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Prediction of rumen fiber pool in cattle from dietary, fecal, and animal variables

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ABSTRACT

Feed intake control in ruminants is based on the integration of physical constraints and metabolic feedbacks. Physical constraints are related to the fill caused by the weight or volume of digesta in the reticulo-rumen. The amount of neutral detergent fiber (NDF) in the rumen (RNDF) may be used as an indicator of rumen fill. The objective of this study was to develop equations predicting RNDF from diet and animal characteristics using a meta-analysis technique. A treatment mean data set (n = 314) was obtained from 84 studies, in which rumen pool size and diet digestibility were determined in lactating cows (n = 231) or growing cattle (n = 83). The data were analyzed using linear and nonlinear mixed models. Intake, rumen pool size, and fecal output of NDF were scaled to $BW^{1.0}$. Due to the heterogeneous nature of dietary NDF, predictions of RNDF based on NDF intake were not precise. Predictions were markedly improved by dividing NDF into potentially digestible and indigestible fractions, because rumen turnover time of indigestible NDF was 2.7 times longer than that of potentially digestible NDF. At equal NDF intake, RNDF was negatively associated with dietary crude protein concentration and positively with the proportion of concentrate in the diet. Models based on fecal NDF output generally performed better than those based on NDF intake, probably because the effects of intrinsic characteristics of dietary cell walls and associative effects of dietary components collectively influence fecal NDF output. The model based on fecal NDF output was improved by including dietary concentration of forage NDF in the model, reflecting slower turnover of forage NDF compared with concentrate NDF. The curvilinear relationship between fecal NDF output and RNDF could be described by a quadratic, Mitscherlich, or power function equation, which performed better than the quadratic or Mitscherlich equation. In addition to fecal NDF output and dietary concentration of forage NDF, animal and forage type had significant effects on RNDF. At the same fecal NDF output, growing cattle had a smaller RNDF than dairy cattle. Increased proportion of alfalfa or corn silages in forage decreased RNDF and increased proportion of tropical forages decreased it. It is concluded that RNDF can be predicted precisely from intake or fecal output data, and that predicted RNDF can be a useful tool in understanding the interplay between physical and metabolic factors regulating feed intake in ruminants.

Key words: diet composition, fecal output, modeling, rumen fiber pool

INTRODUCTION

Accurate prediction of DMI is important for the formulation of economical dairy cow diets. Regulation of feed intake in ruminants involves multiple mechanisms related to dietary and animal factors that are poorly understood (Mertens, 1994a). Several empirical models predicting DMI in cattle have been developed over the past 30 to 40 yr, but no intake model can generally be used for different types of animals fed a wide range of diets. Limited success in this field is at least partly due to complicated interactions between the animal and feed characteristics, and difficulties in distinguishing and quantifying these factors. The main theory of intake control in ruminants is based on the integration of physical constraints and metabolic feedbacks, which in turn determines the maximum DMI for a specific animal under a particular feeding situation (Crampton, 1957; Blaxter et al., 1961; Conrad et al., 1964). Based on this concept, Mertens (1987, 1994a) developed the NDF-Energy intake system. This approach is based on a theoretical relationship between dietary NDF and energy (i.e., intake is limited by the energy demand of the animal or the physical fill of the diet). Maximum intake occurs at the intersection of those theories of intake regulation (Mertens, 1994a).

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Evaluation of intake data from feeding experiments in dairy cows does not provide support to the bi-phasic intake regulation theory because no set-point either for physical or for metabolic feedback mechanisms could be detected. Rumen pool size of NDF decreases with improved digestibility of grass silage (Bosch et al., 1992; Rinne et al., 2002), suggesting that cows do not use all the rumen capacity when highly digestible grass silages are fed. However, DMI increased with improved forage digestibility rejecting the hypothesis that intake was limited by energy intake. Similarly, with increased concentrate supplementation (Keady et al., 2004; Huhtanen et al., 2008), quadratic DMI responses do not support the bi-phasic intake regulation theory. Within physical limitation, the DMI should increase linearly with increased concentrate allowance due to the reduced NDF content (i.e., gut fill) of the diet. On the other hand, no break-point of DMI was reached even with the highest levels of concentrates. These observations support the integration of physical and metabolic constraints on ruminant intake. Fisher et al. (1987) proposed a model integrating the physical and metabolic constraints on ruminant feed intake. They presented a model with a double exponential term expressing intake as a function of rumen distension and nutrient flow, intending to relate the strength of each stimulus in relation to the other. Following this concept, Detmann et al. (2014) presented a model based on energy content and bulkiness of the diet. This model showed that DMI is simultaneously regulated by both physical constraints and metabolic feedbacks.

