Updates to Our Understanding of the Nitrogen and Amino Acid Requirements of Lactating Dairy Cattle

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INTRODUCTION

Improving the efficiency of use of feed nitrogen (N) has become a central component of the ration formulation process, primarily to reduce feed costs and also for the desire to be more environmentally friendly. In order to achieve these goals in the field, producers and nutritionists need tools that can accurately estimate the requirements and supply of both N in the rumen, and metabolizable protein (MP) to the animal. Work is ongoing to improve the ability of the Cornell Net Carbohydrate and Protein System (CNCPS) to predict these parameters as new data becomes available. Evaluations by Lanzas et al. (2007) suggested the way previous versions of the CNCPS characterized feed proteins and their associated degradation and passage rates may have caused protein supply to be under predicted which led to overfeeding in the field. A series of updates have been made to the CNCPS since then (Higgs et al., 2012a, Tylutki et al., 2008, Van Amburgh et al., 2010, Van Amburgh et al., 2007) which have led to more sensitive predictions of N supply. The objective of this paper is to examine rumen N supply, feed N fractions and the behavior of these fractions in the rumen. Changes in the feed library and model framework that have improved the sensitivity of predictions in N supply and subsequently AA balancing will also be discussed. The outcome allows the user to formulate diets lower in overall crude protein if the appropriate feed inventory and forage quality are available.

Ruminal nitrogen metabolism and urea recycling

Protein entering the rumen has at least three fates: it is degraded to ammonia and is used for bacterial protein synthesis, leaves the rumen as ammonia and converted to urea in the liver, or escapes microbial degradation becomes metabolizable protein directly. All ruminants are obligate recyclers of N and the amount of urea N recycled is a function of nitrogen (N) intake, the rate of degradation of the carbohydrate and protein and the associated microbial uptake of feed. There are other factors impacting urea N recycling, but N intake and the total pool size of N within the cow will have the largest impact (Recktenwald, 2010). Urea production ranges from approximately 40 to 70% of total N intake per day and contrary to what was previously believed, this hepatic function does not require a significant amount of energy (Reynolds, 1992). In two studies, lactating cattle were fed diets ranging from 14 to 17% CP with N intakes ranging from 520 g to 736 g per day. In those cattle, urea production ranged from 38% to 68% of the N intake and the range was related to several variables, primarily the level of N intake, the starch content of the diet, and the CNCPS/CPM Dairy predicted rumen N balance. The cattle fed diets predicted to be low in rumen N balance were not different in ureagenesis but did recycle significantly more of the daily urea production into the gastrointestinal tract, thus improving N efficiency. On average among the two studies, measured N intake by the cattle was 588 g and 618 g per day where urea production was 44% and 58% of N intake and urea recycling back to the gastrointestinal tract was 30% and 43% of N intake, respectively (Recktenwald, 2010; Van Amburgh et al., 2010). Thus, the cattle recycled on average 176 g and 265 g of urea nitrogen over the 24 hr period to help meet the needs of the rumen microbial activity.

Prediction equations used in field based models such as the CNCPS, CPM Dairy and the NRC to predict recycling have underestimated the level by more than 50% or are not included in the estimates of rumen N availability. This potentially leads to diets that are formulated to meet the rumen N requirements through over-feeding of rumen degradable protein that most likely end up being excreted by the cow through the urine. To correctly estimate the availability of N in the rumen for microbial growth and the quantity of rumen degradable protein (RDP) that should be fed to meet this requirement, N recycled back to the rumen as urea must be adequately estimated.

Feed fractions, pools, digestion rates and passage rate assignments

To estimate protein digestion and flow along the digestive tract, the CNCPS uses chemically determined N fractions to calculate N pools within the model. The pool structure was established based on the behavior of the various N fractions during digestion (Sniffen et al., 1992). Each pool has a specific digestion rate and is assigned to flow with either the liquid or solid phase out of the rumen. These kinetic parameters are what determine the RDP or RUP supply from each feed to the animal, and the subsequent rumen N availability and MP supply. In recent years there have been a number of changes to the model aimed at better defining these fractions, pools and rate assignments to improve MP predictions. These include changes to the model's feed dictionary, and also internal structure.

