PRECISION NUTRITION FOR RUMINANTS

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Introduction

Ruminant livestock produce high quality protein from feedstuffs of little or no value for humans. Microbial protein synthesis in the fore-stomachs meets much of the animal's amino acid (**AA**) requirement, further reducing ruminant competition for dietary protein. Supplementing starchy feed stimulates microbial protein formation, decreasing urinary excretion of environmentally labile urea N. Large responses to grain supplements in dairy cattle grazing high quality pastures (Wales et al., 2009) or consuming hay-crop silages (Charbonneau et al., 2006) confirm the effectiveness of this strategy. Approaches increasing animal productivity succeed by diluting out the nutritional and environmental costs of maintenance. The need to capture economies of scale has favored larger livestock enterprises in developed nations. However, the law of diminishing returns as it applies to increasing supplementation is often ignored. Recent research indicates that there is widespread over-feeding of protein to ruminants, especially dairy cattle; milk and component yields can be maintained, and sometimes increased, with reduced crude protein (**CP**) intake. Findings of this type have stimulated interest in precision feeding: combining feed analysis with nutritional models to accurately meet the animal requirements. Although the small-holder ruminant enterprises concentrated in tropical and semi-tropical regions of developing countries are subject to different economic and environmental pressures, it is clear that nutritional models can also be used in those settings to improve animal productivity. This paper will emphasize mainly precision feeding for improving protein efficiency of ruminants, particularly dairy cattle.

Amino Acid Requirements of Ruminants

The primary importance of ruminant livestock is to provide high quality protein for human diets. As in all organisms, the genetic code dictates proportions of the 20 AA utilized for protein synthesis in ruminant tissues. Nine protein AA cannot be formed in cellular metabolism and must be absorbed from the gastro-intestinal tract; these "essential" AA (**EAA**) are abbreviated His, Ile, Leu, Lys, Met, Phe, Thr, Trp and Val. Another AA, Arg, is synthesized in the urea cycle and, hence, is not strictly an essential nutrient; however, dietary Arg supplementation may improve protein efficiency in some non-ruminant species when tissue synthesis is inadequate (Ball et al., 2007). Two other AA, Cys and Tyr, spare Met and Phe requirements because those 2 EAA are used partly to synthesize Cys (Met) and Tyr (Phe). Thus, Arg, Cys and Tyr are called "semi-essential" AA. The remaining 8 AA are referred to as "non-essential". Protein quality refers to EAA pattern: the relative proportions of each EAA in feed protein and how well these correspond to animal requirements. Rumen microbial protein has better quality than many common feeds in ruminant diets (Schwab, 1996) because it more closely matches the AA composition of meat and milk. In addition, microbial ammonia assimilation allows the feeding of some nonprotein N (**NPN**), such as urea, as well as capture of some recycled urea N that would otherwise be excreted in the urine.

Nutritional Models for Ruminants

It has been known for more than 60 years that, in highly productive ruminants such as lactating dairy cows, microbial protein synthesis is insufficient in itself and the animal depends partly on rumen-undegraded protein (**RUP**) for additional metabolizable protein (**MP**, the protein absorbed as AA from the small intestine). Thus, it is necessary that ration formulation models quantify both microbial protein formation plus RUP contributed by the diet when estimating MP supply. Early models were simplistic, applying static constants in predicting microbial protein and RUP. However, it soon became obvious that protein digestion and metabolism are complex and dynamic, and rationing models have evolved to keep pace with this new understanding. The review of Tedeschi et al. (2015) gives an excellent description of the evolution of protein and AA models that have been developed for cattle. The most recent nutritional models for ruminants released by the National Research Council of the U.S. are those for beef cattle (NRC, 2000), dairy cattle (NRC, 2001) and sheep and other small ruminants (NRC, 2007). Important nutritional models developed in Europe include the French PDV system (Martin and Sauvant, 2007), Feed into Milk from the U.K. (Thomas, 2004), NorFor from the Nordic countries (Volden, 2011), the Dutch DVE/OEB system (Tamminga et al., 2007), the German system (GfE, 2001), plus AminoCow, a free model available from the Evonik company (AminoCow, 2015). The current version of the Cornell model (Higgs et al., 2015; Van Amburgh et al., 2015) is also widely applied in North America and frequently updated. Currently, there are efforts to update both the NRC dairy and French PDV models.

