.06	1.25	1.32	2.54	2.07	4.75	2.42	4.12	.65	2.80
Barley	.44	.17	.28	.66	.42	.58	.51	.85	.17	.64
Corn	.24	.21	.25	.49	.39	.54	.39	1.12	.09	.51
Ear corn	.20	.16	.19	.45	.33	.42	.40	1.00	.08	.36
Oats	.44	.19	.21	.58	.40	.79	.49	.91	.17	.63
Wheat	.41	.20	.32	.68	.42	.67	.53	.98	.17	.64
Alfalfa hay	.90	.21	.38	.78	.66	.81	.67	1.19		.88
Haylage (66% DM)	.66	.18	.21	.58	.72	.68	.72	.84		.76
Haylage (40% DM)	.91	.20	.21	.63	.57	.32	.75	.95		.81
Corn silage	.43	.44	.21	.36	.36	.97	.25	.93		.45
Rumen microbes	3.73	.74	.73	2.02	2.15	1.70	2.31	3.12		1.70

[1]Adapted from Clark (5), Merchen (12), and NRC (14).

[2]Lys = Lysine; Met = Methionine; His = Histidine; Phe = Phenylalanine; Thr = Threonine; Arg = Arginine; Ile = Isoleucine; Leu = Leucine; Trp = Tryptophan; Val = Valine.

Table 4. Amino acid composition of common feeds.

Feed	Percent of Crude Protein (%)									
	Lys	Met	His	Phe	Thr	Arg	Ile	Lue	Trp	Val
Blood meal	7.94	1.11	4.98	6.88	4.46	4.07	1.09	12.45	1.23	8.17
Brewers DG	3.23	1.70	1.90	5.31	3.44	4.69	5.71	9.18	1.36	5.95
Corn gluten feed	2.77	1.60	2.66	3.52	3.40	3.40	3.83	9.53	.66	4.77
Corn gluten meal	1.67	2.95	2.31	6.62	3.66	3.44	4.20	16.86	.49	5.10
Cottonseed meal	4.41	1.36	2.79	4.85	3.25	10.33	3.49	5.86	1.23	4.82
Distillers DG	2.82	1.44	2.25	3.36	1.74	3.49	3.56	10.81	.70	4.23
DDG w/ solubles	2.61	1.83	2.37	5.56	3.42	3.56	5.15	8.24	.64	5.53
Feather meal	2.80	.66	1.19	3.69	4.80	8.52	4.91	8.38	.63	7.83
Fish meal	7.72	2.86	2.37	4.03	4.09	6.13	4.72	7.33	1.06	5.28
Linseed meal	3.34	1.57	2.01	4.23	3.52	8.49	4.88	5.85	1.46	5.04
Meat & bone meal	5.75	1.29	1.92	3.38	3.27	6.93	3.25	6.08	.59	4.86
Meat meal	6.30	1.37	1.86	3.54	3.19	7.01	3.39	6.20	.68	4.89
Soybean meal	5.99	1.16	2.38	4.73	3.71	6.77	4.55	7.31	1.42	4.51
Soybeans	6.24	1.38	2.48	5.19	4.23	7.27	5.42	7.66	1.38	5.26
Sunflower meal	4.14	2.51	2.65	5.10	4.16	9.54	4.86	8.27	1.31	5.62
Barley	3.26	1.26	2.07	4.89	3.11	4.30	3.78	6.30	1.26	4.74
Corn	2.40	2.10	2.50	4.90	3.90	5.40	3.90	11.20	.90	5.10
Ear corn	2.22	1.78	2.11	5.00	3.67	4.67	4.44	11.11	.89	4.00
Oats	3.31	1.43	1.58	4.36	3.01	5.94	3.68	6.84	1.28	4.74
Wheat	2.56	1.25	2.00	4.25	2.63	4.19	3.31	6.13	1.06	4.00
Alfalfa hay	5.00	1.17	2.11	4.33	3.67	4.50	3.72	6.61		4.89
Haylage (66% DM)	3.38	.92	1.08	2.97	3.69	3.49	3.69	4.31		3.90
Haylage (40% DM)	4.48	.99	1.03	3.10	2.81	1.58	3.20	4.68		3.99
Corn silage	5.18	5.30	2.53	4.34	4.34	11.69	3.01	11.20		5.42
Rumen microbes	8.42	1.67	1.65	4.56	4.85	3.84	5.22	7.04		3.84

