Effect of different potassium levels in hay on acid–base status and mineral balance in periparturient dairy cows

M. Rérat,^{*1} A. Philipp,^{*†2} H. D. Hess,^{*} and A. Liesegang[†]

^{*}Agroscope Liebefeld-Posieux Research Station ALP, PO Box 64, CH-1725 Posieux, Switzerland

[†]Institute of Animal Nutrition, Vetsuisse Faculty, University of Zurich, CH-8057 Zurich, Switzerland

ABSTRACT

Forages commonly used in dry cow rations contain high K concentrations. This results in a high dietary cation–anion difference (DCAD), which can compromise the calcium homeostasis of periparturient cows. The aim of this study was to determine the effect of 2 types of hay, fed during the prepartum period and differing in their K concentrations, on the peripartum acid–base status and mineral balance of dairy cows. During the prepartum period, the cows of group K₃₃ (n = 6) received a diet based on hay with a high K concentration (33 g/kg of DM), whereas the cows of group K₁₃ (n = 6) received a diet based on hay with a low K concentration (13 g/kg of DM). Both experimental diets were formulated to be isoenergetic and isonitrogenous. After calving, all cows received the same diet based on hay K₃₃. Blood and urine samples were taken on d 14, 7, and 3 before parturition, at parturition, and then daily during the first 8 d after calving. Concentrations of minerals were analyzed in both blood and urine. Creatinine was also measured in urine for the calculation of the mineral:creatinine ratio. The acid–base parameters in blood (pH and HCO₃[−] concentration) and urine (pH, net acid–base excretion, and base–acid quotient) were determined on d 14, 7, and 3 before parturition, at parturition, and on d 1 after parturition. The use of hay K₁₃ reduced the DCAD value of the prepartum diet by half (195 vs. 514 mEq/kg of DM). No significant differences between the 2 groups were observed for blood acid–base indicators or plasma minerals except for the Mg plasma concentration, which tended to be higher in group K₁₃ from d 3 prepartum to d 2 after calving. In group K₁₃, urinary Ca excretion tended to be higher from d 3 prepartum to d 1 after parturition than that in group K₃₃. On d 3 before parturition, urinary pH

and net acid–base excretion were significantly lower in group K₁₃ than in group K₃₃. On d 14, 7, and 3 before parturition, base–acid quotient was significantly lower in group K₁₃ than in group K₃₃. In group K₁₃, daily feed intake and hence daily intake of Ca, P, and Mg during d 3 and 4 after parturition were higher than in group K₃₃. The decrease of the DCAD in positive ranges by feeding a low-K hay before parturition induced a reduction of the metabolic alkalotic charge, as observed in acid–base parameters in urine, and increased the availability of Ca and P as a result of higher feed intake at the onset of lactation.

Key words: potassium, dietary cation–anion difference, acid–base status, dairy cow

INTRODUCTION

For economical and ethical reasons, forage-based milk production systems are of increasing importance, particularly in organic production. Grass and grass–legume forages represent the principal feed source in these systems, where the fertilizer used is often based on organic manure. Because of its high K concentration, the use of slurry fertilizer leads to an enrichment of K in the soil (Soder and Stout, 2003) and this in turn results in high K concentrations in forage (ALP, 2008). Because dry cow rations are often exclusively based on forage, the dietary concentration of K during the prepartum period is generally high. These diets have a very high DCAD (Liesegang et al., 2007) and can compromise the calcium homeostasis of periparturient cows. Goff and Horst (1997) demonstrated that a high dietary concentration of strong cations, especially K, can induce metabolic alkalosis in the prepartum dairy cow, which reduces the ability of the cow to maintain Ca homeostasis. Whereas other minerals such as Ca, P, Na, and Cl are usually supplemented with mineral feeds for adjustment of dietary imbalances, K is not usually added (Leiber et al., 2009). Consequently, different K concentrations in forage can influence the DCAD and mineral metabolism in dairy cows.

Some studies have been published on the effects of forages with contrasting DCAD on the acid–base status

Received June 3, 2009.

Accepted September 10, 2009.

¹Corresponding author: michel.rerat@alp.admin.ch

²Part of a thesis for Dr. Med. Vet., accepted by Vetsuisse Faculty, University of Zurich, 2008.

and mineral metabolism of periparturient dairy cows. The study of Delaquis and Block (1995) showed that a slight variation in positive DCAD affected acid–base status but not blood metabolites. The study of Roche et al. (2002) on cows grazing on pastures with altered K concentrations showed that the application of K fertilizer resulted in a DCAD ranging from 350 to 535 mEq/kg of DM, but that the Ca homeostasis in dairy cows was not changed. Charbonneau et al. (2008) reported that feeding low-DCAD timothy hay was an effective means of decreasing the DCAD of rations and obtaining a metabolic response in dry dairy cows. Because K is high in forage and is the major cation that determines the DCAD in this type of feed (Roche et al., 2002), further research is needed to determine how different natural K concentrations in prepartum diets may influence mineral homeostasis and acid–base status of periparturient dairy cows.

