J. Dairy Sci. 97:2502–2511
http://dx.doi.org/10.3168/jds.2012-6490

Association of total mixed ration particle fractions retained on the Penn State Particle Separator with milk, fat, and protein yield lactation curves at the cow level

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ABSTRACT

As part of a larger project aiming to develop management evaluation tools based on results from test-day (TD) models, the objective of this study was to examine the effect of physical composition of total mixed rations (TMR) tested quarterly from March 2006 through December 2008 on milk, fat, and protein yield curves for 25 herds in Ragusa, Sicily. A random regression sire-maternal grandsire model was used to estimate variance components for milk, fat, and protein yields fitted on a full data set, including 241,153 TD records from 9,809 animals in 42 herds recorded from 1995 through 2008. The model included parity, age at calving, year at calving, and stage of pregnancy as fixed effects. Random effects were herd × test date, sire and maternal grandsire additive genetic effect, and permanent environmental effect modeled using third-order Legendre polynomials. Model fitting was carried out using ASREML. Afterward, for the 25 herds involved in the study, 9 particle size classes were defined based on the proportions of TMR particles on the top (19-mm) and middle (8-mm) screen of the Penn State Particle Separator. Subsequently, the model with estimated variance components was used to examine the influence of TMR particle size class on milk, fat, and protein yield curves. An interaction was included with the particle size class and days in milk. The effect of the TMR particle size class was modeled using a ninth-order Legendre polynomial. Lactation curves were predicted from the model while controlling for TMR chemical composition (crude protein content of 15.5%, neutral detergent fiber of 40.7%, and starch of 19.7% for all classes), to have pure estimates of particle distribution not confounded by nutrient content of TMR. We found little effect of class of particle proportions on milk yield and fat yield curves. Protein yield was greater for sieve classes with 10.4 to 17.4% of TMR particles retained on the top (19-mm) sieve. Optimal distributions different from those recommended may reflect regional differences based on climate and types and quality of forages fed.
Key words: lactation curve, particle size, total mixed ration, test-day model

INTRODUCTION

Roughage in ruminant diets stimulates chewing and saliva production, which helps buffer the rumen against severe pH reduction, which may occur in high-producing dairy cows fed energy-dense rations. Both quantity and physical form of the roughage is important to support normal rumen function (Balch, 1971; Allen, 1997). A minimal threshold of total chewing time per day, particularly time spent in rumination, is correlated with adequate physical form of roughage in a diet and is associated with the formation of a mat of coarse material in the rumen (Balch, 1971). The chemical constituent of roughage associated with chewing and mat formation is NDF, plant residues insoluble in neutral detergent, after Van Soest et al. (1991) and Allen (1997). To ensure adequate fiber, the NRC (2001) recommends that diets composed primarily of corn silage and alfalfa haylage as forage sources and dry corn as the main concentrate source contain a minimum of 25% NDF on a DM basis and 76% of the NDF from forage. Typical values for NDF in corn silage and alfalfa haylage may range from 38 to 46% of DM and from 36 to 45% of DM, respectively. Thus, forage content of diets may vary from 43 to 58% of total DM consumed to meet these guidelines. However, these guidelines do not specify a particle size, which can vary greatly depending on several factors such as the chop length set at harvest or the duration of mixing of forages within a TMR, which may ultimately influence the effectiveness of the NDF to maintain a rumen mat and adequate chewing activity.

Received December 16, 2012.
Accepted November 26, 2013.
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Adequate NDF is important in dairy rations to support normal rumen activity and prevent milk fat depression and health problems associated with rumen acidosis. Rations may contain adequate NDF but be processed so finely that normal rumen activity cannot be maintained. Mertens (1997) combined the concept of adequate chemical NDF with physical form to define physically effective NDF (**peNDF**) as a measure that captures the physical characteristics of fiber by accounting for particle length and NDF content. Physically effective NDF promotes chewing and the flow of salivary buffers to the rumen to maintain a normal rumen milieu (Mertens, 1997). Mertens (1997) defined long grass hay as 100% peNDF and ranked peNDF in chopped forages, grains, and byproduct feeds in relation to chewing activity of long grass hay at comparable NDF contents. As mean particle size decreases, peNDF decreases, as does chewing time and rumen pH because of a reduction in saliva production and its buffering action (Woodford and Murphy, 1988; Grant and Colenbrander, 1990a,b).

