J. Dairy Sci. 99:1–13
http://dx.doi.org/10.3168/jds.2016-10917

Effects of dietary crude protein and rumen-degradable protein concentrations on urea recycling, nitrogen balance, omasal nutrient flow, and milk production in dairy cows

T. Mutsvangwa,[1] K. L. Davies, J. J. McKinnon, and D. A. Christensen
Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, SK, S7N 5A8, Canada

ABSTRACT

The objective of this study was to determine how interactions between dietary crude protein (CP) and rumen-degradable protein (RDP) concentrations alter urea-nitrogen recycling, nitrogen (N) balance, omasal nutrient flow, and milk production in lactating Holstein cows. Eight multiparous Holstein cows (711 ± 21 kg of body weight; 91 ± 17 d in milk at the start of the experiment) were used in a replicated 4 × 4 Latin square design with a 2 × 2 factorial arrangement of dietary treatments and 29-d experimental periods. Four cows in one Latin square were fitted with ruminal cannulas to allow ruminal and omasal sampling. The dietary treatment factors were CP (14.9 vs. 17.5%; dry matter basis) and RDP (63 vs. 69% of CP) contents. Dietary RDP concentration was manipulated by including unprocessed or micronized canola meal. Diet adaptation (d 1–20) was followed by 8 d (d 21–29) of sample and data collection. Continuous intrajugular infusions of [$^{15}N^{15}N$]-urea (220 mg/d) were conducted for 4 d (d 25–29) with concurrent total collections of urine and feces to estimate N balance and whole-body urea kinetics. Proportions of [$^{15}N^{15}N$]- and [$^{14}N^{15}N$]-urea in urinary urea, and ^{15}N enrichment in feces were used to calculate urea kinetics. For the low-CP diets, cows fed the high-RDP diet had a greater DM intake compared with those fed the low-RDP diet, but the opposite trend was observed for cows fed the high-CP diets. Dietary treatment had no effect on milk yield. Milk composition and milk component yields were largely unaffected by dietary treatment; however, on the low-CP diets, milk fat yield was greater for cows fed the low-RDP diet compared with those fed the high-RDP diet, but it was unaffected by RDP concentration on the high-CP diets. On the high-CP diets, milk urea nitrogen concentration was greater in cows fed the high-RDP diet compared with those fed the low-RDP diet, but it was unaffected by RDP concentration on the low-CP diets. Ruminal NH_3-N concentration tended to be greater in cows fed the high-CP diet compared with those fed the low-CP diet, and it was greater in cows fed the high-RDP diet as compared with those fed the low-RDP diet. Nitrogen intake and both total N and urea-N excretion in urine were greater for cows fed the high-CP diet compared with those fed the low-CP diet. However, N balance and urinary excretion of purine derivatives were unaffected by dietary treatment. Urea-N entry rate (UER) was greater in cows fed the high-CP diet compared with those fed the low-CP diet; however, UER was unaffected by dietary RDP concentration. The proportion of urea-N recycled to the gastrointestinal tract (as a percentage of UER) was greater in cows fed the low-CP diet compared with those fed the high-CP diet. In summary, reducing dietary CP concentration decreased urinary N excretion but had no effect on milk yield, thus resulting in an overall improvement in milk N efficiency.
Key words: dairy cow, crude protein, microbial protein, rumen-degradable protein, urea-nitrogen recycling

INTRODUCTION

The conversion of dietary N into milk N, which is referred to as milk N efficiency (**MNE**), is rather low (typically 20–35%; Chase et al., 2009). Consequently, 65 to 80% of dietary N intake is lost in urine and feces, thus contributing to environmental pollution (Cowling and Galloway 2002; Hristov et al. 2011). As a result, intensive livestock operations like dairy farms are under increasing public pressure to reduce N excretion so as to improve environmental stewardship. Feeding practices for lactating dairy cows in the United States and Canada have been based on guidelines set by the National Research Council (NRC, 2001), which recommends dietary CP concentrations of 17.5 to 19.0% to support high levels of milk production. However, feeding such high levels of dietary CP increases N excretion while decreasing MNE (Olmos Colmenero and Broderick, 2006); therefore, one approach for decreasing

Received January 19, 2016.
Accepted April 5, 2016.
[1]Corresponding author: tim.mutsvan@usask.ca

N excretion and improving MNE is to reduce dietary CP content (Olmos Colmenero and Broderick, 2006). Olmos Colmenero and Broderick (2006) reported that decreasing dietary CP content from 19.4 to 13.5% decreased urinary N excretion from 36.2 to 23.8% (as a proportion of N intake) and increased MNE from 25.4 to 36.5%. Per unit of feed, protein is a relatively costly nutrient (Chase et al., 2009); therefore, reducing dietary CP could also lower feeding costs for milk production. However, although reducing dietary CP content can improve N efficiency and reduce feeding costs, some studies (Cabrita et al., 2011; Lee et al., 2011; Chibisa and Mutsvangwa, 2013) have reported that it can have detrimental effects on milk and milk protein yields, which would be undesirable for economic reasons.