The aim of this experiment was to determine the effect of 2 types of hay, fed during the transition period and differing in their K concentration, on the peripartum mineral balance of dairy cows. In addition, indicators of acid–base changes in urine and blood were tested during the prepartum period to investigate their suitability as tools to detect early changes in acid–base status in the periparturient cow.

MATERIALS AND METHODS

Design, Animals, and Feeds

All procedures were in accordance with the Swiss guidelines for animal welfare and were approved by the Animal Care Committee of the Canton Fribourg, Switzerland. Sixteen cows (14 Holstein and 2 Brown Swiss), with 2 or more completed lactations and without antecedent episodes of clinical hypocalcemia, were selected for the trial and assigned to 2 diets based on hay with a natural K concentration of 13.4 (diet **K₁₃**) or 33.0 (diet **K₃₃**) g/kg of DM. The cows were paired by breed, number of lactations (mean values = 3.2 and 3.1 for groups **K₁₃** and **K₃₃**, respectively), and milk production (mean values = $8,305 \pm 395$ and $7,976 \pm 373$ kg of milk yield after 305 d of lactation for groups **K₁₃** and **K₃₃**, respectively). During the last 5 wk before the estimated calving (285 d of gestation), 1 cow from each pair was assigned to the experimental **K₁₃** regimen and the other assigned to the experimental **K₃₃** regimen. Cows were individually housed in a tie stall with rubber mat flooring during the prepartum period. After calving, all cows received the same dietary regimen and were kept in metabolism crates equipped with a slatted floor. The balance period lasted for 7×24 h and began

at 900 h on the day after calving (minimum 24 h and maximum 48 h after calving). Prior to the start of the balance period, cows were put in the metabolism crates for 1 d in order to get them accustomed to the crate.

During the prepartum period, the cows of experimental group **K₁₃** received 75 g of DM/kg of $BW^{0.75}$ of hay daily with a natural K concentration of 13.4 g/kg of DM (Table 1). The hay was the first harvest from the previous year and was composed of 60% grasses and 15% legumes. The grass was nonfertilized and floor dried. Additionally, cows were fed 7.5 g of DM/kg of $BW^{0.75}$ of a mineral- and protein-rich supplement containing 463 g of extracted rapeseed meal, 371 g of barley, 72 g of urea, 46 g of molasses, 23 g of ammonium phosphate, and 19 g of sodium phosphate per kg of DM. This supplement to the **K₁₃** diet was formulated to balance the low level of minerals (especially Cl and P) and protein in **K₁₃** hay compared with **K₃₃** hay.

During the prepartum period, the cows of experimental group **K₃₃** were fed 75 g of DM/kg of $BW^{0.75}$ of hay daily with a natural K concentration of 33.0 g/kg of DM. The hay was the second harvest from 2 yr previous and was composed of 72% grasses and 20% legumes. The grass had been fertilized first with ammonium nitrate and later with slurry.

Besides having a lower K concentration, the **K₁₃** hay also presented lower S and Cl concentrations than **K₃₃** hay. Nevertheless, the DCAD of **K₁₃** hay was only approximately half of the DCAD of **K₃₃** hay (228 vs. 544 mEq/kg of DM).

In addition to hay, cows received 15 g of NaCl and 6 g of MgO daily. During the last 2 wk before calving, all cows received an increasing level of feed concentrate (8, 16, and 24 g of DM/kg of $BW^{0.75}$ on d 15 to 11, 10 to 6, and 5 to 1 before calving, respectively) containing 190 g of wheat, 250 g of maize, 230 g of barley, 190 g of soybean meal, 110 g of apple pomace, and 30 g of sugar beet pulp per kg (Table 2).

After calving, all cows were offered daily the **K₃₃** hay ad libitum, 32 g of DM/kg of $BW^{0.75}$ of the feed concentrate, and 2 g of DM/kg of $BW^{0.75}$ of a mineral mixture. The composition of the mineral mixture was 262 g of corn cube, 100 g of wheat bran, 170 g of NaCl, 50 g of calcium carbonate, 300 g of dicalcium phosphate, and 20 g of trace mineral mix (1,300 mg of Zn, 620 mg of Mn, 160 mg of Cu, 6.6 mg of Se, and 3.3 mg of Co) per kg of DM.

The mineral- and protein-rich supplement, the mineral mixture, and the feed concentrate were mixed and provided as 2 equal meals at 0700 and 1630 h for 30 min, after which the feed was withdrawn. Throughout the experiment, cows had unlimited access to fresh water.