Table 5. Grams of dietary AA reaching the small intestine per pound of ingredient fed. (Dry matter basis.)*

	Grams									
Feed	Lys	Met	His	Phe	Thr	Arg	Ile	Lue	Trp	Val
Blood meal	25.76	3.61	16.16	22.34	14.48	13.22	3.54	40.43	3.98	26.51
Brewers DG	2.11	1.11	1.25	3.47	2.25	3.07	3.74	6.01	.89	3.89
Corn gluten feed	.71	.41	.68	.90	.87	.87	.98	2.44	.17	1.22
Corn gluten meal	2.80	4.94	3.87	11.11	6.14	5.77	7.04	28.29	.82	8.56
Cottonseed meal	3.92	1.21	2.48	4.31	2.89	9.19	3.10	5.21	1.09	4.29
Distillers DG	2.06	1.05	1.64	2.45	1.27	2.55	2.60	7.89	.51	3.09
DDG w/ solubles	1.64	1.15	1.49	3.50	2.16	2.24	3.24	5.19	.41	3.48
Feather meal	9.26	2.20	3.95	12.21	15.90	28.22	16.27	27.77	2.08	25.95
Fish meal	14.03	5.20	4.30	7.33	7.44	11.14	8.58	13.32	1.93	9.59
Linseed meal	2.03	.95	1.22	2.57	2.15	5.16	2.97	3.56	.89	3.07
Meat & bone meal	6.92	1.56	2.31	4.07	3.94	8.34	3.92	7.32	.71	5.85
Meat meal	11.90	2.59	3.52	6.69	6.04	13.25	6.42	11.73	1.28	9.25
Soybean meal	4.75	.92	1.89	3.75	2.94	5.37	3.61	5.80	1.13	3.58
Soybeans, raw	3.15	.70	1.25	2.62	2.14	3.67	2.74	3.87	.70	2.66
Sunflower meal	2.43	1.48	1.56	3.00	2.44	5.61	2.86	4.86	.77	3.31
Barley	.54	.21	.34	.81	.51	.71	.63	1.04	.21	.78
Corn	.65	.57	.68	1.33	1.06	1.47	1.06	3.05	.25	1.39
Ear corn	.50	.40	.47	1.12	.82	1.05	1.00	2.50	.20	.90
Oats	.34	.15	.16	.45	.31	.61	.38	.70	.13	.49
Wheat	.41	.20	.32	.68	.42	.67	.53	.98	.17	.64
Alfalfa hay	1.14	.27	.48	.99	.84	1.03	.85	1.51		1.12
Haylage (66% DM)	1.08	.29	.34	.95	1.18	1.11	1.18	1.37		1.24
Haylage (40% DM)	.62	.14	.14	.43	.39	.22	.44	.65		.55
Corn silage	.61	.62	.30	.51	.51	1.37	.35	1.31		.63
Rumen microbes	16.93	3.36	3.31	9.17	9.76	7.72	10.49	14.16		7.72

*Estimate based on total protein undegradability and does not correct for differential degradation of specific amino acids in the rumen.

REFERENCES

1. Canale, C. J., L. D. Muller, H. A. McCahon, T. J. Whitsel, G. A. Varga, and M. J. Lormore. 1990. Dietary fat and ruminally protected amino acids for high producing dairy cows. J. Dairy Sci. 73:135-141.

2. Chalupa W. and C. J. Sniffen. 1991. Protein and amino acid nutrition of lactating dairy cattle. Vet Clin FD. 7:353.

3. Chow, J. M., P. L. Burgess, L. D. Muller, and G. A. Varga. 1990. Effect of rumen-protected methionine and lysine on casein in milk when diets high in fat or concentrate are fed. J. Dairy Sci. 73:1051-1061.