Hanigan (2005) compared the NRC and Cornell models to 3 others and concluded that NRC (2001) was somewhat more accurate at predicting MP supply. However, a recent comparison of rumen protein flows, measured by omasal sampling, with NRC (2001) predictions indicted that NRC (2001) overestimated RUP, underestimated microbial protein, but closely approximated total MP flow (Broderick et al., 2010). Predictions of milk protein yield, made using the NRC (2001) and NorFor models, were compared to milk protein yields observed in 5 feeding studies in which 21 different diets were fed (Broderick and Åkerlind, 2012). Although both models estimated similar MP flows, NorFor more reliably predicted observed milk protein secretion; NRC (2001) underestimated yield at low MP supply. The NorFor model may have proved more reliable because it applies reduced efficiencies of MP utilization with increased MP supply. Lapierre et al. (2007) concluded that the NRC assumption of a constant 67% efficiency of MP utilization explains why its relatively accurate predictions of MP supply do not give rise to more reliable predictions of milk and protein yield. Despite its apparent limitations, modified versions of NRC (2001) continue to be widely applied in commercial practice (Darin Bremmer, 2016, personal communication). Dairy diets are often high in total CP and NPN (from hay-crop silages); frequently, large responses occur with RUP supplements, such as heat-treated soy protein (Faldet and Satter, 1991) or fishmeal (Broderick, 1992) on such diets. We observed substantial responses to 3 true proteins that differ in RUP (Brito and Broderick, 2007; Brito et al., 2007): Flow of RUP and total protein from the rumen was greatest on cottonseed meal, intermediate on canola meal and lowest on soybean meal; however, protein and fat yield were highest on canola meal, intermediate on soybean meal, and lowest on cottonseed meal. Lower component yields probably resulted from the poorer EAA quality of cottonseed meal RUP. Broderick et al. (2015) took advantage of relatively high RUP and Met contents in canola meal to show that, when it replaced equal CP from soybean meal, milk and milk protein yields were increased.

Identifying Limiting Amino Acids for Milk Production

As discussed, ruminants require EAA rather than MP to synthesize proteins and the EAA most often limiting essential for lactating dairy cows are Met, Lys and His. Identification of Met and Lys as limiting in MP supply derived largely from abomasal infusion studies. For example, the early work of Schwab et al. (1976) showed that infusion of only Lys plus Met into cows fed a low CP diet based on maize silage and grain gave on average 43% of the milk protein yield response obtained with infusion of either casein or all nine EAA plus Arg. An assessment of research reported between 1976 and 1996 led Schwab (1996) to conclude that Met and Lys were the 2 EAA most likely to be limiting on “conventional diets” based on maize and hay-crop silages, maize grain plus soybean meal and distillers grains. Dairy cows fed grass silages that supply relatively little RUP (i.e., when cows depend mainly on microbial protein for their MP) appear to be first-limitng in His (Vanhatalo et al., 1999; Korhonen et al., 2000). The suggested, “ideal ratio” of Lys:Met in MP is 3.0 (NRC, 2001). Enhanced production with increased RUP in the studies cited above likely occurred because of better EAA pattern, perhaps more complementary to microbial protein (Broderick, 1994), in RUP supplied by fishmeal and canola meal. Commercial availability of rumen-protected Met (**RPM**) and rumen-protected Lys (**RPL**) make it possible to supplement one or both of these potentially limiting EAA. An early application of this approach was that of Donkin et al. (1989) who showed increased yield of milk protein and milk concentration of total protein and caseins with supplementation of RPM plus RPL. A rather large literature has developed since those early studies. Thus far, responses to RPM have been more consistent than to RPL, even though significant responses have been observed in a number of studies with abomasally infused Lys alone. Lower stability of early RPL preparations may partly explain the poor responses to RPL materials. However, difference between RPM and RPL responses may also be related to the relative amounts of Met and Lys required by the animal. A shortfall in supply of 15 g/d of Lys would be a deficiency of similar magnitude to 5 g/d of Met. Because of greater stability, Lys is marketed as the HCl salt; this increases its equivalent molecular mass from 146 to 183 g/mol, thus requiring 25% more substance to deliver the same amount of effective compound. Note that the racemic mixture, DL-Met, serves about as well as all L-Met in the animal because of efficient conversion of the D- to L-isomer; 100% L-Lys must be provided because the D-isomer of Lys is not utilized for protein synthesis. Recently, we obtained significant improvement in milk yield when feeding RPL as Ajipro-L® (Ajinimoto Company) on a diet containing maize gluten meal plus maize distillers grains as protein supplements (Lobos et al., 2014).