Table 1. Composition of the diet components¹

Item	Hay K ₁₃	Hay K ₃₃	Mineral- and protein-rich supplement	Mineral mixture	Feed concentrate
Ingredient, g/kg of DM					
DM ²	903	893	899	932	878
CP	64	127	458	58	194
NDF	596	525	218	149	218
ADF	380	300	123	69	80
ADL ³	57	35	47	18	21
Ca	4.3	4.2	4.5	92.7	1.1
P	1.7	3.8	18.6	62.6	4.4
Mg	1.6	1.4	2.8	27.6	1.6
Na	0.3	0.3	6.6	73.2	0.4
K	13.4	33.0	10.6	4.3	9.7
Cl	2.1	6.7	4.7	104.5	1.1
S	1.1	2.0	4.3	1.2	2.1
Calculated concentration					
APD, ⁴ g/kg of DM	63	87	105	39	130
NE _L , ⁵ MJ/kg of DM	4.2	5.2	6.1	3.8	8.0
DCAD, ⁶ mEq/kg of DM	228	544	158	273	104

¹K₁₃ = hay with a K concentration of 13 g/kg of DM; K₃₃ = hay with a K concentration of 33 g/kg of DM.

²Grams per kilogram of wet weight.

³ADL = acid detergent lignin.

⁴APD = absorbable protein at the duodenum, according to ALP (2008).

⁵According to ALP (2008).

⁶According to Block (1984).

Data Recording and Sample Collection

Hays were sampled 5 times per week and pooled. The mineral- and protein-rich supplement, the mineral mixture, and the feed concentrate were sampled twice a week and pooled every 2 wk. During the prepartum period, the daily feed refusals were collected individually, stored at -20°C , and pooled together for analysis. During the balance period, hay, mineral mixtures, and feed concentrates were collected individually per cow and per day and the 7 daily samples were pooled. The refusals during the balance period were collected individually, stored at -20°C , and proportionally pooled. Feed intake was recorded daily.

Blood samples were taken between 1400 and 1500 h from the jugular vein with evacuated tubes, with and without heparin (Vacuettes; Greiner Bio-one, Solingen, Germany) on d 14, 7, and 3 before the estimated calving, as well as at parturition, d 1 after parturition, and daily during the balance period (d 2–8 after parturition). Within 1 h after sampling, samples were centrifuged at $1,500 \times g$ for 15 min. Plasma and serum were stored at -20°C . Additionally, tubes with EDTA were used for the determination of blood gases immediately after sampling on d 14, 7, and 3 before the estimated calving.

Urine samples were collected between 1400 and 1600 h on d 14, 7, and 3 before the estimated calving as well as at parturition and d 1 after parturition. Cows were manually stimulated to urinate and a sample of urine

at midstream was collected. Within 1 h after collection, pH and the acid–base status parameters were measured. Urine samples were stored at -20°C for mineral analysis. During the balance period [balance day (BD) 1–7], total amounts of urine and feces were recorded daily at 0900 h and samples were stored at -20°C . Urine was collected in plastic containers from a urinal that was attached around the vulva of the cow with Velcro tapes fixed to the shaved skin with instant glue (Cyanolit; 3M AG, Rüschlikon, Switzerland). Urine was collected without the addition of acid.

During the balance period, milk yields were determined at each milking (0500 and 1600 h). Milk samples from both milkings of each BD were pooled proportionately and stored at -20°C for mineral analysis.

Laboratory Analysis

Before laboratory analysis, feed samples and refusals were ground to pass a 1.0-mm sieve (Brabender mill #880804, Brabender, Duisburg, Germany). Contents of DM were quantified gravimetrically (3 h at 105°C) and feces were quantified by freeze drying, milling, and subsequent heating at 105°C for 3 h. Total ash was determined by incineration at 550°C for 4 h. Cell wall constituents were analyzed using the Ankom 200/220 Fiber Analyzer (Ankom Technology Corporation, Fairport, NY). The ADF was analyzed according to AOAC (1995; method 973.18) and was expressed without residual ash after incineration at 500°C for 1 h.

Table 2. Composition of the experimental diets¹

Item	Days 15 to 11 prepartum ²				Days 10 to 6 prepartum ³				Days 5 to 1 prepartum ⁴			
	K ₁₃		K ₃₃		K ₁₃		K ₃₃		K ₁₃		K ₃₃	
	Per kg of BW ^{0.75}	Per kg of DM	Per kg of BW ^{0.75}	Per kg of DM	Per kg of BW ^{0.75}	Per kg of DM	Per kg of BW ^{0.75}	Per kg of DM	Per kg of BW ^{0.75}	Per kg of DM	Per kg of BW ^{0.75}	Per kg of DM
Ingredient												
CP, g	9.8	108	11.1	133	11.4	115	12.6	139	12.9	121	14.2	143
NDF, g	48.1	531	41.1	495	49.8	506	42.9	470	51.6	484	44.6	450
ADF, g	30.1	332	23.1	278	30.7	312	23.8	261	31.3	294	24.4	246
ADL, ⁵ g	4.8	53.0	2.8	33.6	5.0	50.4	3.0	32.5	5.1	48.2	3.2	31.6
Ca, g	0.37	4.0	0.32	3.9	0.38	3.8	0.33	3.7	0.39	3.6	0.34	3.4
P, g	0.30	3.3	0.32	3.9	0.34	3.4	0.36	3.9	0.37	3.5	0.39	3.9
Mg, g	0.15	1.7	0.12	1.9	0.16	1.7	0.13	1.9	0.18	1.7	0.14	1.9
Na, g	0.07	0.8	0.03	0.9	0.08	0.8	0.03	0.9	0.08	0.8	0.03	0.8
K, g	1.16	12.8	2.55	30.7	1.24	12.6	2.63	28.9	1.31	12.4	2.71	27.3
Cl, g	0.2	2.2	0.51	6.8	0.21	2.1	0.52	6.3	0.22	2.1	0.53	5.9
S, g	0.13	1.5	0.17	2.0	0.15	1.5	0.18	2.0	0.17	1.6	0.2	2.0
Calculated concentration												
APD, ⁶ g	6.6	72	7.6	91	7.6	77	8.6	94	8.6	81	9.7	97
NE _L , ⁷ MJ	0.42	4.7	0.45	5.5	0.49	5.0	0.52	5.7	0.55	5.2	0.58	5.9
DCAD, ⁸ mEq		211		510		203		475		195		445

¹K₁₃ = group receiving hay with a K concentration of 13 g/kg of DM; K₃₃ = group receiving hay with a K concentration of 33 g/kg of DM.

²Eight grams of DM feed concentrate/kg of BW^{0.75}.

³Sixteen grams of DM feed concentrate/kg of BW^{0.75}.

⁴Twenty-four grams of DM feed concentrate/kg of BW^{0.75}.

⁵ADL = acid detergent lignin.

⁶APD = absorbable protein at the duodenum, according to ALP (2008).

⁷According to ALP (2008).

⁸According to Block (1984).

Analysis of NDF was based on the method of Mertens (2002) with the addition of heat-stable amylase and results were expressed without residual ash. Total N concentration of feeds, refusals, milk, and urine was analyzed by the Kjeldahl procedure (method 988.05; AOAC, 1995). The CP concentration was calculated as $6.25 \times$ total N concentration. Levels of Ca, P, Mg, K, and Na were quantified in the incineration residues of feedstuffs, feces, and urine after solubilization in nitric acid 65% with an inductively coupled plasma optical emission spectrometer (Optima 2100 DV ICP-OES, PerkinElmer, Waltham, MA). The levels of S in feedstuffs were analyzed by infrared spectrometry (SC-432; Leco Corporation, St. Joseph, MI). After dilution in nitric acid, Cl concentrations in feedstuffs were determined by argentometrical titration using a Metrohm 716-titroprocessor (Herisau, Switzerland). Creatinine in urine was analyzed using an automatic analyzer (Cobas Mira, Roche, Basel, Switzerland). The urinary density was determined using a density meter (DMA 38; Anton Paar, Graz, Austria). For urine, pH was determined with a pH electrode (model 6.0202.10, Metrohm AG, Herisau, Switzerland) attached to a pH meter (EA 940, Orion, Cambridge, MA) and the fractionated net acid–base excretion (**NABE**) was analyzed by titration (665 Dosimat, Metrohm AG, Herisau, Switzerland) as described by Bender and Staufenbiel (2003). Urine titratable alkalinity was determined by titration of urine samples with 1 *N* HCl. Urine titratable acidity and ammonium concentrations were determined by titration of urine samples with 0.1 *N* NaOH.

The concentration of total Ca in blood plasma was measured using test kit #1489216 from Roche; P and Mg levels were analyzed using test kits #61571 and 61411, respectively, from BioMérieux (Marcy l'Etoile, France). An automatic analyzer was used for their analysis (Alizé 200, BioMérieux). An i-STAT portable clinical analyzer was used for the analyses of pH and HCO_3^- in whole blood (Abbott Point of Care Inc., East Windsor, NJ).

The levels of Ca, Mg, K, and Na in milk were determined by atomic absorption spectrometry (Varian SpectraAA 800, Varian Inc., Palo Alto, CA). The level of P was determined by photometry (V530 photometer, Jasco, Tokyo, Japan).

