J. Dairy Sci. 99:1–11
http://dx.doi.org/10.3168/jds.2016-10853

The effect of cation source and dietary cation-anion difference on rumen ion concentrations in lactating dairy cows

T. L. Catterton and R. A. Erdman[1]
Animal and Avian Sciences Department, University of Maryland, College Park 20742

ABSTRACT

Many studies have focused on the influence of dietary cation-anion difference (DCAD) on animal performance but few have examined the effect of DCAD on the rumen ionic environment. The objective of this study was to examine the effects of DCAD, cation source (Na vs. K), and anion source (Cl vs. bicarbonate or carbonate) on rumen environment and fermentation. The study used 5 rumen-fistulated dairy cows and 5 dietary treatments that were applied using a 5 × 5 Latin square design with 2-wk experimental periods. Treatments consisted of (1) the basal total mixed ration (TMR); (2) the basal TMR plus 340 mEq/kg of Na (dry matter basis) using NaCl; (3) the basal TMR plus 340 mEq/kg of K using KCl; (4) the basal TMR plus 340 mEq/kg of Na using $NaHCO_3$; and (5) the basal TMR plus 340 mEq/kg of K using K_2CO_3. On the last day of each experimental period, rumen samples were collected and pooled from 5 different locations at 0, 1.5, 3, 4.5, 6, 9, and 12 h postfeeding for measurement of rumen pH and concentrations of strong ions and volatile fatty acids (VFA). Dietary supplementation of individual strong ions increased the corresponding rumen ion concentration. Rumen Na was decreased by 24 mEq/L when K was substituted for Na in the diet, but added dietary Na had no effect on rumen K. Rumen Cl was increased by 10 mEq/L in diets supplemented with Cl. Cation source had no effect on rumen pH or total VFA concentration. Increased DCAD increased rumen pH by 0.10 pH units and increased rumen acetate by 4 mEq/L but did not increase total VFA. This study demonstrated that rumen ion concentrations can be manipulated by dietary ion concentrations. If production and feed efficiency responses to DCAD and ionophores in the diet are affected by rumen Na and K concentrations, then manipulating dietary Na and K could be used either to enhance or diminish those responses.

Key words: dietary cation-anion difference, rumen ions, dairy cattle

INTRODUCTION

Dietary cation-anion difference is used as a tool to evaluate the strong ion (Na, K, and Cl) balance in formulation of dairy cattle diets; DCAD (mEq/kg of DM) can be calculated as Na + K – Cl (Mongin, 1981; Tucker et al., 1988) or as Na + K – Cl – S (Ender et al., 1962). Although extensive research has shown that manipulating DCAD can increase performance by improving feed intake, milk production, and acid-base status of the animal (Mongin, 1981; Tucker et al., 1988; Hu and Murphy, 2004), little research has been done to examine the effects of the individual ions that contribute to DCAD or the effect of DCAD on the rumen environment. Although the effect of diet on the rumen ion environment has been studied previously (Bailey, 1961; Bennink et al., 1978), to our knowledge, only one study has investigated the effect of DCAD on rumen ion concentrations (Tucker et al., 1988).

Increasing DCAD enhances animal performance by increasing DMI, milk yield, and feed efficiency (Tucker et al., 1988; Sanchez et al., 1994; Hu and Murphy, 2004). In addition to total DCAD, there is some evidence that cation source may affect animal performance. Iwaniuk et al. (2015) found that substitution of Na for K as the supplemental cation source in DCAD constant diets increased milk fat percentage and fat yield. In contrast, Wildman et al. (2007) and Hu and Kung (2009) found no effect of cation source on these parameters when DCAD remained constant. Unfortunately, none of these studies measured rumen ion concentrations or considered the rumen cation-anion difference (**RCAD**). Tucker et al. (1988) did measure rumen parameters when using different combinations of ions to achieve specific DCAD values but only reported the results by DCAD concentration and not by the different ion concentrations used to achieve each DCAD.