In ruminants, shuttling of N in the form of NH_3-N and urea between the portal-drained viscera (particularly the rumen) and the liver, a physiological mechanism referred to as urea-N salvaging, is important for the conservation of N (Lapierre and Lobley, 2001). Urea-N that is recycled to the rumen can become an important source of N for microbial growth when RDP supply is limited (Lapierre and Lobley, 2001), and it represents a repartitioning of urea-N away from urinary excretion toward anabolic use. Enhancing urea-N recycling to the rumen can therefore be a feasible strategy to improve N efficiency. Many factors regulate urea-N secretion into the rumen, including ruminal NH_3-N concentration. Earlier studies indicated that ruminal NH_3-N concentration was negatively correlated with urea-N transfer into the rumen (Kennedy and Milligan, 1980), although the exact mechanisms for the inhibitory effect of ammonia are still unclear. Egan et al. (1986) proposed that increased NH_3-N concentration decreased the permeability of the ruminal epithelium to urea-N. Rémond et al. (1996) indicated that urea-N transfer into the rumen was facilitated by bacterial urease activity that maintained a favorable concentration gradient. Because urease activity is negatively correlated with ruminal NH_3-N concentration (Cheng and Wallace, 1979), decreasing ruminal NH_3-N concentration should favor urea-N transfer into the rumen. Recently, Lu et al. (2014) confirmed the inhibitory effect of ammonia on urea transfer across ruminal epithelia using a Ussing chamber model and demonstrated that the inhibitory effect was concentration dependent, with saturation at 5 mmol/L. These authors hypothesized that ruminal uptake of ammonia as NH_4^+ at physiological ruminal pH (<7) resulted in intracellular acidification that reduced the permeability of urea transporters to urea. It is well established that ruminal NH_3-N concentration is positively correlated with both dietary N and RDP intakes (Seal and Reynolds, 1993; Reynolds and Kristensen, 2008), so manipulating dietary N and RDP intakes can alter urea-N recycling to the rumen. Decreasing N intake by feeding low-CP diets increases the proportion of endogenous urea production that is transferred from the bloodstream into the portal-drained viscera (Marini and Van Amburgh, 2003; Wickersham et al., 2008a; Chibisa and Mutsvangwa, 2013). Limited studies have investigated the impacts of altering dietary RDP concentration on urea-N transfer to the rumen. Wickersham et al. (2008b) observed that increasing dietary RDP concentration increased urea-N transfer to the gastrointestinal tract (**GIT**), but RDP concentration had no impact when urea-N transfer to the GIT was expressed as a proportion of endogenous urea-N production. In that study, however, both RDP concentration and N intake (which can alter endogenous urea-N synthesis) increased at the same time so no definitive conclusion could be made about how altering RDP concentration affected urea-N transfer to the GIT. To our knowledge, no published studies have reported the interactive effects of dietary CP and RDP concentrations on urea-N transfer to the GIT and ruminal microbial protein production in dairy cows that have a high requirement for MP to support high levels of milk production.

Our hypothesis for the present study was that, under feeding conditions that feature reduced dietary N and RDP concentrations, urea-N recycling to the GIT will increase to provide N in support of microbial growth. Therefore, the objective was to determine the interactive effects of dietary CP and RDP concentrations on urea-N recycling, N balance, omasal nutrient flow, and milk production in dairy cows. By providing insufficient dietary RDP to meet microbial N needs in low-CP diets, it may be possible to increase urea-N recycling to the rumen and maintain microbial protein synthesis that would provide sufficient MP to maintain high levels of milk production that are typically attained with higher-CP diets.

MATERIALS AND METHODS

Cows used in this study were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993), and their use was approved by the University of Saskatchewan Animal Care Committee (UCACS Protocol 20040048).

Animals and Experimental Design

Eight multiparous, lactating Holstein cows (711 ± 21 kg of BW; 91 ± 17 DIM at the start of the experiment) were used in a replicated 4 × 4 Latin square design with a 2 × 2 factorial arrangement of dietary treatments. Four cows were surgically fitted with 10.2-