Calculations and Statistical Analysis

The dietary concentrations of absorbable protein at the duodenum and NE_L were calculated according to ALP (2008). The DCAD was calculated with the formula $\text{DCAD (mEq/kg of DM)} = (\text{Na}^+ + \text{K}^+) - (\text{Cl}^- + \text{S}^{2-})$ (Block, 1984). The fractionated NABE was calculated with the formula $\text{NABE (mmol/L)} =$

urine base concentration – (urine acid concentration + ammonium concentration), and the base–acid quotient (**BAQ**) calculated with the formula $\text{BAQ (mmol/L)} = \text{urine acid concentration/urine base concentration}$ according to Bender and Staufenbiel (2003). For the analysis of the results, the times of sampling in relation to calving were calculated from the actual time of parturition and not from the estimated calving time.

Data were analyzed using the RANDOM and REPEATED methods of the MIXED procedure of NCSS 2000 (NCSS, Kaysville, UT). Group effects were tested using the Kruskal-Wallis test and the time effect was tested using the Wilcoxon-Rang test. Values were expressed as means $\pm$ SEM; $P \leq 0.05$ was considered statistically significant.

RESULTS

Animals and Feeds

Of the 8 cows in each group at the beginning of the trial, 2 of the animals in group K_{33} and 1 in group K_{13} suffered from clinical hypocalcemia and were excluded from the trial. One cow from group K_{13} was recumbent on the day after calving and was treated for hypocalcemia. Although the pretreatment plasma Ca concentration was within the normal range, this cow was also excluded from the trial because of the intravenous Ca treatment. The mean DCAD values of the consumed prepartum K_{13} and K_{33} diets are shown in Table 3. The daily feed intakes were similar ($P > 0.05$) in both groups during the prepartum period. Except for Ca, the effective intake of nutrients was different ($P < 0.001$) between the 2 experimental groups during the prepartum period. The daily feed intake decreased ($P < 0.05$) in group K_{33} from d 2 prepartum to calving (Figure 1). After parturition, the daily feed intake in group K_{13} increased ($P < 0.05$) from d 2 to 4 and was higher ($P < 0.05$) than in group K_{33} on d 3 and 4. The mean daily feed intake and the effective intake of nutrients were similar ($P < 0.05$) during the balance period in both experimental groups (Table 3).

Concentrations of Blood Parameters

Plasma Ca concentrations declined ($P < 0.05$) from d 3 prepartum to d 1 after calving in both groups (Figure 2). Calcium increased ($P < 0.05$) from d 1 to 5 after calving in group K_{13} and from d 1 to 8 after calving in group K_{33} . In group K_{13} , plasma P concentrations declined ($P < 0.05$) from d 3 prepartum to calving and increased ($P < 0.05$) from calving to d 4 postpartum (Figure 3). In group K_{33} , P increased ($P < 0.05$) from d 1 to 6 after calving. Plasma Mg concentrations in

Figure 1. Variations in DMI for cows fed diets with different K levels in hay before parturition. Bars represent standard errors of the means. K₁₃ and K₃₃ = groups receiving hay with a K concentration of 13 or 33 g/kg of DM, respectively.

Figure 2. Profiles of mean serum Ca concentrations in cows fed diets with different K levels in hay before parturition. Bars represent standard errors of the means. K₁₃ and K₃₃ = groups receiving hay with a K concentration of 13 or 33 g/kg of DM, respectively.

group K₁₃ increased ($P < 0.05$) from d 3 prepartum to parturition (Figure 4). In both groups, Mg decreased ($P < 0.05$) from parturition to d 4 postpartum. No differences ($P > 0.05$) between the 2 groups were observed for plasma Ca and P during the entire experimental period. However, as is apparent in Figures 2 and 3, plasma Ca and P did return to normal values more rapidly in group K₁₃ than they did in group K₃₃. Plasma Mg tended to be higher ($P < 0.1$) in group K₁₃ from d 3 prepartum to d 2 after calving. The mean HCO₃ concentration (27.3 ± 1.1 and 26.9 ± 0.9 mmol/L for

groups K₁₃ and K₃₃, respectively) and pH (7.38 ± 0.02 and 7.39 ± 0.02 for groups K₃₃ and K₁₃, respectively) in blood were similar ($P > 0.05$) in both groups.

Concentrations of Urinary Parameters

Because excretion of creatinine is relatively constant (Albin and Clanton, 1966), the urine creatinine concentration was used as an index to estimate excretion of minerals in urine. The expression of urine minerals as a mineral:creatinine ratio overcomes variations in

Table 3. Effective nutrient intake during the prepartum and balance periods of cows fed diets with different K levels in hay¹

