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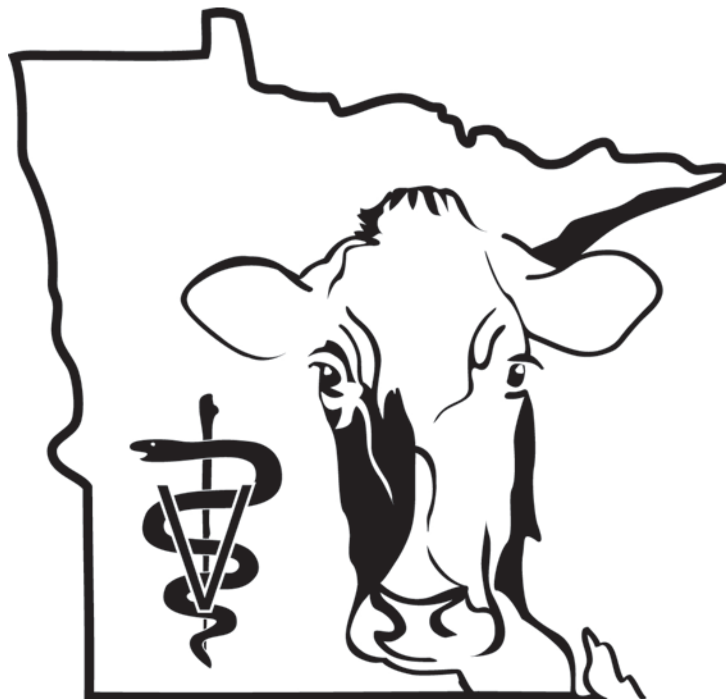

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SIGNIFICANCE OF RUMINAL BYPASS PROTEIN FOR LACTATING DAIRY COWS

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INTRODUCTION

Absorbed amino acids (AA) from the small intestine of ruminants are supplied by microbial protein synthesized in the rumen, undegraded (bypass) dietary protein and endogenous protein (Figure 1.) Microbial protein usually accounts for the largest proportion of the total amino acid-nitrogen (AA-N) entering the small intestine of ruminants. Microbial protein synthesis in the rumen is dependent mainly on the nitrogen and energy supply to the rumen microbes, which is determined by quantity and ruminal fermentability of protein and carbohydrates. If the energy supplied by the diet is not sufficient, there may be a corresponding decrease in microbial protein synthesis due to less ammonia uptake by the microbes. Therefore, deficiency of energy may lead to a reduced intestinal protein supply and at the same time may precipitate excessive ammonia levels in the rumen, especially when feeding highly degradable proteins. Use of high ruminal bypass or protected proteins in diets fed to ruminants with high protein requirements improves the AA supply to the animal and concurrently decreases the surplus of ammonia, thereby reducing stress on liver metabolism.

Even when nutrients are nonlimiting in the rumen, the rumen system may not supply sufficient microbial protein to meet the animal's need for maximum production. Under conditions of high production (fast growth, late pregnancy, or early lactation), the animal depends on an additional exogenous supply to the duodenum, e.g., feeding proteins that because of their physical state escape ruminal fermentation. The fact that protein passes through the rumen undegraded and reaches the small intestine for digestion does not necessarily mean that it is digested efficiently nor, once digested, that the AA profile is such that it provides a better balance of AA for milk production and growth. Protecting protein from microbial degradation in the rumen will be successful only in affecting animal performance if proteins are not denatured to the extent that intestinal absorption of AA is diminished so that the net effect on AA supply is reduced and the animal has the metabolic capacity to respond to an increase of AA supply; that is, requirements for AA have not been met.

MICROBIAL PROTEIN SYNTHESIS IN THE RUMEN

The rumen is a site where digestion occurs through the action of microbes that live in symbiotic association with the animal. Ingested dietary protein is extensively degraded in the rumen to amino acids and deaminated to ammonia, and both are used as a source of nitrogenous nutrients for the synthesis of rumen bacterial and protozoal protein (Figure 2).

Microbial protein synthesis in the rumen requires specific nutrients such as sulfur, branched-chain fatty acids and trace nutrients, however under most dietary circumstances these substances are not limiting. Therefore, nutrient supply to the microbes is considered largely in terms of ruminal availability of nitrogen and digestible organic matter, mainly carbohydrate, that can be fermented in the rumen to provide a carbon skeleton and energy in the form of adenosine triphosphate for microbial protein synthesis.

NUTRITIVE VALUE OF MICROBIAL PROTEIN TO THE DAIRY COW

Under most feeding practices, microbial protein synthesized in the rumen comprises a substantial part of the protein entering the small intestine (60 - 85% of total amino acid nitrogen), where enzymatic digestion releases amino acids that are absorbed to furnish the animal's needs. In general, the amino acid composition of duodenal digesta usually reflects that of microbial protein except on diets where significant amounts of dietary protein have avoided degradation. Storm et al. (1983) observed that the composition of microbial protein appeared to be constant irrespective of dietary and animal conditions. They also concluded that the mean true digestibility of microbial amino acid nitrogen in sheep was 84.7% in the small intestine, while efficiency of utilization of absorbed amino acid nitrogen was 80.1%. Because rumen microbes are an important source of high quality protein for the ruminant and microbial growth rates can affect amino acid availability to the animal, it is important to maximize microbial protein synthesis in the rumen.

Because microbial protein accounts for such a large proportion of total amino acid nitrogen supply to ruminants, it would be meaningful to determine any limiting amino acids in rumen microbes. Due to the complexity of amino acids and nitrogen metabolism of the ruminant and its microbes, it is difficult to quantify limiting amino acids. Storm and Ørskov (1984) described a method to quantitatively determine the order of limitation of essential amino acids in rumen microbes or more precisely, the limiting amino acids in those absorbed from the small intestine in sheep nourished by infusion of volatile fatty acids and given rumen microbes as the only source of protein. They found that methionine was the most limiting amino acid in ruminal microbial protein and that lysine was second limiting, followed by arginine and histidine.

Based on these observations and other available information, it should be theoretically possible via protein or amino acid supplementation to considerably improve the utilization of microbial protein, provided that complementary amino acids are provided to the animal in such a way that the rumen is bypassed, or that they are protected from ruminal degradation.

Table 1 shows the theoretical contribution of microbial protein to the host animal calculated at three levels for efficiency of microbial protein synthesis. Contribution of microbial protein to total protein requirement was determined using NRC values (1989) for a 635 kg (1,400 lb) lactating dairy cow producing 25 (55), 35 (77) and 45 (100) kg (lb) milk daily respectively with 4.0% milk fat. At these three levels of milk yield, microbial protein would contribute 55 to 68% of the total protein required by the animal

when microbial synthesis in the rumen is 30 g N/kg organic matter truly digested (OMD). When milk yield is 45 kg/d, contribution of microbial protein required by the cow would increase from 37 to 73% with an increase in efficiency of microbial protein synthesis from 20 to 40 g N/kg OMD. Stern and Hoover (1979) reviewed the literature and found that a mean value of approximately 30 g N were synthesized per kg OMD in the rumen, with values ranging from 10 to 50 g. Efficiencies for microbial protein synthesis used in table 1 are therefore realistic and the calculated contribution of microbial protein clearly depicts the importance of optimizing microbial protein synthesis in the rumen of the high producing dairy cow. In addition, these calculations demonstrate that as milk production increases, a substantial quantity of additional dietary protein from protein supplements must bypass ruminal fermentation to meet the animal's protein requirement.