The major feed library change was to replace non-protein nitrogen (NPN) with ammonia (Higgs et al., 2012a). Non-protein N is defined as the N passing into the filtrate after precipitation with protein specific reagent (tungstic or tricholoracetic acid; (Licitra et al., 1996) and previously represented the A1 pool in the model. Non-protein N is typically assumed to be completely degraded in the rumen (Lanzas et al., 2007). However, small peptides and free AA not precipitated by the chemical method are still metabolically relevant to the animal if they escape rumen degradation and flow through to the small intestine (Givens and Rulquin, 2004). Choi et al. (2002) suggested 10% of the AA flowing through to the small intestine originated from dietary NPN sources which under the current system are unaccounted for. Likewise, Velle et al. (1997) infused free AA into the rumen at various rates and showed up to 20% could escape degradation and flow through to the small intestine which is in agreement with data from Volden et al. (1998). Van Amburgh et al. (2010) suggested it may be more appropriate to redefine the protein A1 pool from NPN as described by Licitra et al. (1996) to ammonia. This would shift small peptides and free AA previously associated with the A1 pool into the

A2 pool where they could contribute to MP supply. Ammonia has the advantage of being easily measured and available from most commercial laboratories. Therefore, the NPN pool in previous feed libraries has been updated to ammonia in the current version.

Other changes include a rate adjustment to the protein A1 pool. Previous versions of the model have assumed protein A1 utilization was instantaneous with a kd of 10,000%/hr implying a rumen retention time of 0.6 min. This would imply that any addition of urea would be dissolved and captured by rumen bacteria in 36 seconds, an unrealistic expectation. This value was generated to represent the rate of solubilization and not necessarily microbial uptake. Considering this, digestion rates for protein A1 were reduced to 200%/hr. Also, passage rate assignments of the soluble pools (protein A1 and A2) have been re-assigned to the liquid passage rate equation to more appropriately reflect the biology of the cow. Both the solid and liquid passage rate equations were updated and account for a greater amount of variation in liquid turnover than the equation found in v5.0 (Seo et al., 2006). Prior to v6.1 of the CNCPS, soluble pools were predicted to flow out of the rumen with the solids passage rate, thus with the high digestion rates for the A1 and A2 pools and slow passage rates, all of the soluble fractions were degraded in the rumen. This change in passage rate assignment improves the sensitivity of the model to changes in feeds high in soluble carbohydrates and protein and reduces, but doesn't fully eliminate, the under-prediction bias observed in a previous evaluation of the model (Tylutki et al., 2008; Van Amburgh et al. 2010).

Amino Acids

In order to have confidence in the ability of the model to predict AA supply and requirements accurately, the model needs to be able to account for the MP allowable milk with reasonable accuracy and precision. The previous parts of this paper have summarized some of the updates made to the CNCPS to better represent the biology of N transactions that have enabled the model to be more sensitive to MP supply and thus more robust in evaluating the most limiting nutrient under field conditions. This has allowed current users to balance diets at crude protein levels below 16% and maintain milk yield to increase overall efficiency of N use and in many cases enhance milk protein output (Chase et al., 2009, Higgs et al., 2012b). However, as excess protein is removed from the diet, AA balancing becomes increasingly important.

The current CNCPS balances for amino acids using a factorial approach based on the amino acid content of the predicted MP supply. The approach is identical to that described by O'Connor et al. (1993). However, comparison of feed AA profiles in the original CNCPS feed library with profiles of other databases used in the industry showed that there were inconsistencies among the data. Much of this can be attributed to the analytical methods used to generate data for the original AA CNCPS feed library (O'Connor et al., 1993). To improve the consistency and accuracy of AA profiles in the CNCPS feed library, profiles have been updated using datasets provided by Evonik Industries AG (Hanau, Germany), Adisseo (Commentary, France) and from the NRC (2001). Data provided were mean values from analyses completed in the respective companies' laboratories or published in the NRC (2001). Proprietary feeds were not changed and were assumed to analyzed using appropriate methods that provided adequate AA recoveries. Another area of consideration has been the efficiency of AA utilization used by the CNCPS. Currently, AA requirements for maintenance and lactation are derived using two separate efficiencies of use as described by Fox et al., (2004). Lapierre et al. (2007) questioned the biological correctness of this assumption and suggested when considering the distribution of enzymes for AA catabolism and the dominate role the liver plays in the modifying peripheral AA supply, using a combined efficiency of use makes more sense and recommended the efficiencies derived by Doepel et al. (2004). These changes have been implemented in the latest version of the model and work is underway to evaluate the effects of the changes prior to the release of this updated version.

SUMMARY

Improving the efficiency of N use in lactating cows has become increasingly important due to high feed costs and increasing concerns for the environment. Producers and nutritionists need robust field usable tools to accurately predict N supply in the rumen and MP supply to the animal in order to reduce total N intake. Between analytical improvements, error corrections, and new research being implemented within the CNCPS framework, model accuracy has been improved. These changes allow the nutrition professional to reduce dietary crude protein levels while maintaining or improving production and profitability.

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