A better understanding of the additive nature of feedback mechanisms would lead to more accurate predictions of voluntary DMI (Allen, 1996). Progress made in the prediction of DMI by mechanistic models has been disappointing, primarily because of an inadequate understanding of the mechanisms that affect flow from the reticulorumen and insufficient data with which to develop and validate models (Allen, 1996). One difficulty in modeling the effects of physical limitation is how to express rumen capacity or filling (distension) effect of the feed or diet. It could be speculated that the size of rumen NDF pool is the best descriptor of rumen fill or capacity, because nonfiber DM can be assumed to occupy very little rumen capacity. The rumen evacuation technique has been used to determine NDF pool size and parameters related to fiber kinetics. However, this technique is invasive, time-consuming, expensive, and laborious, and demands rumen-cannulated animals. Therefore, our objective was to evaluate if rumen NDF pool can be predicted from feed intake, fecal output, and diet characteristics using a meta-analytical approach.

MATERIALS AND METHODS

Experimental Data

A treatment means data set (n = 314) was obtained from 84 studies, in which rumen pool size and diet digestibility were determined either in lactating dairy cows (n = 231) or growing cattle (n = 83; Appendix), and used for statistical analysis to predict rumen pool size of NDF (**RNDF**). Rumen pool size was determined by manual evacuation of rumen contents. Diet digestibility was determined using either total fecal collection or different external or internal markers. The minimum prerequisite for an experiment to be included in the data set was that BW, forage and total DMI, adequate diet characterization (forage plant species, forage and concentrate NDF concentrations, dietary CP concentration, RNDF, and total-tract NDF digestibility) were available. In addition, data on dietary concentrations of indigestible NDF (**iNDF**), rumen pool sizes of fresh matter, DM and OM, and total-tract OM digestibility were collected.

Forage species were classified as temperate grasses, tropical grasses, corn silage, whole crop (barley, wheat) silage, alfalfa, other legumes (mainly red clover), and straw. Proportions of each forage type of the total forage DMI were calculated. Proportions of concentrate of total intake were calculated on DM and NDF basis. Intake, rumen pool size, and fecal output of NDF {NDF intake × 0.001 × [1,000 − NDF digestibility (g/kg)]} were scaled to $BW^{1.0}$ (g/kg of BW). Scaling to $BW^{1.0}$ can be justified because fiber occupies space in the gastrointestinal tract and rumen pool size is likely to scale to $BW^{1.0}$ (Mertens, 1987; Van Soest, 1994).

Statistical Analysis

Deviating properties of RNDF were investigated from leverage and influence using the $DFFITS_i$ and $DFBETAS_{ji}$ diagnostics, where $i = 1, 2, \ldots, 318$ and j,i denotes the jth regression coefficient in the regression equation (= 0 or 1) estimated without observation i, where $i = 1, 2, 3 \ldots, 318$, respectively (Belsley et al., 1980). Cut-off values suggesting that an observation warrants further examination were set at $|DFFITS_i| > 2\sqrt{\ } (p/n)$ and $|DFBETAS_{j,i}| > 2/\sqrt{n}$, where p is the number of parameters estimated in the model and n is the total number of observations. After outliers were removed, the data set contained a total of 294 treatment mean observations (dairy cows 220, growing cattle 74).

The relationships between RNDF (g/kg of BW) and independent variables were explored by regression analysis within the MIXED procedure of SAS 9.4 (Littell et al., 1996) using the following basic model: