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Physically adjusted neutral detergent fiber system for lactating dairy cow rations, II: Development of feeding recommendations

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ABSTRACT

The objective of this work was to leverage equations derived in a meta-analysis into an ensemble modeling system for estimating dietary physical and chemical characteristics required to maintain desired rumen conditions in lactating dairy cattle. Given the availability of data, responsiveness of ruminal pH to animal behaviors, and the chemical composition and physical form of the diet, mean ruminal pH was chosen as the primary rumen environment indicator. Physically effective fiber (peNDF) is defined as the fraction of neutral detergent fiber (NDF) that stimulates chewing activity and contributes to the floating mat of large particles in the rumen. The peNDF of feedstuffs is typically estimated by multiplying the NDF content by a particle size measure, resulting in an estimated index of effectiveness. We hypothesized that the utility of peNDF could be expanded and improved by dissociating NDF and particle size and considering other dietary factors, all integrated into a physically adjusted fiber system that can be used to estimate minimum particle sizes of TMR and diet compositions needed to maintain ruminal pH targets. Particle size measures of TMR were limited to those found with the Penn State particle separator (PSPS). Starting with specific diet characteristics, the system employed an ensemble of models that were integrated using a variable mixture of experts approach to generate more robust recommendations for the percentage of dietary DM material that should be retained on the 8-mm sieve of a PSPS. Additional continuous variables also integrated in the physically adjusted fiber system include the proportion of material (dry matter basis) retained on the 19- and 8-mm sieves of the PSPS, estimated mean particle size, the dietary concentrations of forage, forage NDF, starch, and NDF, and ruminally degraded starch and NDF. The system was able to predict that the minimum proportion of material (dry matter basis) retained on the 8-mm sieve should increase with decreasing forage NDF or dietary NDF. Additionally, the minimum proportion of dry matter material on the 8-mm sieve should increase with increasing dietary starch. Results of this study agreed with described interrelationships between the chemical and physical form of diets fed to dairy cows and quantified the links between NDF intake, diet particle size, and ruminal pH. Feeding recommendations can be interpolated from tables and figures included in this work.

Key words: ensemble models, particle size, effective fiber, ruminal pH

INTRODUCTION

The NDF component of feed has 2 important nutritional elements of interest. The first is the extent to which it is degraded in the rumen (Robinson and McQueen, 1997), because it is made up of both potentially degradable NDF and undegradable NDF fractions (Harvatine et al., 2002). The second has been termed physically effective NDF (**peNDF**), which is defined as the extent to which the physical structure of fiber stimulates chewing and contributes to the floating mat of large particles in the rumen (Mertens, 1997). Both degradability and physical effectiveness influence ruminal pH (Allen, 1997). The peNDF content of individual feedstuffs has been estimated by multiplying the NDF concentration of a feed by the proportion of material retained on a 1.18-mm sieve determined using vertical dry sieving methods or by multiplying by the actual NDF content of the retained material (Mertens, 1997). The multiplication of particle size by feed composition makes peNDF an interaction term with an apparent implicit assumption that the 2 factors are linked, independent of the individual factors. In contrast with dry sieving, the Penn State particle separator (**PSPS**;

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Lammers et al., 1996; Kononoff et al., 2003) is more commonly used on farms to estimate the particle size of TMR. Several investigators have estimated peNDF as the NDF concentration of a TMR multiplied by the proportion of material retained on each or any of the sieves used in the PSPS (19-, 8-, and 1.18-mm; Einarson et al., 2004; Yang and Beauchemin, 2006; Zebeli et al., 2008, 2012); these peNDF values were used to evaluate effects of these fractions on ruminal pH. Although the Dairy NRC (2001) did not include recommendations for peNDF, it did note that quantitative measures of particle size are needed and, if developed, should improve fiber recommendations for dairy cows.

The factors affecting ruminal pH and its role on ruminal fiber digestibility and microbial growth have been described (Firkins, 2010); however, each factor is typically evaluated when all other factors are held constant, often evaluated in vitro, which generally leaves out the various interactions that occur in vivo. Furthermore, models of the rumen environment are limited by data uncertainty because rumen conditions are also difficult to observe accurately (Sarhan and Beauchemin, 2015). Finally, identifying data sets with sufficient independent variation in all key independent variables to accurately derive parameter estimates is challenging. Overcoming this uncertainty requires evaluation of response surfaces that overlap multiple dimensions, and no single study can possibly evaluate all of these dimensions simultaneously. Interestingly, these challenges are similar to those inherent to weather forecasting models (Meier et al., 2014). To overcome data and model limitations in weather forecasting models, climatological researchers have employed ensemble modeling approaches to generate robust predictions of weather patterns as affected by various driving forces (Meier et al., 2014; Pollard et al., 2016). Ensemble models aggregate predictions from multiple different models to yield a mean and range of responses. Compared with individual models, ensemble approaches have advantages in probabilistic event modeling because they provide more reliable predictions of events, estimate confidence in the reliability of those predictions, and are less likely to generate systematic errors (Ebert, 2001). Rather than forcing integration of all models over an entire range of conditions, such that the full range has areas of instability, the ensemble approach uses a mixture of expert algorithms intelligently to integrate equations with varying weighting factors over the entire range of conditions. Therefore, an ensemble modeling approach (Roebber et al., 2004) was chosen to generate robust means and confidence intervals to describe the need for particle size, fiber, and other dietary components in diets for lactating cows. Compared with individual models, an ensemble approach will have improved utility, particularly in situations where minimal data are available for equation development (Polikar, 2006).

The objective of our work was to leverage equations derived in a meta-analysis (White et al., 2017) into a multidimensional system for estimating dietary physical and chemical characteristics required to maintain desired rumen conditions. Given the responsiveness of ruminal pH to animal behaviors and the chemical composition and physical form of the diet (Allen, 1997; White et al., 2017), mean ruminal pH was chosen as the indicator to describe whether the diet supported the desired ruminal characteristics. This indicator was chosen because it was frequently reported in many of the studies included in our data set, but it should be noted that other measures that were rarely reported, such as minimum or maximum pH, time under 5.8, or area under the curve of pH measures taken over time (Danscher et al., 2015), may serve as better indicators of problematic rumen conditions. Nonetheless, under varying dietary conditions, we tested adequacy of model combinations to predict mean ruminal pH. Because model combinations may be dependent upon diet situations, we used the ensemble modeling approach to enable differential weighting of model predictions to generate description of diet effect. We hypothesized that the utility of peNDF could be expanded and improved by dissociating NDF and particle size and considering other dietary factors of the entire diet, all integrated into a physically adjusted fiber (**paNDF**) system that can be used to estimate minimum particle sizes of TMR and diet compositions needed to maintain varying ruminal pH targets under the range of dietary conditions experienced by dairy cattle in North America. Although development and simulation of the paNDF system was conducted in R v. 3.4.0 (Foundation for Statistical Computing, Vienna, Austria), the system of equations is simple enough to be implemented in any computational framework, including spreadsheet-based software such as Microsoft Excel (Microsoft Corporation, Redmond, WA).

MATERIALS AND METHODS

White et al. (2017) generated equations describing the effects of dietary physical and chemical characteristics on DMI, eating activity, rumination activity, and ruminal pH. Our approach to integrate these equations allowed us to test and detect small effects of dependent variables while also including research that spans both controlled and noncontrolled factors, such as basal plane of nutrition (St-Pierre, 2007). To avoid confusion between equations referenced from White et al.