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Meta-analysis of postruminal microbial nitrogen flows in dairy cattle. II. Approaches to and implications of more mechanistic prediction

Robin R. White,* Yairanex Roman-Garcia,† and Jeffrey L. Firkins†[1]
*Department of Dairy Science, Virginia Tech, Blacksburg 24060
†Department of Animal Sciences, The Ohio State University, Columbus 43210

ABSTRACT

Several attempts have been made to quantify microbial protein flow from the rumen; however, few studies have evaluated tradeoffs between empirical equations (microbial N as a function of diet composition) and more mechanistic equations (microbial N as a function of ruminal carbohydrate digestibility). Although more mechanistic approaches have been touted because they represent more of the biology and thus might behave more appropriately in extreme scenarios, their precision is difficult to evaluate. The objective of this study was to derive equations describing starch, neutral detergent fiber (NDF), and organic matter total-tract and ruminal digestibilities; use these equations as inputs to equations predicting microbial N (MicN) production; and evaluate the implications of the different calculation methods in terms of their precision and accuracy. Models were evaluated based on root estimated variance $(\hat{\sigma}_e)$ and concordance correlation coefficients (CCC). Ruminal digestibility of NDF was positively associated with DMI and concentrations of NDF and CP and was negatively associated with concentration of starch and the ratio of acid detergent fiber to NDF (CCC = 0.946). Apparent ruminal starch digestibility was increased by omasal sampling (compared with duodenal sampling), was positively associated with forage NDF and starch concentrations, and was negatively associated with wet forage DMI and total dietary DMI (CCC = 0.908). Models were further evaluated by calculating fit statistics from a common data set, using stochastic simulation, and extreme scenario testing. In the stochastic simulation, variance in input variables were drawn from a multi-variate random normal distribution reflective of input measurement errors and predicting MicN while accounting for the measurement errors. Extreme scenario testing evaluated each MicN model against a data subset. When compared against an identical data set, predicting MicN empirically had the lowest prediction error, though differences were slight ($\hat{\sigma}_e$ 23.3% vs. 23.7 or 24.3%), and highest concordance (0.52 vs. 0.48 or 0.44) of any approach. Minimal differences were observed between empirical MicN prediction ($\hat{\sigma}_e$ 25.3%; CCC 0.530) and MicN prediction ($\hat{\sigma}_e$ 25.3%; CCC 0.532) from rumen carbohydrate digestibility in the stochastic analysis or extreme scenario testing. Despite the hypothesized benefits of a more mechanistic prediction approach, few differences between the calculation approaches were identified.

Key words: rumen microbial protein, meta-analysis, NDF digestibility, starch digestibility, intake

INTRODUCTION

Precision protein feeding is gaining interest in the dairy industry because dietary protein sources can be expensive and excessive N excretion is an environmental concern (Ndegwa et al., 2008; Lee et al., 2012; Reed et al., 2015). Precision protein feeding on dairy operations will be impractical until AA or MP requirements can be predicted with accuracy and precision. Systematic biases in model calculation structure such as errors in estimating microbial N are prohibitive to efforts to improve the profitability and sustainability of dairies and must be remediated.

Several attempts have been made at quantifying microbial N production (**MicN**) in dairy diets (Fox et al., 2004; Huhtanen and Hristov, 2009; Broderick et al., 2010). A series of evaluations of microbial protein predictions have also been undertaken (Bateman et al., 2001; Yu et al., 2003; Tedeschi et al., 2015). Although these exercises have been useful, few have evaluated the role of rumen carbohydrate digestibility on MicN flow based on actual carbohydrate digestibility (ruminal or total-tract), whereas other evaluations assumed that book or predicted digestibility values for feeds are accurate and unbiased (Huhtanen et al., 2009). Previous evaluations of microbial N predictions have had limited evaluation of ruminal digestibility predictions, and thus a more thorough evaluation of the role of unbiased

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[1]Corresponding author: firkins.1@osu.edu

estimates of ruminal carbohydrate digestibility on the prediction of postruminal MicN flows is warranted.

