

Optimizing Performance of Cattle by Increasing the Digestion of Forages with Protein Supplementation

Francis L. Fluharty, Ph.D.
Department of Animal Sciences
The Ohio State University

Ruminant animals in grazing situations need to maximize forage digestion in order to increase performance parameters such as average daily gain or milk production. Factors that limit the animal's ability to reach production goals may include the forage's energy and protein content, or availability. These factors are impacted by the forage species, maturity, lignin concentration, and ruminal ammonia requirements of cellulose digesting bacterial species. In recent years, degradable intake protein (DIP) has been reported to be the first-limiting nutrient for beef cattle grazing low-quality forages (Köster et al., 1996; Olson et al., 1999; Bandyk et al., 2001). However, unlike grain-based diets, there is a time period, referred to as the lag phase, required for cellulose digesting bacteria to attach to forage particles. This creates a situation where protein availability in the rumen must match the timing of energy availability in order to achieve optimum microbial digestion.

Several factors have been shown to alter bacterial degradation of protein, and, in turn, the amount of microbial protein reaching the ruminant small intestine. In production situations where energy is limiting, either because of relatively low-quality forage such as native tall grass prairie, mature fescue, or corn stover, etc., or in production situations where there is reduced dry matter intake, microbial protein reaching the small intestine may be insufficient to maximize animal growth, and ruminally undegradable intake proteins (UIP, or bypass protein) may be warranted, (Firkins and Fluharty, 2000). The daily microbial yield to the ruminant animal is a product of the efficiency with which microbes are synthesized and presented post-rationally to the small intestine where they are absorbed as amino acids. This is usually defined as microbial nitrogen synthesized per kilogram of organic matter fermented in the rumen, and the total kilograms of organic matter fermented in the rumen per day (Hoover and Stokes, 1991). The efficiency of microbial protein synthesis is a major factor affecting the overall amino acid requirement of ruminants, and is influenced by a number of factors including; 1) energy source, 2) supply of nutrients such as nitrogen, sulfur, branched chain fatty acids, and 3) ruminal environmental characteristics such as dilution rate, pH and microbial species present in the rumen (Hespell and Bryant, 1979). An average efficiency of microbial synthesis of 17 grams of microbial protein per 100 grams of digestible organic matter was determined for many diets, although values were generally higher for sheep compared with cattle, and forage-based diets compared with grain-based diets (Bergen et al., 1982). The key factor to consider is 'digestible organic matter', therefore, a mature forage with less potential digestibility will result in less microbial production compared with a more immature forage with less lignin and more potentially digestible organic matter. In this situation, two interrelated opportunities to increase the digestibility of the forage as a result of more microbial growth and a faster rate of digestion are: first, increasing the surface area of forage available for bacterial attachment and degradation

and second, increasing the amount of protein (or nitrogen, N) that rumen bacteria need in order to replicate.

As Hoover and Stokes (1991) pointed out, the ruminal microbial population achieves the highest growth rate when peptides, amino acids and ammonia are all present, even though all three may individually serve as sources of N for various microbes. Ruminal bacteria can supply a large part of the amino acids reaching the small intestine when high-energy diets are fed in conjunction with ruminally degradable protein. However, the energy and protein content of many crop residues or mature forages alters supplemental protein requirements. When energy and protein are limiting, there is a reduction in both the number of bacteria and the growth rate of bacteria, which results in a reduction in the amount of ruminal NH_3N that can be used for protein synthesis (Satter and Roffler, 1975). Several researchers have reported lower ruminal NH_3N concentrations when ruminal bypass proteins were fed compared with SBM in forage-based diets (Titgemeyer et al., 1989; Cecava et al., 1990; Hussein et al., 1991a; Sultan et al., 1992a). The lower ruminal NH_3N concentrations with ruminal bypass proteins would be expected in diets that are inherently low in CP, and that have a large proportion of their supplemental protein bypassing ruminal degradation. Additionally, total amino acid flow to the duodenum has been greater when ruminal bypass proteins have been fed compared with SBM (Cecava et al., 1988, 1990; Titgemeyer et al., 1989; Sultan et al., 1992b).

In diets based on crop residues, and low-quality or mature forages, sufficient evidence is available to justify feeding combinations of ruminally available (DIP) protein sources such as urea or soybean meal (SBM) in combination with UIP sources that mostly bypass rumen degradation but are available for enzymatic degradation in the small intestine if not over-heated during drying. Common sources of UIP include corn gluten meal (CGM), distillers grains (DG), feather meal (Fth), or fish meal (FM), or blood meal (BM). This is due to the fact that diets low in readily available carbohydrates and protein result in reduced microbial growth, so a greater percentage of the animal's protein presented to the small intestine must come from non-microbial sources, or a deficiency in amino acids reaching the small intestine may limit animal production. One way to make more of the cellulose and hemicellulose, the primary carbohydrates in forage, available would be to grind the forage and thereby increase the amount of carbohydrates available for immediate attachment by bacteria. However, in many production situations, it is not possible or feasible to grind forage. In these situations, it is simply more economical and easier to provide N for the ruminal bacteria and use bypass protein sources, in combination, to maximize performance.

