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Analysis of pasture supplementation strategies by means of a mechanistic model of ruminal digestion and metabolism in the dairy cow

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ABSTRACT

Effective pasture supplementation is critical to the efficiency of resource management in milk production. We understand a great deal about ruminal and metabolic processes in dairy cattle that control efficiency but we need to improve our ability to predict effects of practical feeding strategies based on the basic biological processes of the cow. Therefore, a large-scale pasture supplementation study was used to explore the details of both practical management and the underlying biological principles and processes involved. This included a multiple lactation study coupled with shorter-term experiments that tested the type and rate of supplementation. Basal supplementation strategies were (1) pasture allowance [14 kg of dry matter (DM)/d per cow] supplemented with milled barley grain fed twice daily in the milking parlor and pasture silage provided in the paddock; the ratio of grain:forage fed as supplement was 0.75:0.25 (control; DM basis); (2) the same pasture allowance plus the same amounts of milled barley grain and pasture silage, but the supplements were mixed and chopped before being fed immediately after each milking; and (3) the same pasture allowance and offered a partial mixed ration comprising barley (25%) and corn grain (30% of DM), corn silage (20% of DM), and alfalfa hay (25% of DM) after each milking. In late lactation (227 d in milk), a short-term experiment was done feeding the same pasture allowances but with the 3 supplements offered at 6, 8, 10, and 12 kg of DM/d for an 11-d measurement period following adaptation to the diet to each of the 3 long-term supplementation groups. Production responses were recorded and ruminal volatile fatty acids (VFA) and pH were measured in a subset of animals. Model descriptions of yields of milk and milk constituents as well as mean concentrations of ruminal fluid VFA and ruminal fluid pH were compared with measured values resulting when dairy cows were fed 12 different pasture-based diets with different levels and types of dietary supplement. Inputs into the model were measured dry matter intake and feed composition on the 12 combined treatments as well as initial body weight and composition. The model described milk and milk component production within 1 standard deviation of the treatment means (less than 5% of the mean as measured in the root mean square error). The simulated proportions of ruminal acetate, propionate, and butyrate were consistent with observed effects of supplemental treatments and rate of supplementation; however, the error analysis showed room for improvement. The model described, to a general extent, the changes in ruminal pH; however, this investigation showed that the equations that describe ruminal pH need to be improved or modified. These results show that the fundamental knowledge of ruminal and organ metabolism in this mechanistic model is sufficient to describe the qualitative responses to complicated dietary strategies, but our quantitative understanding of the parameters involved such as degradation and absorption kinetics and ruminal pH still demands more specific research.
Key words: pasture, supplementation, digestion, mechanistic modeling

INTRODUCTION

In many parts of the world, pasture provides the basic nutrient supply for lactating dairy cattle. Although much is understood about grazing management, a wide variety of supplemental systems are available, and producers must account for the variability, availability, and cost of feedstuffs. Production increases in response to supplements in pasture-fed cows are well established (Walker et al., 2001; Leddin et al., 2009), but often the response is curvilinear, with poorer responses being observed as the amount of grain increases (Stockdale et al., 1987; Walker et al., 2001). The pasture amount, quality, and stage of lactation all affect milk production responses to supplemental grain (Walker et al., 2001; Beever and Doyle, 2007). Feeding high amounts of cereal supplements in the parlor can increase variations in ruminal fluid pH, impair NDF digestion, and lead to

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less pasture being consumed (Mould et al., 1983; Stockdale, 2000; Wales and Doyle, 2003; Leddin et al., 2009).

Research models are used in systems and quantitative biology approaches to describe the complex digestive and metabolic processes in the dairy cow (Baldwin, 1995; Hanigan et al., 2009; McNamara and Shields, 2013; Gregorini et al., 2014). One is the Molly model from Baldwin (1995) that has been developed over 4 decades and is in use in several research programs worldwide (Hanigan et al., 2009, 2013; Gregorini et al., 2013, 2014; McNamara, 2015). The model describes digestive processes and organ metabolism in lactating dairy cattle and is useful in describing the underlying biological processes that control practical production responses (McNamara and Baldwin, 2000; Hanigan et al., 2006, 2013; Gregorini et al., 2013, 2014; McNamara and Shields, 2013). Although the model has elements that describe feeding of high forage and highly soluble forage, it has not been specifically studied to determine how well it would describe more complicated pasture feeding and supplementation regimens, and more importantly, where it does not describe these situations well. In particular, it is challenging to describe ruminal VFA metabolism and resultant metabolic pathway fluxes as a result of complex feeding strategies (Hanigan et al., 2013). Research models such as Molly are most useful when they point out remaining gaps in knowledge and are continually improved. Such challenges are valuable in improving our quantitative understanding of biological control mechanisms in a wide variety of feeding situations, which can improve our flexibility in such feeding systems.

Therefore, we used a large-scale pasture supplementation study that was designed in part to challenge and improve existing research and applied models to provide a modeling challenge and analysis. Therefore, in this modeling experiment, the objective was to use an existing well-validated mechanistic, dynamic model of metabolism in the dairy cow (Baldwin, 1995; and updates: Hanigan et al., 2009) to determine how well the model describes key aspects of digestion and metabolism in the dairy cows. The specific hypothesis tested was that the model can describe the response to increasing the amounts of grain and forage supplement fed to cows grazing a low allowance of pasture in late lactation, including the pattern of rumen fermentation. Instances in which the model could not describe observations well would point to specific gaps in knowledge that could be filled with further experiments.

MATERIALS AND METHODS

The full experimental description and results of the animal trial are published in Auldist et al. (2013). In brief, to conduct the full-lactation experiment, 216 Holstein Friesian cows were allotted to 1 of 3 groups of 72 cows. Cows in the 3 groups grazed separately but on similar adjacent paddocks over a 34-wk period. For the first 17 wk, partial mixed rations (**PMR**) were offered once daily, following the morning milk and pasture offered once daily following the afternoon milking. Diets were (1) control (**CONT**): grazed perennial ryegrass pasture supplemented with milled barley grain fed twice daily in the milking parlor and pasture silage offered once daily in the paddock. The ratio of barley:silage was 0.75:0.25 (DM basis); (2) the same pasture and allotment supplemented with the same amounts of milled barley grain and pasture silage, but presented as a mixed ration on a feed pad after each milking (**PMR1**); and (3) the same pasture and allotment, supplemented with a mixed ration of barley grain, alfalfa hay, corn silage and corn grain (**PMR2**). All supplements were formulated to be isoenergetic and all feeding strategies provided the same ME intake and grain:forage ratio.

For the short-term supplementation study, at a mean of 227 DIM (range 176 to 256 d), within each of the 3 long-term dietary treatment groups of 72 cows, cows were randomly allotted to 2 groups of 36 cows. Animals within each of these 2 groups were then randomly allotted to 4 groups of 9 cows, which were fed the trial supplements (CONT, PMR1, PMR2). The supplements were fed at 4 rates of feeding: 6, 8, 10, and 12 kg/d of DM. Thus, CONT animals received the CONT supplement at 4 rates and the PMR1 and PMR2 groups their respective supplement at each of the 4 rates. The 25-d experiment comprised a 14-d adaptation period and an 11-d measurement period. Pasture allowance for all cows was approximately 14 kg (DM)/cow per day, and pasture intake ranged between 7.9 and 9.5 kg DM/cow per day. Table 1 contains the production characteristics of the animals immediately before the short-term supplementation study and the parameter values of the model set to represent those conditions. Tables 2 and 3 list the amount of pasture and feed supplements consumed and the nutritive characteristics of the diets fed.

Simulation Modeling Analysis

Molly is a deterministic, mechanistic, dynamic model representing the digestion, metabolism, and production of a dairy cow (Baldwin, 1995). The rumen model is constructed at an aggregated biochemical pathway level to describe degradation and fermentation of feedstuffs and substrates (soluble carbohydrate, starch, cellulose, hemicellulose, organic acids, proteins) in the rumen, microbial growth, digestion, and absorption of nutrients. In the animal model, the major pathways