PROTEIN DEGRADATION IN THE RUMEN

Dietary protein degradation in the rumen becomes more of an important factor influencing the amount of amino acids absorbed from the small intestine as milk production per cow increases. Protein degradation (Figure 3) involves basically two stages: (1) hydrolysis of the peptide bond (proteolysis) to produce peptides and amino acids; and (2) deamination and degradation of amino acids (NRC, 1985).

The extent to which protein is degraded depends primarily upon microbial proteolytic activity in the rumen, microbial access to the protein and ruminal retention time of dietary protein. Other factors influencing protein degradation include protein solubility and ruminal pH.

TREATMENT OF PROTEIN TO INCREASE RUMINAL BYPASS

Dietary proteins have been protected against microbial degradation in the rumen by introducing linkages by various physical and chemical treatments. These include the use of tannins and more commonly the use of aldehydes and heat. Animal responses to these treatments have been inconsistent and in some cases may be due to underprotection and in other cases to overprotection so that protein become indigestible. The tanning process involves reactions of mainly hydrogen bonds between hydroxyl groups of tannin and peptide groups of protein. The tannin-protein complex is a reversible reaction and the complex is hydrolyzable by proteases and in particular by trypsin. Irreversible reactions with quinones, formed by tannin oxidation may also occur and reduce digestibility and availability of some amino acids. Formaldehyde, a very reactive substances reacts on activated hydrogen containing molecules and forms hydroxyl methyl derivatives which can react further with formaldehyde or other amino acid side chains to form cross-links in the form of methylene bridges. The extent to which these linkages can be reversed is not known. Heating facilitates the Maillard reaction between sugar aldehyde groups and the free amino groups of protein to yield an amino-sugar complex. These linkages are more resistant than normal peptides to enzymatic hydrolysis. Reversibility of this reaction is dependent upon temperature and time of heat exposure.

In addition to heat, formaldehyde and tannins, other treatments have been successful in decreasing degradability of protein in the rumen. These include the use of other aldehydes such as the dialdehydes, glutaraldehyde and glyoxal (Ashes et al., 1984), sodium bentonite (Britton et al., 1978), sodium hydroxide (Mir et al., 1984), calcium lignosulfonate (Stern, 1984), blood (Mir, et al., 1984), fish hydrolysate (Mir et al., 1984), alcohol (Van der Aar et al., 1982), and xylose (Cleale et al., 1987).

Influence of Heating on Protein Utilization

The most commonly used treatment for reducing ruminal microbial protein degradation has been the use of heat processing. Controlled heating of proteins can reduce ruminal degradation of the protein without adversely affecting intestinal protein digestibility (Chalupa, 1975). Tagari et al. (1962) were the first researchers to report that heat treatment of soybean meal resulted in decreased protein solubility and increased efficiency of utilization of the soy protein. Animal production responses as a result of heat treatment are primarily due to decreased ruminal degradation of the dietary protein, although heat destruction of inhibitors in some protein sources, such as trypsin inhibitor in soybeans, can also increase animal performance.

Factors involved in the heating process are not fully understood. Both temperature and length of heating time are important factors. Tagari et al. (1962) reported that heating soybean meal at 120°C for .33 h was effective in decreasing the solubility of the soy protein and improving the efficiency of utilization of the soy protein. In contrast, Mir et al. (1984) reported that 120°C for .33 h was not effective in reducing in situ ruminal degradation of soybean meal protein. Nishimuta et al. (1974) and Stern et al. (1985) reported that treatment of soy protein at temperatures of 132 and 149°C resulted in increased quantities of amino acids available to the small intestine. McMeniman et al. (1979) reported that a temperature of 105°C for 24 h did not affect the flow of protein to the duodenum.

When sugars or carbohydrates are present, heating of protein causes carbonyl groups of the sugars to combine with free amino groups of proteins (Mauron, 1981). The amino acid most affected during the heating process is lysine, presumably due to its free epsilon-amino group.

Heat Processing Methods

Expeller Processing. Most soybean meal fed to dairy cattle in the U.S. is produced using solvent extraction to remove the oil. An alternative method which generates considerable heat during oil removal is the expeller process. This method involves heating to a maximum of 163°C which results in the Maillard reaction between sugar aldehyde groups and free amino groups. Broderick (1986) reported that expeller processed soybean meal provided about 65% more bypass dietary protein than solvent soybean meal and improved milk to feed ratio in lactating dairy cows. He also found that smaller amounts of expeller soybean meal could replace solvent extracted soybean meal without reducing milk production.

Jet sploding. This process uses a high temperature of 315°C for a short period and utilizes only the moisture within the seed. Deacon et al. (1988) found that jet-sploding of whole canola seed reduced protein degradability from 83.5 to 43.2% without dramatically decreasing intestinal digestibility.

Extrusion. The effect of extruding whole soybeans at 132 and 149°C compared to soybean meal and raw soybeans on ruminal protein degradability measured in situ is shown in Figure 4. Raw soybeans were clearly more degradable than the extruded soybeans or soybean meal at all intervals of rumen exposure. At 1 hour of ruminal exposure time, soybean meal and the two extruded soybean products appeared to be similar in readily available or soluble nitrogen. However, as time in the rumen increased, the extruded soybeans were more resistant to microbial degradation than soybean meal.

These same four soybean sources were fed to ruminal and intestinal cannulated lactating Holstein cows (Stern et al., 1985) to measure protein degradation in the rumen and amino acid flow and absorption from the small intestine (Table 2). Flow of total amino acids to the duodenum and subsequent absorption from the small intestine were lowest for the diet containing unprocessed whole soybeans. Extrusion of whole soybeans at 132 and 149°C increased the flow of amino acids to the duodenum approximately 10% and caused a 17% higher absorption (g/day) from the small intestine compared with unprocessed soybeans. This effect was probably due to increased resistance of protein in extruded whole soybeans to microbial degradation. Amino acid absorption from the small intestine, expressed as a percentage of amino acid flow to the duodenum, was higher for the extruded soybean diets, indicating that heat treatment did not overprotect the protein. Lower digestion in the intestine with unprocessed soybeans could possibly be attributed to higher trypsin inhibitor activity compared to the heat processed soybeans. Mielke and Schingoethe (1981) determined that trypsin inhibitor activities of extruded soybeans and raw soybeans were 2.7 and 24.0 trypsin inhibitor units/mg, respectively.

Roasting. Heating full fat whole soybeans in roasters has supported greater milk (4.5 kg/d), 3.5% FCM (4.0 kg/d) and milk protein (.09 kg/d) yields when fed to dairy cows compared with soybean meal or raw soybeans (Faldet and Satter, 1991). However, roasting temperature and holding time after soybeans exit the roaster can markedly affect ruminal bypass and postruminal availability of amino acids (Faldet et al., 1991; Faldet et al., 1992). In addition, physical form (particle size) of the soybeans can have a major impact on ruminal protein degradability (Figure 5; Mansfield and Stern, unpublished data).

Calcium lignosulfonate. The term lignosulfonate is used to describe any product derived from the spent sulfite liquor that is generated during the sulfite digestion of wood and containing a percentage of lignosulfonic acid or its salt as well as hemicellulose and sugars. Because lignosulfonates can bind and precipitate protein, it was hypothesized that soybean meal treated with lignosulfonates could be rendered less degradable in the rumen. Winowiski and Stern (1987) examined various processing factors involved in the lignosulfonate-soybean meal reaction and concluded

that heat and the presence of wood sugars in the lignosulfonate preparation were necessary to reduce ruminal protein degradation. In general, calcium lignosulfonate contains a variety of wood sugars, with the main sugar being xylose. Cleale et al. (1987) found that treatment of soybean meal with xylose (3 mol xylose/mol lysine) was effective in reducing degradation of soybean protein by rumen microorganisms. It was concluded that controlled nonenzymatic browning improved efficiency of soybean protein utilization by ruminants.