Item	Prepartum diet				Balance period			
	K ₁₃	K ₃₃	SEM	P-value	K ₁₃	K ₃₃	SEM	P-value
DMI, kg/d	12.6	12.3	0.19	0.295	16.2	15.6	0.45	0.488
Ingredient, g/d								
Ca	47.3	48.2	0.72	0.418	74.6	71.4	2.00	0.287
P	41.4	48.6	0.98	<0.001	78.6	75.9	1.94	0.386
Mg	20.5	23.4	0.33	<0.001	29.0	28.3	0.75	0.516
Na	9.1	11.2	0.19	<0.001	23.9	22.4	0.84	0.221
K	158	371	3.0	<0.001	409	405	14.0	0.831
Cl	29.3	80.7	0.57	<0.001	109	106	4.0	0.567
S	18.5	23.1	0.44	<0.001	33.1	32.0	0.88	0.387
Calculated values								
APD, ² g/d	1,017	1,168	18.3	<0.001	1,535	1,469	45.2	0.318
NE _L , ³ MJ/d	66.0	74.3	0.96	<0.001	76.5	72.2	2.49	0.256
DCAD, ⁴ mEq/d	195	514	4.9	<0.001	393	407	4.8	0.384

¹K₁₃ = group receiving hay with a K concentration of 13 g/kg of DM; K₃₃ = group receiving hay with a K concentration of 33 g/kg of DM.
²APD = absorbable protein at the duodenum, according to ALP (2008).
³According to ALP (2008).
⁴According to Block (1984).

Figure 3. Profiles of mean serum P concentrations in cows fed diets with different K levels in hay before parturition. Bars represent standard errors of the means. K₁₃ and K₃₃ = groups receiving hay with a K concentration of 13 or 33 g/kg of DM, respectively.

urine volume among animals. Urinary Ca excretion in group K₁₃ increased ($P < 0.05$) during the first 24 h after calving, from 0.006 mmol/mmol of creatinine at calving to 0.008 ± 0.003 at d 1 postpartum. Urinary concentrations of Ca in group K₁₃ tended to be higher ($P < 0.1$) from d 3 prepartum to d 1 after calving than they were in group K₃₃ (mean values = 0.009 ± 0.003 and 0.005 ± 0.001 mmol/mmol of creatinine for groups K₁₃ and K₃₃, respectively). The urinary P excretion in both experimental groups remained unchanged (mean values = 0.031 ± 0.007 and 0.031 ± 0.001 mmol/mmol

Figure 4. Profiles of mean serum Mg concentrations in cows fed diets with different K levels in hay before parturition. Bars represent standard errors of the means. K₁₃ and K₃₃ = groups receiving hay with a K concentration of 13 or 33 g/kg of DM, respectively.

of creatinine for groups K₁₃ and K₃₃, respectively) and was not affected by experimental treatment. Urinary Mg excretion was higher ($P < 0.001$) in group K₁₃ than in group K₃₃ from d 14 prepartum to d 1 after calving (mean values = 0.49 ± 0.14 and 0.21 ± 0.06 mmol/mmol of creatinine for groups K₁₃ and K₃₃, respectively). Urine pH and NABE were significantly lower in group K₁₃ than in group K₃₃ on d 3 prepartum (Figures 5 and 6). During the first 24 h after calving, NABE increased ($P < 0.05$) in group K₁₃. During the entire prepartum period, the BAQ values were significantly lower ($P < 0.05$) in group K₁₃ than in group K₃₃ (Figure 7).

Balance Period

The daily intakes of DM and Ca, P, and Mg in group K₁₃ on BD 2 and 3 were higher ($P < 0.05$) than in group K₃₃ (Table 4). The urinary excretion of Mg during the entire balance period was higher ($P < 0.05$) in group K₁₃ than in group K₃₃ and urinary Na excretion was higher ($P < 0.05$) on BD 3 in group K₁₃ than in group K₃₃. The retention of Mg on BD 1 was more negative ($P < 0.05$) in group K₁₃ than in group K₃₃ and on BD 3 the retentions of Ca and P in group K₁₃ were higher ($P < 0.05$) than in group K₃₃.

DISCUSSION

Effect of Different K Concentrations in the Prepartum Diet on DCAD

Feed refusals were higher in group K₁₃, particularly the mineral- and protein-rich supplements. Consequent-

Figure 5. Profiles of mean urinary pH in cows fed diets with different K levels in hay before parturition. Bars represent standard errors of the means. K₁₃ and K₃₃ = groups receiving hay with a K concentration of 13 or 33 g/kg of DM, respectively.

Figure 6. Profiles of mean urinary net acid–base excretion (NABE) in cows fed diets with different K levels in hay before parturition. Bars represent standard errors of the means. K₁₃ and K₃₃ = groups receiving hay with a K concentration of 13 or 33 g/kg of DM, respectively.

ly, the effective intake of energy, protein, and minerals (especially Cl) in group K₁₃ was lower. In addition, a decrease in the K concentration in plants is accompanied by a decrease in the concentration of Cl (Roche et al., 2000). Chloride is a strong anion and has an important influence on DCAD (Goff, 2000). Despite this, the differences in DCAD between diets K₁₃ and K₃₃ were large (195 vs. 514 mEq/kg of DM), but the DCAD of diet K₁₃ was not sufficiently low to induce metabolic acidosis. This is in accordance with the findings of Roche et al. (2002), who reported that DCAD levels of 140 to 200 mEq/kg of DM were not sufficient to reduce systemic pH. Ions like Na, Cl, and S are present in relatively low amounts in forage and are not as relevant as is K in the determination of DCAD (Roche et al., 2002). Despite a significantly lower daily intake of P, Mg, Na, Cl, and S in group K₁₃, the observed reduction in the DCAD was primarily caused by the difference in K concentration in the 2 days. In conclusion, it was possible to reduce the DCAD value of the prepartum diet by half by using hay with a low K concentration.