There have been many feeding studies with RPM and RPL and readers are directed to recent reviews on RPM and RPL supplementation of dairy cows (Vyas and Erdman, 2009; Robinson, 2010). Patton (2010) meta-analyzed 37 different trials, comparing responses to 2 commercial RPM products, Smartamine M and Mepron; the average response was an increase of 27 g/d of milk true protein to an estimated 10 g/d of absorbed Met. If it is assumed that there is 3.7% Cys plus Met in milk protein (NRC, 2001), average Met recovery was about 10%. Although Patton (2010) concluded Mepron was somewhat more effective, this has been disputed (C. G. Schwab, personal communication). We observed similar responses in milk protein yield to RPM provided as Mepron (Broderick et al., 2008; 2009), Smartamine M (Chen et al., 2011) and Meta-Smart (Chen et al., 2011). The Met in Meta-Smart is in the form of isopropyl-2-hydroxy-4-(methylthio)-butanoic acid; this compound depends on rumen protection of the Met precursor as the isopropyl ester. Zanton et al. (2014) have reviewed responses to various chemical forms of RPM.

Reports of His being first-limiting EAA come mainly from Finnish trials in which lactating cows were fed diets based on grass silage plus cereal concentrates. In 2 studies, abomasal infusion of Met and Lys did not increase milk protein yield (Varvikko et al., 1999); however, abomasal infusion of His, either alone or in combination with Met and/or Lys, increased protein secretion by about 30 g/d (Vanhatalo et al., 1999). Moreover, this same group found a linear response in milk protein secretion with abomasal infusion of 0 to 6 g/d of His in lactating cows fed a similar dietary regime (Korhonen et al., 2000). Doelman et al. (2008) observed an increase in milk yield of 1.7 kg/d, and a tendency for increased protein yield, by including 2.5 g His/L in drinking water; cows drank 92 L/d, making a total His dose of 230 g/d. Although very little His would escape to the intestine, post-rumen supplementation via drinking water of very degradable, soluble substrates such as glucose (Osbourne et al., 2002) have been accomplished; however, the milk and protein yield responses were obtained with abomasal His infusion of only 6-8 g/d. Hadrova et al. (2012) found that duodenal His infusion in cows fed diets based on maize silage plus lucerne hay increased both milk and milk protein secretion. Relative to an MP-adequate control diet, Lee et al. (2012) compared diets that were MP inadequate without supplement, supplemented with RPM and RPL, or supplemented with RPM, RPL plus an experimental preparation of rumen-protected His. Feeding the MP inadequate diet depressed milk yield by 3.6 kg/d and protein yield by 120 g/d; however, supplementing RPM and RPL restored 90 g/d of protein yield and adding all 3 rumen-protected EAA gave milk and protein yield equivalent to the MP-adequate control diet. Feeding the 3 rumen-protected EAA allowed dietary CP to be reduced from 15.7 to 13.5%, reduced urinary N excretion from 143 to 97 g/d and increased apparent N efficiency (Milk N/N intake) from 29 to 34% (Lee et al., 2012). Recently, Giallongo et al. (2015) reported results confirming the observations of Lee et al. (2012).

The findings of Lee et al. (2012) and Giallongo et al. (2015) illustrate what will likely be the principal strategy used when balancing for EAA: supplementing with rumen-protected EAA when reformulating the diet to meet EAA requirements at reduced CP intake. This approach will decrease urinary N excretion and, because urinary N is the most labile excretory form of N (Misselbrook et al., 2005), will make dairy production more environmentally sustainable. The potential value of exploiting this strategy was also shown in German studies where supplementing RPM on 14.7% dietary CP resulted in milk protein secretion equal to that at 17.5% CP, and 31 versus 27% conversion of dietary N to milk N (Kröber et al., 2000). We obtained similar protein yield, and even greater yield of milk and fat-corrected milk, when RPM was added to diets containing 17.3 and 16.1% CP versus an 18.6% CP diet without RPM (Broderick et al., 2008). Moreover, production on 15.8% CP plus RPM was about equal to that on 17.1% CP without RPM in a later study (Broderick et al., 2009). Furthermore, we obtained similar improvement in a third trial in which the dietary treatments were fed continuously (Broderick and Muck, 2009), giving us confidence that supplementing RPM will correct Met limitations occurring in typical production settings. Additionally, Rulquin et al. (2006) and Chen et al. (2011) both obtained increased yields of milk protein when supplementing with 2 different forms of RPM.

Summary

All animals, including ruminants, cannot synthesize the nine EAA in their tissues and must absorb them from the intestine. Microbial protein synthesis in the rumen converts NPN into good quality protein; however, microbial protein formation cannot supply all of the EAA required by productive ruminants. Ration formulation models predict when lactating cows will respond to supplementation of MP in the form of RUP. Models can also be used to identify limiting EAA. Data indicate that Met and Lys are most often the first-limiting EAA on typical diets. Lactation trials conducted with cows fed grass silage-based diets indicate that His may also be limiting. Altering dietary RUP sources or supplementing with rumen-protected Met and Lys may be used to maintain milk and protein yield of lactating cows fed less total CP, improving protein efficiency while reducing urinary N excretion and environmental impact.

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