Stern (1984) used an artificial rumen system to determine the effects of calcium lignosulfonate (CL) on nitrogen utilization by rumen bacteria. Ammonia-N concentration decreased when soybean meal was pelleted with CL and a modified CL at 4 g/100 g SBM and was further reduced at 8 g CL/100 g SBM (Table 3). This decrease was due to increased resistance of protein to bacterial degradation. In addition, total volatile fatty acid (VFA) production and organic matter (OM) digestion were lower with diets containing treated SBM, indicating a possible effect of CL on carbohydrate digestion. Similar observations were made by Faichney (1974) who showed less OM digestion and VFA production in the rumen of sheep receiving diets with formaldehyde treated casein. Stern (1984) showed no differences for nonstructural carbohydrate digestion, however, cellulose digestion was lower in diet 4 and had a tendency to be lower in diets 2 and 3 compared with diet 1. Decreases in VFA production, OM digestion, cellulose digestion and bacterial N synthesis with CL treatment may have been due to deficiency of degradable N from the protected SBM which would be similar to effects with diets deficient in nitrogen. Folman et al. (1981) and Windschitl and Stern (1988a) also reported a decrease in the quantity of bacterial protein synthesized in dairy cows when protected (formaldehyde and CL-treated) proteins were fed. It is possible that ammonia-N concentrations may have been insufficient to meet the requirements of the ruminal microbial population. The extent of these effects may have been diminished if a fermentable N source such as urea had been included in the diet. Windschitl and Stern (1988b) found that ammonia-N concentrations, bacterial protein synthesis, OM digestion and cellulose digestion were higher as the level of degraded N supplied to the bacterial population increased via increasing levels of urea supplementation. These results indicate that it might be beneficial to feed readily fermentable nitrogen (urea) in conjunction with high ruminal bypass proteins.

Evaluation of Various Methods for Protecting Soybean Meal Protein

Waltz and Stern (1989) used the in situ technique and an artificial rumen system to study the effects of protection method on protein degradation of soybean meal by ruminal bacteria. Treatments included solvent extraction (control), sodium hydroxide, formaldehyde, expeller processing, propionic acid, extrusion, ethanol and lignosulfonate. Results from the in situ study (Figure 6) showed that expeller processing, calcium lignosulfonate treatment and formaldehyde treatment were most effective in reducing ruminal protein degradation. Diets provided to ruminal bacteria in the artificial rumen contained approximately 17% crude protein, with 50% of the crude protein coming from the respective treated soybean meal. Crude protein degradation of formaldehyde treated, expeller processed, propionic acid treated, extruded and

lignosulfonate treated soybean meal diets were lower than the control diet. Total bacterial N output was lowest for soybean meal protected by formaldehyde, expeller processing and lignosulfonate treatments. Bypass dietary N in the effluent was highest for soybean meal protected by formaldehyde, expeller processing, propionic acid and lignosulfonate treatments.

ANIMAL PROTEINS

Animal proteins or by-products of animal processing such as meat and bone meal, blood meal, feather meal and fish meal are high in protein content and are also high bypass protein sources compared with some of the more commonly fed plant proteins (Figure 7). In addition to these characteristics, palatability, protein quality, intestinal absorption of amino acids, cost per unit of protein, availability and consistency of product, and impact on animal performance are key elements in deciding how to use animal by-products in diet formulations for ruminants.

Ruminal Fermentation and Postruminal Utilization of Animal Proteins

Animal By-Products. Ruminal protein degradation values of 18, 36 and 31% for blood meal (BM), meat meal (MM) and hydrolyzed feather meal (HFM) (Klopfenstein and Goedeken, 1986) and 46% for meat and bone meal (MBM) (Kirkpatrick and Kennelly, 1987) indicate their potential for delivering more undegraded dietary amino acids from the rumen. However, to achieve a greater supply of total or essential amino acids to the small intestine with these highly resistant proteins it is important that: 1) the dietary crude protein contains a substantial portion of true protein and/or amino acids and, 2) that microbial protein is not depressed to the point of counteracting the increased supply of amino acids from undegraded dietary protein. Blake and Stern (1988) showed that despite a lower degradation of CP (66 vs 85%) for MBM compared to soybean meal (SBM), total amino acid flows from an artificial rumen were not different between diets containing 80% of total dietary CP as MBM or SBM. Diets were similar in total CP content, however amino acid intake was lower for the 100% MBM diet presumably due to its higher nonprotein-N content. They suggested that this may be related to the relatively high amounts of nucleic acids found in bone marrow. In addition, while dietary amino acid flow was higher, bacterial amino acid flow was lower for the MBM diet compared with the SBM diet. These combined effects resulted in similar total amino acid flows for the two diets. In contrast, when a combination of HFM, MBM and BM replaced SBM as the protein source, Mansfield and Stern (1991) observed an increase in dietary N and total protein flow from the artificial rumen.

In a study using duodenally cannulated steers, Loerch et al. (1983) found that ruminal bypass CP was 28.7, 81.7, 49.3 and 66.3 % for SBM, BM, MBM and dehydrated alfalfa (DA). Supplementation with BM or DA resulted in greater CP flow to the duodenum than supplementation with SBM. Although dietary CP flow was greater with MBM compared to SBM, a reduction in bacterial CP flow with the MBM diet resulted in similar total CP flow to the duodenum. This response with MBM is similar to in vitro observations presented earlier by Blake and Stern (1988). In contrast to these

findings, Metwally (1989) found no difference in bacterial or dietary CP flow to the duodenum of lactating cows fed diets containing SBM and MBM as the major protein supplements. However, he detected a higher flow (13%) and absorption (15%) of amino acids from the small intestine (Table 4) with MBM compared to SBM.

Soybean meal, BM, HFM and a 50-50 combination of BM and HFM provided 50% of the protein in diets fed to lactating cows fitted with ruminal, duodenal and ileal cannulae (Waltz, et al., 1989). There was no effect of protein source on OM, fiber or nonstructural carbohydrate digestion in the rumen. Use of HFM or a 50-50 combination of BM and HFM decreased dietary protein degradation in the rumen and increased amino acid flow to the duodenum compared to SBM (Table 5). However, only the BM + HFM diet increased total and essential amino acid absorption from the small intestine. Amino acids reaching the small intestine from the HFM diet were less available than those from the other diets. This is consistent with observations by Rathmacher and Perry (1989) who determined that HFM-N was less digestible (64.0%) compared with other supplemental proteins averaging 70.9%. Failure of the BM diet to produce a significant decrease in protein degradation or an increase in amino acid supply to the small intestine in the study by Waltz et al. (1989) was possibly due to difficulties with sorting and feed refusal by animals fed this diet. It is important to note that calculated DM intake of BM would have been 1.54 kg/d (3.4 lb/d) which is extremely high, and therefore may have caused palatability problems with this diet. However, despite the lower intake of total amino acids with this diet, flow and absorption of amino acids from the small intestine was similar to SBM. This suggests that, if the intakes had been equal, the BM diet would have increased the supply of available amino acids provided to the small intestine or that SBM can be replaced with a smaller amount of BM without reducing amino acid supply to the animal.