Ruminants have the ability to recycle N in the rumen, which reduces the amount of DIP that needs to be fed to meet the bacteria's requirement for N for growth. However, N recycling differs greatly between diets. Nitrogen recycling in the rumen provided 38 and 49% of N intake for SBM and BM supplemented wheat straw diets that contained 10.2% CP, and its' subsequent flow to the duodenum was equivalent to providing additional N to the animal (Sultan et al., 1992a). The regulatory factors for increased N recycling in the rumen are lower ruminal NH_3N concentrations and greater organic matter digestion. Therefore, ruminants fed slowly degraded protein sources in crop residue-based diets benefit from both an increased supply of protein to the small intestine and increased conservation of N through N recycling (Sultan et al., 1992a). However, total microbial N flow to the duodenum increased when SBM was added to the diet

compared with CGM/BM combinations (Cecava et al., 1990, 1991) FM (Hussein et al., 1991b), or BM (Sultan et al., 1992b) demonstrating the benefit of using combinations of DIP and UIP.

When DIP sources of protein are fed, the profile of amino acids entering the small intestine closely resembles microbial protein, and amino acids that are limiting in bacterial protein will probably be limiting to the ruminant's production capability (Willms et al., 1991). Additionally, Titgemeyer et al. (1989) reported that SBM, CGM, BM, and FM varied greatly in their ruminal degradability and the quantities of individual amino acids, and all were a poor source of at least one of the essential amino acids. Therefore, supplying combinations of DIP and UIP could best meet the animal's amino acid requirement.

Protein supplementation costs can be reduced if a portion of the DIP comes from non-protein nitrogen (NPN) sources such as urea $[(\text{NH}_2)_2\text{CO}]$ or biuret $(\text{NH}_2\text{CONHCONH}_2)$. In fact, cellulolytic bacteria prefer ammonia (NH_3) as their N source (Russell et al., 1992), so substituting NPN for a portion of the degradable true protein in supplements for range cows should be a viable option (Köster et al., 2002). Urea has a protein equivalent of 287% protein equivalents on a dry matter basis (NRC, 1996). However, urea hydrolyzes rapidly to ammonia and carbon dioxide (CO_2) (Helmer and Bartley, 1971), and can result in ammonia toxicity if consumed in large quantities in a short time period (Bartley et al., 1976). At high levels, .44 gm/kg of body weight, urea is almost always fatal, unless acetic acid is administered at levels of one mole of acetic acid / 1 mole of urea within 3 hours, because the acetic acid lowers the pH of the rumen, slowing the rate of absorption of urea into the blood (Word et al., 1969). Additionally, Williams et al. (1969) and Rush et al. (1976) reported reduced performance in cattle receiving NPN-based supplements compared with cattle receiving true-protein supplements. However, in those studies, NPN was a high proportion of the total supplemental N, and in the case of Rush et al. (1976), was used in conjunction with molasses-based supplements. The basal rations that Williams et al. (1969) used contained 4% or 12.1% urea and was not consumed every day, and Rush et al. (1976) fed 30% protein supplements with half of the CP coming from NPN. Rush et al. (1976) reported that rumen biuretolytic activity was apparent within 6 days, reached a high level of activity within 20 days, and continued through the 74 day feeding period. Furthermore, Rush et al. (1976) reported that cows fed biuret refused less feed than cows consuming urea and suggested that the slower hydrolysis of biuret resulted in an ammonia release rate more comparable to the rate of energy release from the mature forage being consumed. In another series of studies, urea or biuret provided 50% of the nitrogen in 30% CP dry supplements, or urea provided 94% of the nitrogen in 30% CP liquid supplements with molasses. In these studies, cow winter weight loss, cow summer weight gain, and calf performance were not different ($P > .50$) for cows fed natural protein or liquid supplements (Rush and Totusek, 1976).

Hersom (2007) suggested that the improvement in performance which occurs with the addition of protein to diets of ruminants being fed low-quality forage occurs due to a correcting of a protein/N deficiency in the diet, resulting in a better synchronization of the supply of energy and protein in the rumen, and in many cases occurs regardless of the source of protein, although increasing the proportion of natural protein often improves animal performance. Currier et al. (2004a) used cows in the last third of gestation to compare the difference between urea (5.2% of supplement dry matter) or biuret (6.1% of supplement dry matter) in diets where NPN treatments

were formulated to provide 90% of the estimated DIP requirement, with the supplements being fed at .04% of the cows' body weight per day, or roughly .5 lb/d for a 1250 pound cow. Both NPN sources resulted in greater positive weight and body condition score (BCS) changes compared with the control group, and calf birth weight was not affected by NPN supplementation or NPN source, and the authors concluded that ruminants consuming low-quality forage can effectively use supplemental NPN to maintain nitrogen status and performance in both hand-fed and self-fed situations. In a concurrent study with steers consuming low-quality forage, these same diets were used in daily or alternate-day supplementation, and did not adversely affect forage intake, nutrient digestibility, site of digestion, or microbial efficiency compared with unsupplemented animals (Currier et al., 2004b), and ruminal pH never fell below 6.3, suggesting that it would not negatively affect fiber digestion (Currier et al., 2004c). These findings would support the conclusion of Köster et al. (2002) that urea could replace between 20 and 40% of the DIP in high-protein supplements, containing 30% protein, without significantly altering supplement palatability or cow and calf performance. In summary, supplying combinations of DIP and UIP could best meet the animal's amino acid requirement through maximizing microbial growth and cellulose digestion, as well as providing amino acids from both microbial and feed origin to the small intestine.

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