Predicting milk protein responses and the requirement of metabolizable protein by lactating dairy cows

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ABSTRACT

The objective of this study was to develop a modeling framework to predict milk protein yield responses to varying metabolizable protein (MP) supplies and to determine the requirement of MP by lactating dairy cows. The logistic curve was used to model milk protein yield while accounting for a variable efficiency of MP utilization and between-study variability. Models were developed with databases from 2 recently published meta-analyses and based on either total MP supply or MP supply available for milk production. All models provided reasonable fit to data, with root mean square prediction error ranging from 18 to 22% of the average milk protein yield. The estimated horizontal asymptotes were 1.15 (posterior SD = 0.01) and 1.39 (posterior SD = 0.02) in the 2 databases, suggesting that the limiting milk protein yield, as MP supply increases, converges to 1.15 or 1.39 kg/d in the environments determined by the 2 databases. The observed efficiencies ranged from 0.68 to 0.17 when total MP supply was used as the denominator and practically 1 to 0.22 when the MP supply available for milk production was used as the denominator. The predicted efficiencies were in good agreement with the data, decreasing nonlinearly with the MP supply. The MP requirement was calculated with a function constructed with the inverse of the logistic model and modified at regions of maximum marginal efficiency and minimum second derivative. This strategy assumes that the MP solution, or the MP needed to predict a given protein yield in the fitted logistic curve, determines the MP requirement for maintenance and lactation. Requirements calculated with the independent variable as total MP supply refer to the total requirement of maintenance plus lactation, whereas the requirement from models based on MP supply available for milk production are referent to the MP required only for lactation. The requirements were, on average, smaller than the ones predicted by the current Northern American feeding system for dairy cows at lower protein yields and greater than currently recommended at high yields.

Key words: protein, requirement, efficiency, meta-analysis

INTRODUCTION

The dairy industry faces increasing governmental and societal pressure to deliver dairy products at competitive prices while maintaining rigorous environmental stewardship. The number of worldwide policies regulating environmental impacts from livestock operations has increased substantially in the past 2 decades (Oenema, 2004). In the United States, most livestock operations are required to implement nutrient management plans and comply with guidelines, many times updated annually (USDA-EPA, 1999). Nitrogen balance in dairy operations is of particular interest because dietary N supplied in excess is excreted in manure. Nitrate leaching from manure might contribute to eutrophication of water sources and ammonia volatilization is related to health issues in animals and humans (McCubbin et al., 2002). From a producer's perspective, N not retained in milk or tissue represents an inefficiency on the use of an expensive dietary nutrient. Therefore, augmenting the efficiency of incorporating dietary N into milk not only increases the economic competitiveness of the dairy industry but also reduces the environmental impact of milk production. A large variation exists on the efficiency of incorporating dietary N into milk across production systems: Huhtanen and Hristov (2009) reported minimal and maximal efficiency at 14 and 45%, respectively, from 1,734 treatment means from the literature. Dijkstra et al. (2013) estimated a maximum theoretical efficiency around 43%; however, commercial dairies are often far from this maximum theoretical efficiency of N utilization. To achieve gains in efficiency, a more comprehensive description of nutrient availabil-

ity from feeds and a more precise determination of the animal's nutrient requirements for various physiological functions are necessary.

A more comprehensive and precise determination of MP and AA requirements is necessary for matching the delivery with the requirement for various physiological functions of a lactating cow. For instance, the NRC (2001) often underestimates MP allowable milk at low MP supplies and overestimates at greater supplies (Lapierre et al., 2007). This is due to the assumption of a constant efficiency (0.67) of utilization of MP for both maintenance and lactation. The direct implication of the fixed efficiency is that 1.5 kg of MP is required for each kilogram of true protein outputted in milk, regardless of the level of MP supply. The use of a constant efficiency of utilization of MP for lactation has been challenged by a series of studies (Doepel et al., 2004; Van Duinkerken et al., 2011; Daniel et al., 2016). Furthermore, Metcalf et al. (2008) suggested that the efficiency of utilizing supplied MP for milk true protein synthesis decreased from 0.77 to 0.50 when MP supply varied from 25% below to 25% above the predicted MP requirement. The authors suggested that the efficiencies might follow a continuous curvilinear function with respect to the supply. Likewise, Arriola Apelo et al. (2014) suggested that the efficiency of using MP for milk true protein yield decreases with increasing MP supply, possibly in a curvilinear fashion. Daniel et al. (2016) reported cumulative efficiencies of utilizing MP above maintenance decreasing from 0.82 to 0.58 with MP supplies increasing from –0.4 to +0.3 kg/d relative to the MP supply needed for an efficiency of 0.67.

In this context, the objective of this study was to develop a modeling framework that (1) predicts the milk protein yield response to the increased MP supply and (2) provides a framework for computing the MP requirement while accounting for a variable efficiency of MP utilization. Because of the increasing interest in moving from a MP system to an individual AA system (Arriola Apelo et al., 2014; Lapierre et al., 2014), the framework was structured to be flexible and easily extended to the estimation of efficiencies and requirements of individual AA.

MATERIALS AND METHODS

Data

Two distinct but complementary databases from 2 recently published meta-analyses were used in this study. The first database is from a meta-analysis conducted with studies that infused casein postruminally (Martineau et al., 2017). The second database is from a meta-analysis conducted with studies reporting duo-

denal or omasal N flow (White et al., 2016). In the first database, all studies systematically vary MP supply through casein infusions, providing a controlled system for which variation of protein supply is measured and probably the main factor limiting and driving changes in milk protein yield. The second database encompasses studies with a much broader range of experimental treatments. Not only protein supply but other dietary factors might be limiting and driving milk protein yield. The idea of using these 2 distinct databases is to examine the appropriateness of the framework with 2 different systems and examine a potential need for developing more complex models that account for other factors affecting MP use efficiency, such as energy and AA supplies and potential of cows. By design, studies with casein infusion should have improved AA profile, whereas in the second database studies comprise a varied mix of AA profiles in RUP. For both databases, all studies had at least 2 different MP supplies (i.e., at least 2 treatment means).

Database 1

The first database was composed of 130 treatment means summarized in 36 scientific publications. The data represents a subset of the data from Martineau et al. (2017). The study from Larsen et al. (2014) was removed from the database because cows were in early transition period (i.e., DIM 4, 15, 29) and likely relying heavily on body reserves to support milk protein yield. Studies for which the standard error of milk protein was not available or could not be approximated through error propagation techniques were also removed from the database. A complete list with all studies used in our analysis is provided as Supplemental Data (https://doi.org/10.3168/jds.2016-12507). The meta-design is presented in Figure 1 (panels a and b), and summary statistics of the database are presented in Table 1. In short, the data are composed of studies that infused casein postruminally in lactating dairy cows, systematically altering the MP supply and milk protein yield. For a comprehensive description of the literature search and study selection, see Martineau et al. (2017). When BW was not available, it was assumed to be, respectively, 602 and 564 kg for North American cows and cows from Europe and other countries (for 25% of the data), as adopted in the meta-analyses of Martineau et al. (2017) and reported by Huhtanen and Hristov (2009). The total MP supply and MP supply available for milk production were calculated according to Lapierre et al. (2014). Specifically, the total MP supply was determined as the calculated MP supply (NRC, 2001) minus the MP supply from endogenous sources entering the duodenum, also calculated according to the NRC