Fish Meal. Although FM is generally resistant to microbial degradation in the rumen, there are considerable differences in degradability of various fish meals due to processing. Mehrez et al. (1980) found that the largest single factor influencing degradability was the length of time that fish was stored prior to processing, which increased degradability by 14 percentage units. This is due to enzymatic and bacteriological changes that take place in fish postmortem, causing proteolysis of fish muscle which leads to a higher soluble protein in the FM and an increase in degradability. Heat used in the drying process of fish protein can induce formation of S-S cross-linking from -SH oxidation (Opstvedt et al., 1984). Fish protein heated for 20 min at temperatures ranging from 50°C to 115°C showed a linear decrease in the content of -SH (sulfhydryl) groups and a concomitant increase in the content of S-S (disulfide) bonds. The amino acid most affected during heating of fish protein is cysteine. Opstvedt et al. (1984) determined that heating at 115°C caused a loss in cysteine and cystine. At temperatures of 95°C or greater, protein and amino acid digestibility of fish protein in rainbow trout was reduced compared to raw fish protein. Moderate heat, as used in the processing of FM, can result in a decrease in the rate of ruminal proteolysis of fish protein due to a large number of disulfide bridges (Chen et al., 1987). Other processing factors affecting ruminal microbial degradation of FM protein are the amount of solubles added back to the product and the type of fish used to produce the FM. Yoon and Crooker (unpublished data) showed that the

addition of high solubles to FM increased protein degradation by approximately 50%. Using the in situ N disappearance data of Sticker et al. (1986) and the equation of Mathers and Miller (1982) at k_r = .05 h^{-1} for estimating protein degradability in the rumen, degradation of Maine herring and Mexican anchovy FM was calculated to be approximately 40% lower than Menhaden FM.

Hoover et al. (1989) examined the effects of various forms of FM on microbial metabolism in continuous culture of rumen contents. Fish meals were: FM containing 34.4% free fatty acids, FM containing 34.4% free fatty acids with $CaCl_2$ added, FM containing 65.6% free fatty acids and defatted FM. With pH maintained at 6.2, the inclusion of any FM except the defatted FM greatly reduced the acetate:propionate ratio and microbial CP production and efficiency were impaired. Because these effects were not shown when the diet was prepared with defatted FM, the effects were probably due to the fatty acid content of FM. Protein degradation was also greater for the defatted FM diet than other FM diets. Similarly, Calsamiglia et al. (1992) observed a lower acetate:propionate ratio with a diet containing FM versus SBM. However, they showed no differences in microbial CP production and efficiency between dietary treatments. Reductions in microbial CP flow to the duodenum with FM supplementation have been observed in vivo with cattle (Rooke and Armstrong, 1987; Zerbini et al., 1988; Titgemeyer et al., 1989) and sheep (Hussein et al., 1991). In contrast, Dawson et al. (1988) noted an increase in total microbial CP flow to the duodenum when FM was added to an all silage diet fed to steers.

Intake of amino acids was greater when cows were fed a SBM diet compared with a FM diet, but total flows of amino acids to the duodenum were similar for both diets (Zerbini et al., 1988). Greater quantity of protein leaving the rumen undegraded in cows fed FM compared with SBM was counterbalanced by less microbial protein synthesis in the rumen. A similar response in total amino acid flow was detected by Hussein et al. (1991) in lambs fed SBM vs FM as the protein supplement. Rooke and Armstrong (1987) found that as FM was added to diets fed to cattle, the quantity of amino acid-N increased and the amino acid composition of the duodenal digesta changed such that the content of arginine increased and isoleucine decreased. Dawson et al. (1988) also observed an increase in flow of amino acids to the duodenum of steers with FM supplementation.

Titgemeyer et al. (1989) evaluated the value of SBM, corn gluten meal (CGM), BM and FM in supplying amino acids to steers. They showed that decreases in bacterial CP compared to a basal diet were greatest when FM was fed, followed by CGM, BM and SBM. Fish meal supplied more total amino acids to the duodenum than SBM, whereas BM and CGM supplied the greatest amount. However, these latter two protein sources were quite different in the amounts of individual amino acids that escaped ruminal degradation. Blood meal supplementation led to larger increases in lysine, histidine, arginine and valine, whereas CGM resulted in more methionine, isoleucine, leucine and tyrosine supplied to the duodenum. Goedeken et al. (1990) calculated amino acid flow to the small intestine based on in situ amino acid degradation and found that BM increased lysine flow and HFM increased sulfur amino acid flow. Based on these types of observations, Titgemeyer et al. (1989) concluded

that combinations of protein sources may be best able to supply the individual amino acids required by the ruminant animal in optimal proportions.

CONCLUSIONS

In general, research with high ruminal bypass protein sources indicates the potential for their use. However, results from studies examining the impact of high ruminal bypass proteins on animal performance have been variable. Possible reasons for the lack of response in animal performance include: low production potential of animals, stage of lactation, type of diet fed, level of feeding, decreased microbial protein synthesis, specific amino acid limitations, inadequate protection of protein supplements and overprotection of protein supplements rendering protein indigestible in the small intestine. In many cases, much of the dietary protein is naturally high in bypass protein (e.g., corn, corn silage) or the level of undegradable intake protein in the control diet is already adequate. Some studies have also used experimental animals in a lower productive state, e.g., non-pregnant, mid to late lactation or mature ruminants where protein requirements are low or where energy intake is restricted. In order to elicit an animal response to high ruminal bypass protein, two main criteria must be satisfied. First, the animal must be capable of a response; that is, microbial protein should be insufficient to meet the host animal requirement. Secondly, protection must be effective in increasing amino acid supply to the host animal. The bottom line in feeding high ruminal bypass protein sources may not necessarily be improved performance which would be desirable, but may be dependent on whether smaller quantities of high bypass protein can be fed to replace protein without deleteriously affecting performance. Also, if equal amounts of protein are to be fed, another major consideration would be cost per unit of protein.

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Table 1. Contribution of microbial protein to total protein requirement of the lactating dairy cow.[a]

Efficiency of microbial synthesis, g N/kg OM truly digested[b]	Theoretical contribution of microbial protein when milk production (kg) equals:		
	25	35	45
	----------	%	----------
20	45	40	37
30	68	59	55
40	91	79	73

[a]Requirements determined using NRC (1989).
[b]Assumed that 50% of OM intake is truly digested in the rumen.

Table 2. Daily amino acid intake, flow and digestion in the digestive tract of cows fed diets containing various soybean sources.[1]

	Diets containing:			
			Whole soybeans extruded at	
Amino acid	Soybean meal	Whole soybeans	132°C	149°C
Intake (g/day)	2081	2064	2085	2097
Degradation in the stomach (% of intake)	71.7[a]	73.5[a]	58.7[b]	57.7[b]
Flow to duodenum (g/day)				
Total	2265[a]	2090[b]	2314[a]	2361[a]
Bacterial	1679	1535	1456	1476
Bypass	586[a]	554[b]	857[a]	885[a]
Absorption from small intestine,				
(g/day)	1617[ab]	1459[b]	1749[a]	1777[a]
(% entering)	71.4[b]	69.8[b]	75.7[a]	75.4[a]

[1] Adapted From Stern et al. (1985).
[a,b] Means in the same row not having a common superscript differ ($P<.05$).