4. Clark, J. H. 1974. Lactational responses to postruminal administration of proteins and amino acids. J. Dairy Sci. 58:1178-1197.

5. Clark, J. H., M. R. Murphy, and B. A. Crooker. 1987. Supplying the protein needs of dairy cattle from by-product feeds. J. Dairy Sci. 70:1092-1109.

6. Hogan, J. P. 1974. Quantitative aspects of nitrogen utilization in ruminants. J. Dairy Sci. 58:1164-1177.

7. Hoover, W. H., and S. R. Stokes. 1991. Balancing carbohydrates and proteins for optimum rumen microbial yeild. J. Dairy Sci. 74:3630-3644.

8. King, K. J., W. C. Bergen, C. J. Sniffen, A. L. Grant, D. B. Grieve, V. L. King, N. K. Ames. 1991. An assessment of absorbable lysine requirements in lactating cows. J. Dairy Sci. 74:2530-2539.

9. King, K. L., J. T. Huber, M. Sadik, W. G. Bergen, A. L. Grant, D. B. Grieve, and V. L. King. 1990. Influence of dietary protein sources on the amino acid profiles available for digestion and metabolism in lactating cows. J. Dairy Sci. 73:3208-3216.

10. Klusmeyer, T. H., R. D. McCarthy, Jr., J. H. Clark, and D. R. Nelson. 1990. Effects of source and amount of protein on ruminal fermentation and passage of nutrients to the small intestine of lactating cows. J. Dairy Sci. 73:3526-3537.

11. McCarthy, R.D., Jr., T.H. Klusmeyer, J.L. Vicini, J.H. Clark and D. R. Nelson. 1989. Effects of source of protein and carbohydrate on ruminal fermentation and passage of nutrients to the small intestine of lactating cows. J. Dairy Sci. 72:2002-2016.

12. Merchen, N. R., and L. D. Satter. 1983. Changes in nitrogenous compounds and sites of digestion of alfalfa harvested at different moisture contents. J. Dairy Sci. 66:789-801.

13. National Research Council. 1989. Nutrients requirements of dairy cattle. 6th ed. Natl. Acad. Sci., Washington, DC.

14. National Research Council. 1982. United States-Canadian tables of feed composition. Natl. Acad. Sci., Washington, DC.

15. Nocek, J. E., and J. B. Russel. 1988. Protein and energy as an integrated system. Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. J. Dairy Sci. 71:2070-2107.

16. Oldham, J. D. 1981. Amino acid requirements for lactation in high-yielding dairy cows. Page 33 in Recent developments in ruminant nutrition. W. Haresign and D. J. A. Cole, ed. Butterworths, London, England.

17. Owens, F. N., R. Zinn. 1988. Protein metabolism of ruminant animals. Pages 227-249 in The ruminant animal; Digestive physiology and nutrition. D.C. Church, ed. Prentice Hall, Englewood Cliffs, New Jersey.

18. Polan, C. E., K. A. Cummins, C. J. Sniffen, T. V. Muscato, J. L. Vicini, B. A. Crooker, J. H. Clark, D. G. Johnson, D. E. Otterby, B. Guillaume, L. D. Muller, G. A. Varga, R. A. Murray, and S. B. Peirce-Sandner. 1991. Responses of dairy cows to supplemental rumen-protected forms of methionine and lysine. J. Dairy Sci. 74:2997-3013.

19. Robinson, P. H., R. E. McQueen, and P. L. Burgess. 1991. Influence of rumen undegradable protein levels on feed intake and milk production of dairy cows. J. Dairy Sci. 74:1623-1631.

20. Spain, J. N., M. D. Alvarado, C. E. Polan, C. N. Miller, and M. L. McGilliard. 1990. Effect of protein source and energy on milk composition in midlactation dairy cows. J. Dairy Sci. 73:445-452.

21. Tamminga, S. 1979. Protein degradation in the forestomachs of ruminants. J. Anim. Sci. 49:1615-1630.