Effect of Different K Concentrations in the Prepartum Diet on DMI and Mineral Balance of Periparturient Cows

Lowering DCAD in nonlactating cows may decrease DMI, as demonstrated by the meta-analysis of Charbonneau et al. (2006). The usual method is to add anionic salts, which can drastically reduce the DCAD but also reduce the palatability of the diet (Vagnoni and Oetzel, 1998). A more moderate reduction of the DCAD

values of prepartum diets by feeding forages with low K concentration, as tested in the present study, would seem to avoid this problem and may still have some positive effects on mineral balance. In contrast to the data presented by Roche et al. (2002), in the current study, a diet with a DCAD of approximately 200 mEq/kg of DM tended to increase the peripartum urine Ca concentration. This could indicate an increased intestinal absorption, increased bone resorption, or a reduced renal reabsorption even though plasma Ca concentration was unaffected (Roche et al., 2002). Tucker et al. (1992) explained that an increase in urinary Ca excretion typically represents an increased availability of Ca for metabolic functions and may be a useful measure for evaluating Ca status.

In the present study, the prepartum urinary excretion of Mg in group K₁₃ may have been increased by the lower dietary K concentration, and hence by a decreased DCAD, in agreement with earlier studies (Gaynor et al., 1989; Roche et al., 2002). The negative interaction between ruminal K concentration and Mg absorption (Martens and Schweigel, 2000) can explain the absence of increased Mg levels at calving in the blood of cows receiving the high-K diet. Regardless of dietary K, the increase in the concentration of plasma Mg at calving is probably the result of enhanced renal Mg absorption (Goff and Horst, 1997). The lower Mg concentrations in group K₃₃ from d 3 prepartum to d 2 after calving could be explained by the interference of high dietary K with ruminal absorption of Mg (Schonewille et al., 1997).

Further effects of feeding the low-K hay were also observed after calving. The daily feed intake in group

Figure 7. Profiles of mean urinary base–acid quotient (BAQ) in cows fed diets with different K levels in hay before parturition. Bars represent standard errors of the means. K₁₃ and K₃₃ = groups receiving hay with a K concentration of 13 or 33 g/kg of DM, respectively.

K₁₃ during BD 2 and 3 was higher, which had a positive effect on the Ca and P balances during the first days after parturition. Because of the higher DMI during BD 2 and 3, daily intake of Ca, P, and Mg in group K₁₃ increased. The excretion of these minerals was similar in both experimental groups, except for a slightly higher

urinary Mg excretion in group K₁₃. This resulted in an increased retention of Ca and P on BD 3. Thus, the increased availability of Ca and P during the first days after parturition may have contributed to the faster return of plasma Ca and P to normal levels in group K₁₃. These results indicate that a moderate reduction

Table 4. Daily intake of DM, Ca, P, Mg, K, and Na and urine excretion and retention of Ca, P, Mg, K, and Na during the balance period of cows fed diets with different K levels in hay¹