Table 3. Effect of calcium lignosulfonate-treated soybean meal on carbohydrate and nitrogen metabolism by ruminal bacteria.[1]

Item	Diets[a]			
	1	2	3	4
NH_3-N (mg/100 ml)	5.14[b]	4.17[cd]	4.36[c]	2.82[d]
VFA (mol/d)	.35[b]	.32[bc]	.29[c]	.30[c]
Digestion (%)				
True organic matter	52.3[b]	50.6[b]	45.5[bc]	42.4[c]
Protein	75.7[b]	69.0[bc]	58.4[c]	57.5[c]
Nonstructural carbohydrate	91.7	88.9	86.7	84.3
Cellulose	28.5[b]	20.5[bc]	20.6[bc]	11.0[c]
Effluent N (g/d)				
Ammonia	.129[b]	.104[cd]	.110[c]	.097[d]
Bacterial	1.95[b]	1.76[b]	1.46[c]	1.46[c]
Bypass	.72[c]	.94[bc]	1.24[b]	1.27[b]

[1] Adapted from Stern (1984).
[a] Diet 1, pelleted SBM without any CL addition; Diet 2, CL included in pelleting process at 4 g/100 g SBM; Diet 3, modified CL included at 4 g/100 g SBM; Diet 4, CL included at 8 g/100 g SBM.
[b,c,d] Means in the same row not having a common superscript differ ($P<.05$).

Table 4. Daily amino acid intake, flow and absorption from the small intestine of cows fed soybean meal or meat and bone meal.[1]

Amino acid	Soybean meal	Meat and bone meal
	------- g/d -------	
Intake	1,759	1,886
Flow to duodenum	1,927	2,213
Absorption from small intestine		
Total[a]	1,459	1,712
Essential amino acids[a]	649	746

[1] Adapted from Metwally (1989).
[a] Mean values differ ($P<.05$).

Table 5. Ruminal protein degradation and amino acid supply to the small intestine of cows fed diets containing soybean meal, blood meal, feather meal and a combination of blood meal and feather meal.[1]

	Protein source			
	Soybean meal	Blood meal	Feather meal	Blood meal + feather meal
Ruminal CP degradation, %	53.2[a]	43.1[ab]	32.5[b]	36.7[b]
Amino acid				
Intake, g/d	2,481[a]	2,205[b]	2,475[a]	2,552[a]
Flow to duodenum, g/d	2,131[b]	2,097[b]	2,642[a]	2,524[a]
Absorption from small intestine, g/d	1,588[b]	1,647[ab]	1,727[ab]	1,873[a]
Absorption from small intestine, %	74.5[ab]	78.5[a]	65.4[b]	74.2[ab]

[1] Adapted from Waltz et al. (1989).
[a,b] means in the same row without a common superscript differ ($P < .05$).

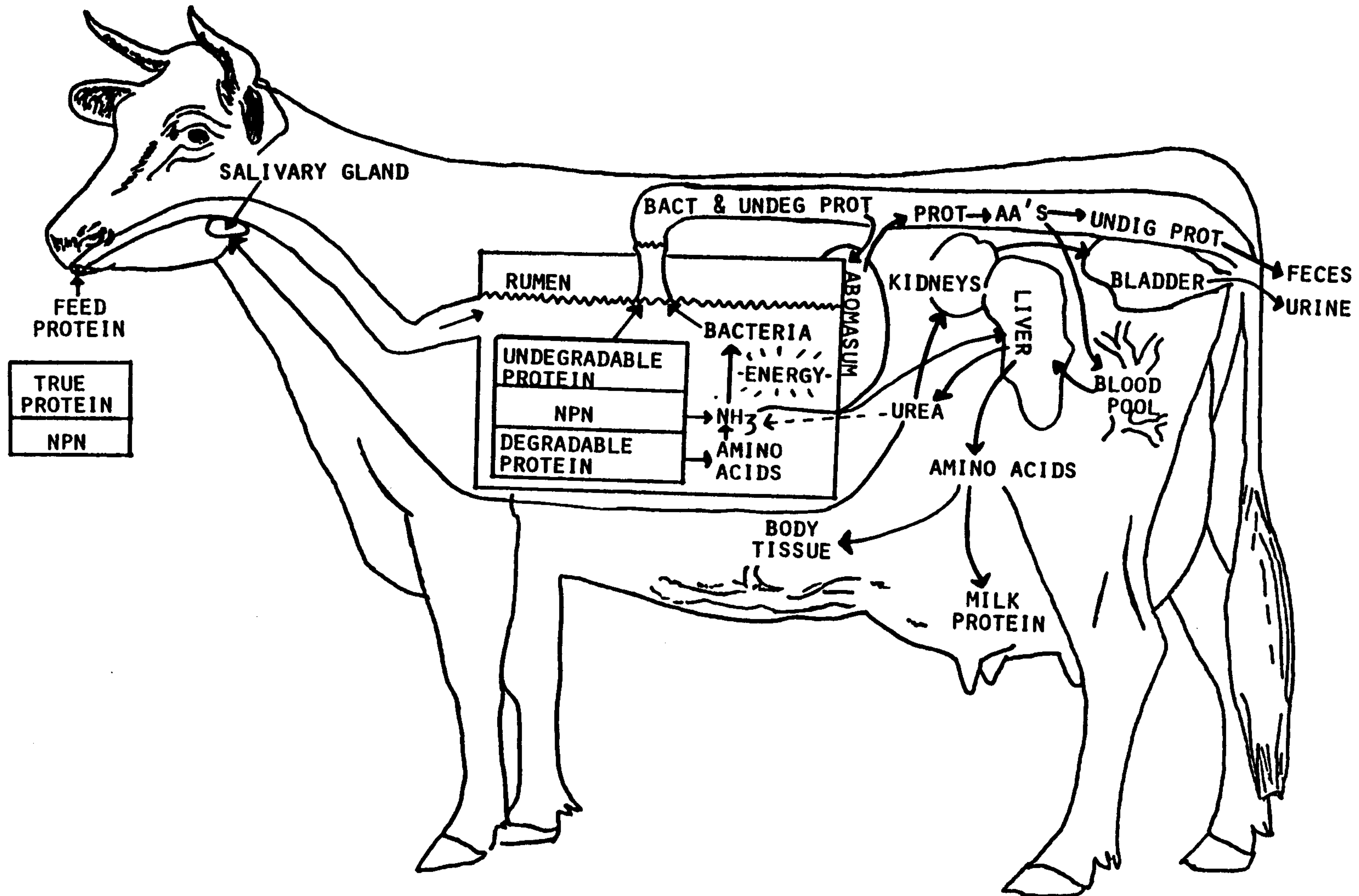

Figure 1. Schematic summary of protein metabolism in the lactating dairy cow.