To more mechanistically represent the role of ruminal carbohydrate digestibility in microbial protein synthesis, it is useful to compare equation methods that directly predict MicN flow with those that predict ruminal carbohydrate (starch + NDF) digestibility as a first step to subsequently multiply by a predicted efficiency of microbial protein synthesis (**EMPS**; MicN/amount of carbohydrate degraded in the rumen). In a companion paper (Roman-Garcia et al., 2016), 3 equations estimating microbial protein were developed. These equations estimated MicN flow as a function of (1) diet composition, (2) ruminal digestibility of starch and NDF, or (3) ruminal digestibility of OM and EMPS. The compounding calculation structure of the latter 2 calculation methods might affect the precision and accuracy of the resultant MicN estimate, although the complexity might also help bound the equation responses in extreme input scenarios. A more thorough comparison of the compounding error structures of more mechanistic prediction approaches is necessary to better understand the effects of including ruminal carbohydrate digestibility equations in predictions of MicN.

The objectives of this study were to derive equations describing starch, NDF, and OM total-tract and ruminal digestibility; to use ruminal equations as inputs to predictions of ruminal MicN production; and to evaluate the implications of the different calculation methods in terms of their precision and accuracy. We hypothesized that more mechanistic approaches to estimating MicN would yield poorer statistical fit when compared with more empirical approaches but that the precision of mechanistically estimated MicN, given the potential global variation in input parameters, will be favorable compared with the empirical approaches, thus supporting the use of the latter in models. Furthermore, we hypothesized that MicN production in scenarios that are notably different from average would be better predicted by more mechanistic prediction approaches.

MATERIALS AND METHODS

Data Collection and Preparation

Data were collected and prepared for analysis as described in Roman-Garcia et al. (2016). Briefly, a literature search was conducted to identify studies that measured duodenal or omasal N flows. A total of 183 studies (613 treatments) were collected from the available literature. Most studies reported the inclusion rates of the ingredients used in diets; however, few studies reported nutrient composition of all ingredients. When ingredient nutrient composition data were available, they were used to calculate dietary nutrient provision. When ingredient-level data were not available, data were filled in from the NRC (2001) feed table. To minimize bias from incorrectly specifying ingredients, the study-level nutrient residuals were calculated and used to adjust book values to ensure no mean bias within a study, as described in Hanigan et al. (2013). Means and standard errors were collected for all response variables of interest, and when standard errors were not directly reported, calculated using error propagation (Roman-Garcia et al., 2016).

Microbial N Models and Model Derivation Procedure

Three estimates of MicN production were derived in a companion paper (Roman-Garcia et al., 2016). Models were based on diet (Equation [1]), ruminal carbohydrate digestibility (Equation [2]), or microbial efficiency (EMPS; Equation [3]):

$$\text{MicN} = -18.3 + 109.0 \times \text{Omasal} + 10.8 \times \text{DMI} + 5.31 \times \text{Starch} - 0.0839 \times \text{Starch}^2, \quad [1]$$

$$\text{MicN} = -52.1 + 122 \times \text{Omasal} + 12.5 \times \text{DMI} + 1.23 \times \text{dStarch} + 2.23 \times \frac{\text{dStarch}}{\text{dNDF}}, \quad [2]$$

$$\text{MicN} = \begin{pmatrix} 43.4 - 1.27 \times \text{DMI} + 0.0342 \\ \times \text{DMI}^2 - 0.110 \times \text{NDF} \end{pmatrix} \times \frac{\text{dOM}}{100} \times \text{DMI}, \quad [3]$$

where Omasal was a binary indicator holding a value of 1 if omasal sampling was used and 0 if duodenal samping was used, DMI was kilograms per day, Starch was diet starch (% of DM), dStarch was ruminally digestible starch (kg/d), dNDF was ruminally digestible NDF (kg/d), and dOM was ruminally digestible OM, (kg/d). Starch and OM digestibilities were on an apparent basis. Fit statistics were calculated for the models (Equations [1], [2], and [3]; Table 1) assuming all variables were measured inputs, and plots of residuals are shown in Supplemental Figures S1, S2, and S3 (http://dx.doi.org/10.3168/jds.2015-10662).

Derivation of Digestible Carbohydrate Equations

To deploy Equation [2] or [3] in any normal model, a prediction of digestible starch, NDF, or OM would be essential. Rumen starch, NDF, and OM digestibilities