Although Na is the predominant cation in rumen fluid, Bennink et al. (1978) demonstrated that dietary Na and K could influence the respective rumen concentrations of Na and K. Shifts in rumen Na and K concentrations could potentially mediate rumen fermentation responses to ionophores. Ionophores form complexes with specific cations, and these complexes

Received January 4, 2016.
Accepted April 21, 2016.
[1]Corresponding author: erdman@umd.edu

bind to cell walls of bacteria, resulting in extracellular Na replacing intracellular K, limiting the bacteria's ability to function and divide (McGuffey et al., 2001; Ipharraguerre and Clark, 2003). Monensin binds Na ions with 10 times the affinity that it binds K ions, whereas lasalocid binds K ions with 3 to 10 times the affinity that it binds Na ions (McGuffey et al., 2001). Newbold et al. (2013) recently demonstrated increased monensin sensitivity in rumen bacteria by increasing media Na, but reduced monensin sensitivity in media with increased K. These results support previous in vivo evidence (Rumpler et al., 1986) that showed a much greater reduction in methane production in steers fed monensin or lasalocid when supplemented with added dietary Na but not with added dietary K. Further, rumen propionate responses to lasalocid were attenuated in lambs supplemented with K (Funk et al., 1986).

The previous in vivo (Funk et al., 1986; Rumpler et al., 1986; Iwaniuk et al., 2015) and in vitro studies (Newbold et al., 2013) suggested that, in addition to DCAD concentration, cation source and changes in rumen ion concentrations might also influence rumen fermentation and production responses. Our hypothesis was that dietary strong ion concentrations and DCAD affect rumen ion concentrations. The objective of this study was to examine the effects of DCAD, cation source, and anion source on the rumen ionic environment and further examine their effects on rumen fermentation.

MATERIALS AND METHODS

Research Facilities and Animals

All procedures involving animals were carried out as approved by the Institutional Animal Care and Use Committee at the University of Maryland. Animals were housed at the Central Maryland Research and Education Center in Ellicott City, Maryland. Five rumen-fistulated, multiparous Holstein cows in late lactation (245 ± 4.5 DIM at the start of the experiment) were used in a 10-wk study that was conducted between June and August 2014. Three cows were in early pregnancy and 2 cows were not pregnant at the start of the experiment. The cows were housed in tie stalls that were fitted with water mattresses and bedded with sawdust. Water was available ad libitum through automatic waterers located in between each stall. The cows were taken out of the barn for milking twice daily, at approximately 0615 and 1530 h. Stalls were cleaned and bedded while the cows were out of the barn for milking. Fans were used to help increase air circulation and reduce temperatures in the barn. The barn photoperiod during the study was 16 h of light and 8 h of dark. Cows were individually fed a TMR once daily, at 0700 h, and had continuous access to feed except when they were turned out for milking.

Experimental Diets

Cows were fed a TMR formulated to meet or exceed the NRC (2001) requirements for cows producing 40 kg of milk per day. The TMR basal diet consisted of 57.4% corn silage and 8.4% alfalfa hay as the forages (DM basis), with the remainder of the diet consisting of ground corn, soybean meal (48% CP), and a vitamin-mineral premix using corn gluten meal as the carrier. Ingredient composition of the basal and treatment diets is shown in Table 1. The basal TMR was prepared in a Calan Data Ranger feed mixer (American Calan, Northwood, NH). Feed was dispensed into individual feed bins, with each cow receiving enough feed to generate an as-fed feed refusal rate of 2 to 4 kg/d.

Experimental treatments consisted of (1) the basal TMR (Basal); (2) the basal TMR plus 340 mEq/kg added Na (DM basis) using supplemental sodium chloride (NaCl); (3) the basal TMR plus 340 mEq/kg added K using supplemental potassium chloride (KCl); (4) the basal TMR plus 340 mEq/kg added Na using supplemental sodium bicarbonate ($NaHCO_3$); and (5) the basal TMR plus 340 mEq/kg added K using supplemental potassium carbonate (K_2CO_3). The level of supplementation, 340 mEq per kg of diet DM equivalent to 0.78% and 1.33% added Na and K, respectively, was selected to ensure a treatment response while keeping within the expected potential range of DCAD and K concentrations observed when feeding ingredients with high K and Cl concentrations such as in diets containing small grain silages and alfalfa. Treatments were applied in a 5 × 5 Latin square design with 2-wk experimental periods.

During each experimental period, there was only one cow per dietary treatment. Thus, to prevent the loss of mineral supplements during the feed mixing process, treatment mineral supplements were added to the basal TMR for each cow in their individual feeding tubs and then mixed with a pitchfork. The mineral treatments supplied an additional 342 ± 0.4 (average ± SEM) mEq/kg of diet DM of either Na or K. Diets that were supplemented with chloride received an additional 347 ± 4.1 (average ± SEM) mEq/kg of diet DM of Cl. Table 2 shows the chemical composition of the experimental diets.

Measurements

Cows were weighed after the morning milking before feeding on the last day of wk 1 and 2 of each