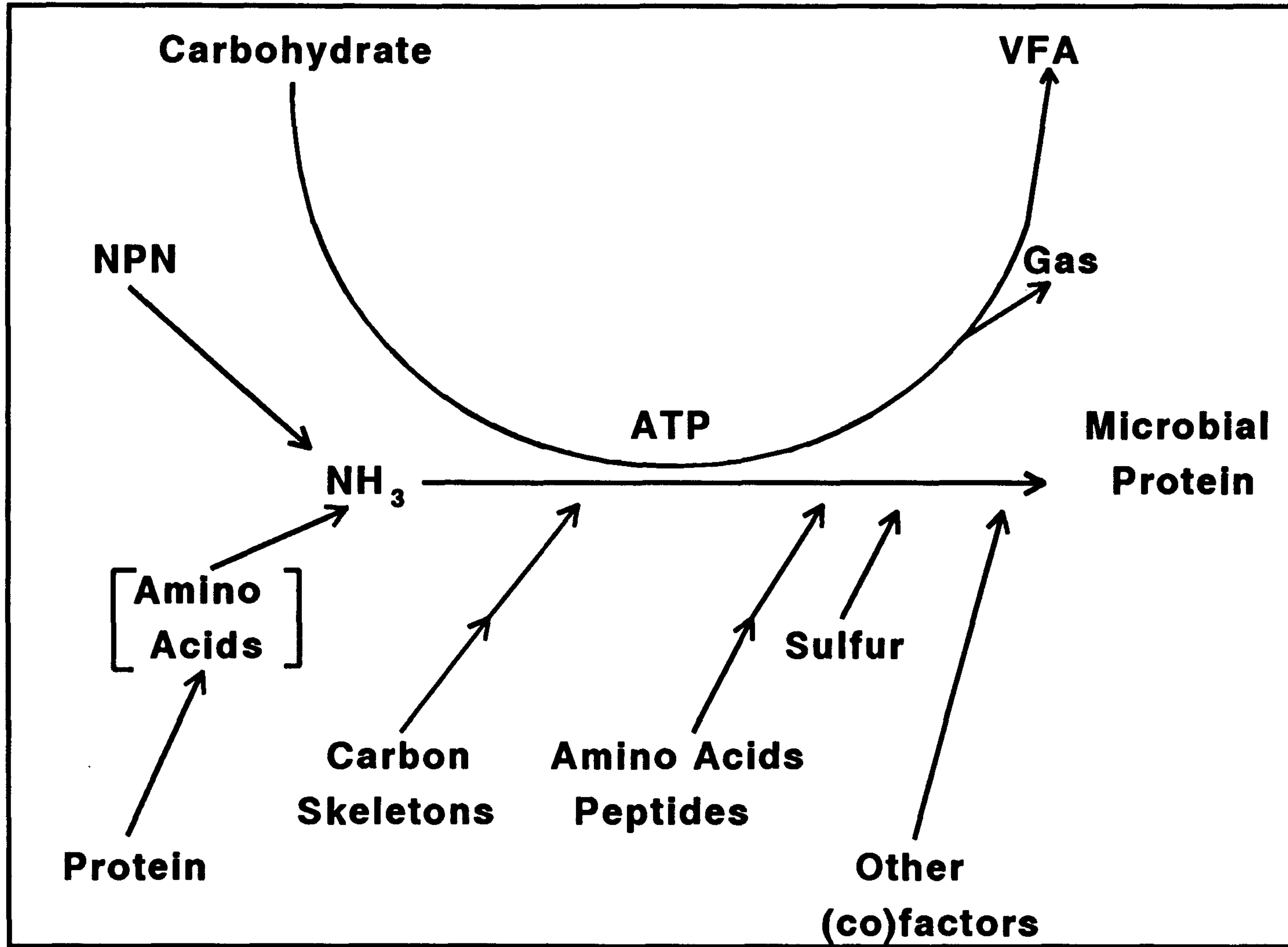

Figure 2. Microbial protein synthesis in the rumen (adapted from Owens and Zinn, 1988).

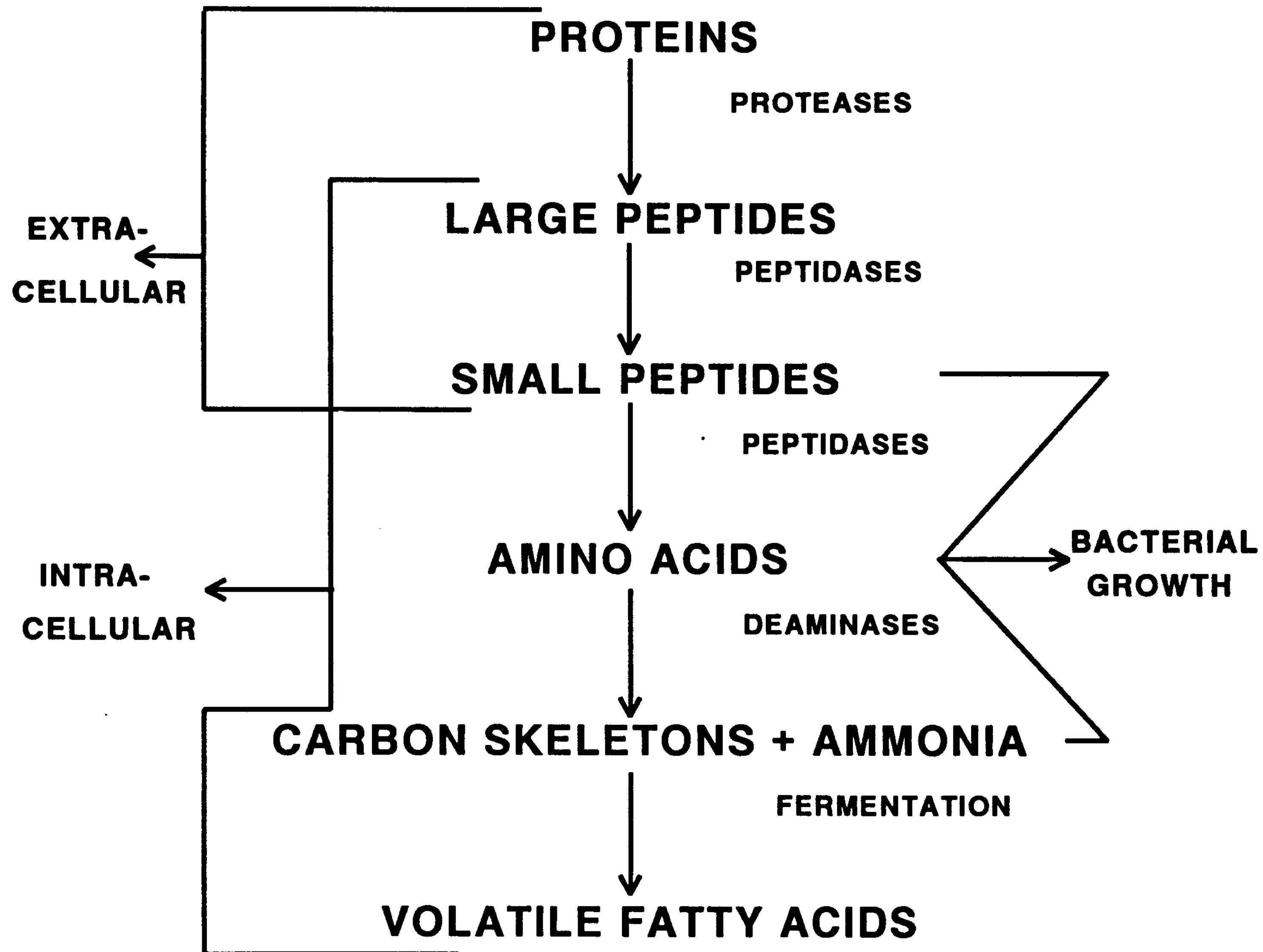

Figure 3. Protein degradation and fermentation in the rumen (adapted from Cotta and Hespell, 1986).