Physically effective fiber is the fraction of the diet that stimulates chewing (NRC, 2001), but standard guidelines are qualitative in nature. Because forage provides the majority of long particles in a dairy ration and the majority of NDF, adequate peNDF and particle size are often used interchangeably to describe adequate fibrosity of dairy rations; however, these terms are not entirely interchangeable. Forages may be finely chopped, providing adequate NDF and forage content of diets but inadequate particle size. Thus, peNDF is either estimated based on guidelines of average theoretical chop length of hays, haylages, and corn silages or based on particle distribution of the roughage, assuming uniformity of NDF content across particles. However, particle distribution of roughages and TMR may contain varying content of NDF (Kononoff et al., 2003); therefore, peNDF may not be consistent with estimates based on roughage or TMR particle distribution. It is not practically possible to measure the NDF content of particles separated by particle length within feeds or TMR. Therefore, forage content, NDF content, and particle distribution are typically described to adequately account for rumen effectiveness of long particles and roughages in dairy rations.

A challenge has been to establish a method to define adequate particle length in dairy rations that is simple and repeatable. Lammers et al. (1996) developed a simple field-usable device to estimate particle size of forages and TMR (Penn State Particle Separator, **PSPS**). The PSPS was designed to allow separation of feed particles by a shaking motion duplicating vertical sieving. Initially 2 screens, 19.0 mm and 8.0 mm, and a pan were used to estimate mean particle size. Since that publication, the PSPS has been modified to include a third screen, 1.18 mm in size (Kononoff et al., 2003). Guidelines published by Heinrichs and Kononoff (2002) recommend that adequate chewing is maintained when a TMR contains 2 to 8% of material on the top screen (19.0 mm), 30 to 50% of material on the middle screen (8 mm), 30 to 50% of material on the lower screen (1.18 mm), and <20% of material in the pan. Most authors have focused on the total feed material retained on the top 2 screens as the physically effective material in dairy rations. In fact, Schadt et al. (2012) found that swallowed boli from hay particles retained on the top 2 screens contained particles sufficiently long enough to contribute to long particles in the rumen. Particles retained on the 1.18-mm screen when masticated and swallowed were too fine to contribute to formation of the rumen mat.

Various approaches have been used to estimate peNDF from particle distribution in the PSPS. The simplest is based on as-fed distribution of feed particles, with the proportion retained on the top 2 screens serving as an estimate of the peNDF. Further refinements include DM retained on the top 2 screens times the NDF content of the entire diet as an estimate of peNDF, or to estimate peNDF as the proportion of NDF retained on the top 2 screens as a proportion of total NDF. In addition, mean geometric particle size has been calculated based on proportions retained on the 3 screens and pan, and this has been used to evaluate chewing activity and mean ruminal pH. An accurate and repeatable method to estimate peNDF and adequate particle length of TMR on dairy farms is still to be determined.

It is generally recognized that rumen particles >1.18 mm are large particles retained in the rumen and are an index of peNDF (Mertens, 1997). However, Kononoff and Heinrichs (2003a,b) and Maulfair and Heinrichs (2010) found that particles larger than those retained on a 1.18-mm screen were not a critical measure of the effectiveness of chewing activity, but larger particles, either >8 mm or >19 mm, were more indicative of the effectiveness of fiber in dairy rations. In addition, Kononoff and Heinrichs (2003a) observed that particles >1.18 mm ranged from 42.9 to 54.1% of fecal particles in cows consuming cottonseed hull-based diets, suggesting that, in high-producing dairy cows, the rumen threshold size is >1.18 mm. It may be that cows consuming higher DM amounts from wet forages will pass larger particles than observed by Poppi (1980), who investigated fecal particles in cattle consuming dry hay diets at lower DMI. In fact, fecal particles correspond to the size of particles leaving the rumen, as little reduction in size occurs in the distal gastrointestinal tract. Fecal particle size should perhaps be included in an assessment of