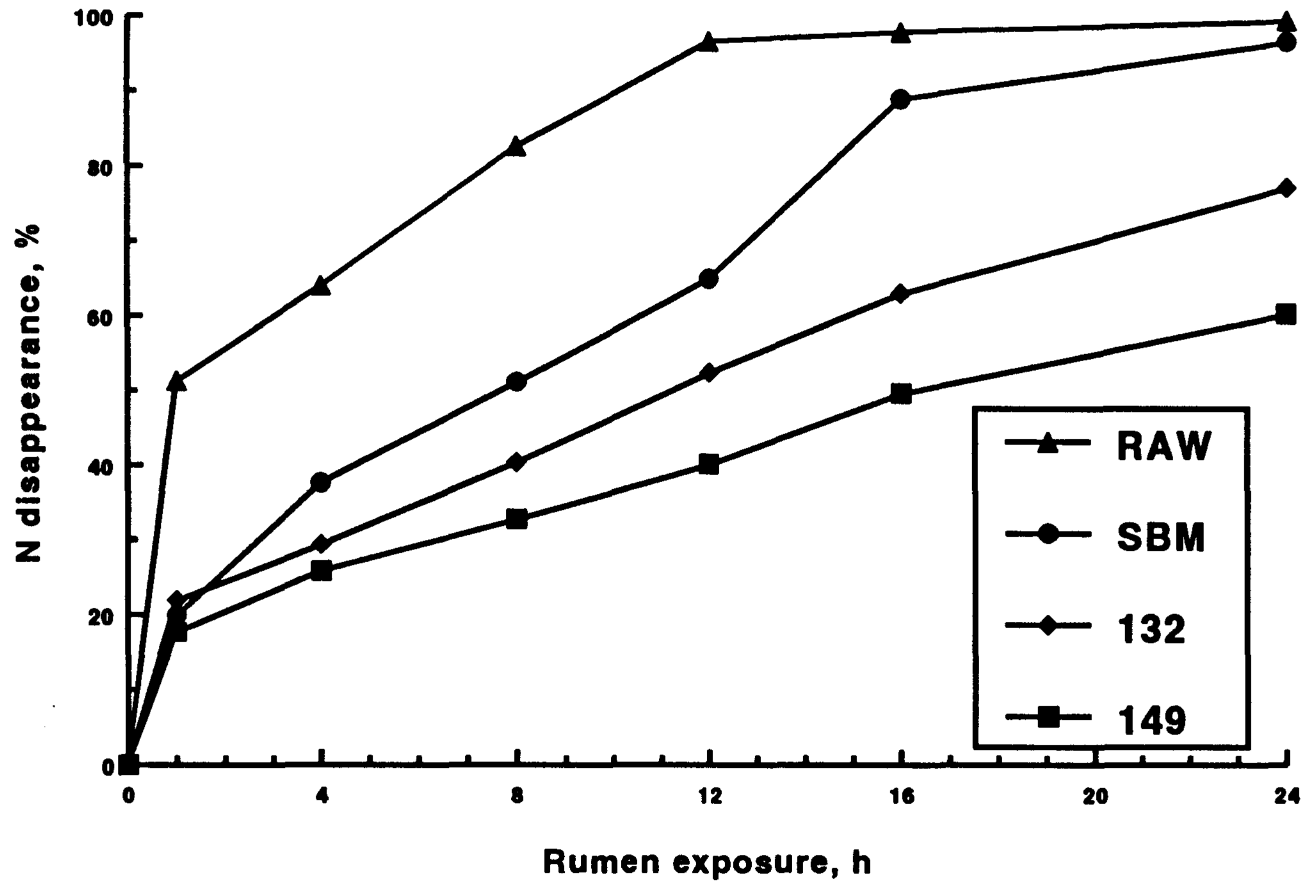

Figure 4. Nitrogen disappearance from Dacron bags suspended in the rumen containing soybean meal (SBM), whole soybeans (RAW) or whole soybeans extruded at 132C (132) or 149C (149).

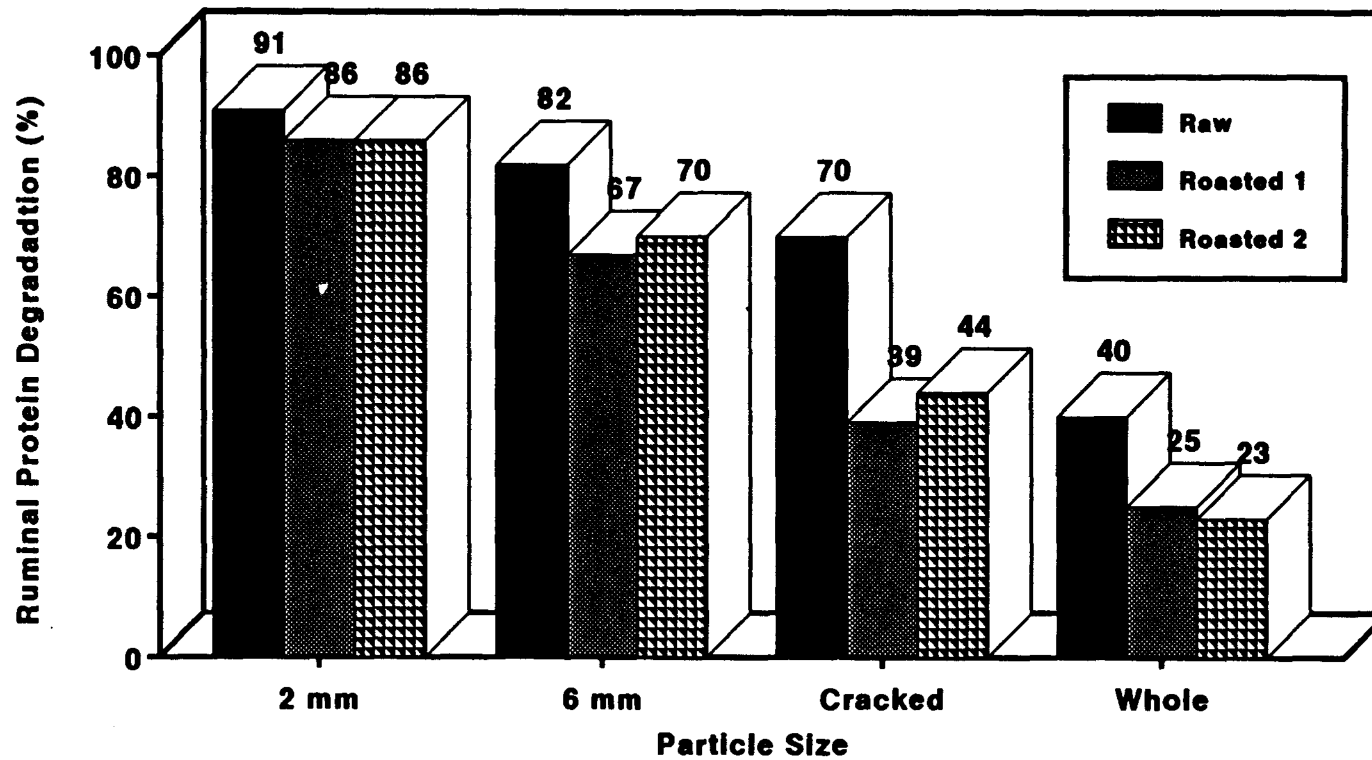

Figure 5. Influence of particle size on ruminal protein degradation of raw and roasted soybeans (Mansfield and Stern, unpublished data).

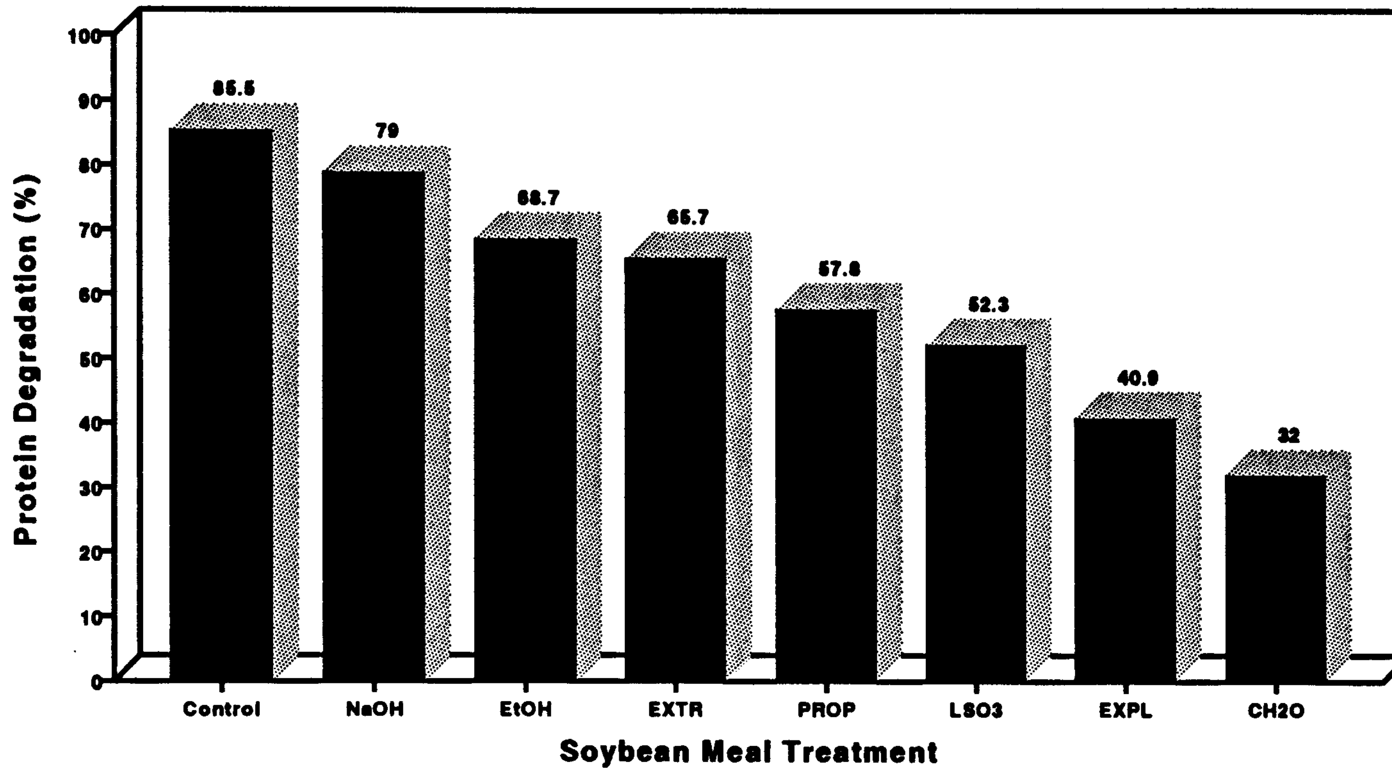

Figure 6. Extent of ruminal protein degradation of solvent extracted soybean meal (control), soybean meal treated with sodium hydroxide (NaOH), ethanol (EtOH), formaldehyde (CH2O), expeller processed (EXPL),propionic acid (PROP), extrusion (EXTR) and calcium lignosulfonate (LSO3).

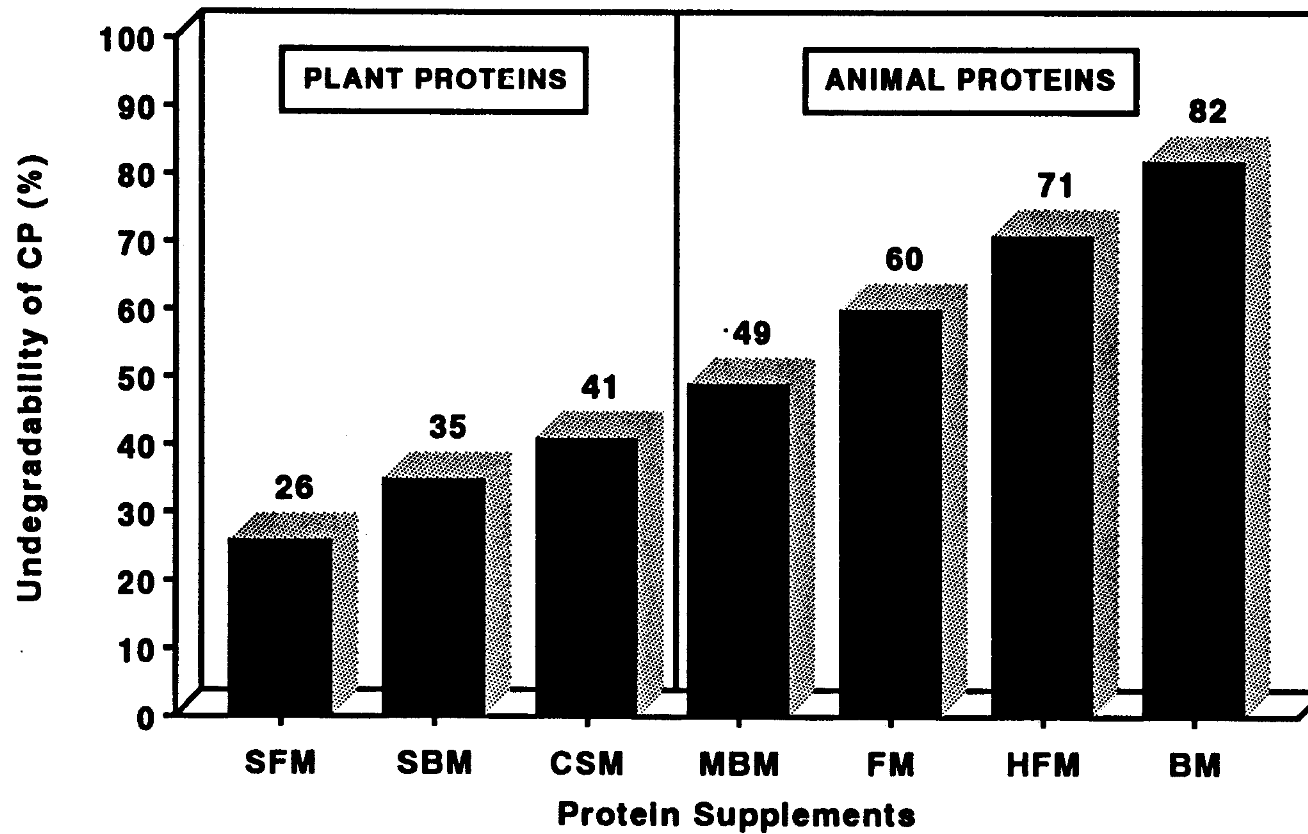

Figure 7. Ruminal undegradability of protein (NRC, 1989) of sunflower meal (SFM), soybean meal (SBM), cottonseed meal (CSM), meat and bone meal (MBM), fish meal (FM), hydrolyzed feather meal (HFM) and blood meal (BM).