Item	Balance day							SEM	P-value	
	1	2	3	4	5	6	7		Group	Group × d
DMI, kg/d										
K ₁₃	13.8	16.5 ^a	17.7 ^a	16.9	16.6	15.8	16.0	0.45	0.488	0.002
K ₃₃	15.3	13.0 ^b	15.1 ^b	16.2	16.3	16.5	16.9			
Intake, g/d										
Ca										
K ₁₃	63.3	77.2 ^a	81.7 ^a	78.1	76.7	72.5	72.5	2.00	0.287	0.001
K ₃₃	73.5	61.2 ^b	70.3 ^b	72.4	72.6	74.2	75.4			
P										
K ₁₃	67.8	81.0 ^a	85.3 ^a	82.0	81.1	75.7	76.8	1.94	0.386	0.002
K ₃₃	76.9	65.0 ^b	74.0 ^b	77.7	78.0	79.0	80.9			
Mg										
K ₁₃	24.8	30.1 ^a	31.6 ^a	30.3	30.0	28.0	28.1	0.75	0.516	0.002
K ₃₃	29.1	24.5 ^b	27.7 ^b	28.7	28.8	29.3	29.8			
K										
K ₁₃	333	419	457	430	415	405	407	14.0	0.831	0.018
K ₃₃	401	333	403	415	417	424	442			
Na										
K ₁₃	20.3	25.5	25.7	25.2	25.5	22.7	22.1	0.84	0.221	0.062
K ₃₃	24.2	18.5	20.2	23.4	23.4	23.5	23.6			
Urine, g/d										
Ca										
K ₁₃	0.12	0.14	0.16	0.10	0.10	0.13	0.10	0.022	0.636	0.248
K ₃₃	0.05	0.12	0.11	0.12	0.10	0.10	0.15			
P										
K ₁₃	0.91	1.15	1.08	0.84	0.41	0.39	0.21	0.401	0.750	0.823
K ₃₃	0.59	1.12	1.62	1.21	0.81	0.54	0.39			
Mg										
K ₁₃	2.53	1.65	1.92	1.30	1.06	2.23	1.19	0.342	0.034	0.778
K ₃₃	1.11	0.85	0.54	0.56	0.18	0.12	0.17			
K										
K ₁₃	256	260	290	266	255	266	250	24.2	0.381	0.657
K ₃₃	236	222	238	201	216	231	278			
Na										
K ₁₃	4.17	8.69	11.76 ^a	6.32	6.07	6.34	2.97	1.567	0.182	0.027
K ₃₃	5.40	4.78	3.47 ^b	2.33	1.77	1.42	4.85			
Retention, g/d										
Ca										
K ₁₃	-16.8	3.8	15.1 ^a	6.8	5.9	1.7	3.8	2.66	0.238	0.005
K ₃₃	1.7	-4.4	4.7 ^b	8.8	9.6	15.0	18.1			
P										
K ₁₃	13.9	27.4	36.7 ^a	28.6	26.8	18.4	25.0	2.22	0.300	0.007
K ₃₃	27.3	17.0	25.8 ^b	31.1	29.6	33.5	36.7			
Mg										
K ₁₃	-9.19 ^b	-1.54	0.22	-2.66	-2.50	-5.05	-2.80	0.821	0.171	0.042
K ₃₃	-2.55 ^a	-4.41	-1.77	-1.05	-2.21	0.04	0.45			
K										
K ₁₃	4.4	80.7	99.1	90.5	86.9	65.2	86.9	11.42	0.067	0.402
K ₃₃	109	52.9	99.1	145	127	123	90.5			
Na										
K ₁₃	12.7	10.3	5.8	11.0	8.7	2.6	10.1	2.89	0.078	0.340
K ₃₃	16.9	11.4	14.6	19.2	19.5	19.9	16.3			

^{a,b}Means of groups K₁₃ and K₃₃ at the same balance day with different superscripts differ ($P < 0.05$).

¹K₁₃ = group receiving hay with a K concentration of 13 g/kg of DM; K₃₃ = group receiving hay with a K concentration of 33 g/kg of DM.

in the DCAD (from 514 to 195 mEq/kg of DM) in the prepartum diet may be effective in increasing both feed intake and the availability of Ca and P at the onset of lactation, which is a period of great demand for Ca and P.

Effect of Different K Concentrations in the Prepartum Diet on the Acid–Base Status of Periparturient Cows

Changes in dietary K levels could modify the acid–base status of dry cows. A decline in urinary pH by decreasing dietary K levels, and hence a decrease in DCAD value, has been previously observed (Roche et al., 2002). In group K₁₃, the significantly lower urinary pH and NABE values on d 3 before parturition and the significantly lower BAQ during the last 2 wk before parturition clearly indicate a reduction of the alkalotic charge in the metabolism of the cows of this group. Despite lower values of pH and NABE for group K₁₃ on d 14 and 7 before parturition, it was only on d 3 prepartum that a significant difference between the groups was evident. This was not the case for BAQ, which was significantly lower in group K₁₃ during the entire prepartum period. In accordance with Bender and Staufenbiel (2003), who affirmed that BAQ seemed to be more representative than NABE because of the independence of the factor BAQ to diuresis (proportional ratio between base and acid), BAQ indicated in this study an earlier reduction of the metabolic alkalosis than did either pH or NABE. The decrease observed in pH, NABE, and BAQ as calving approached in group K₁₃ could be related to the increasing proportion of concentrate feed in the diet, which resulted in lower DCAD values. However, in group K₃₃, the DCAD decreased more than in group K₁₃, but urinary pH, NABE, and BAQ remained unchanged. The reasons for these inconsistent observations are unknown. In agreement with the results of Hu et al. (2007), blood pH and HCO₃[−] concentration in both experimental groups remained stable. This showed that the reduction in the concentration of strong ions was insufficient to induce metabolic acidosis. The effect of the addition of anions to the prepartum diet to attain negative DCAD values and to alter the metabolic acid–base status has already been shown on several occasions (Block, 1984; Oetzel et al., 1988). The requirement for large amounts of anionic salts to sufficiently reduce the DCAD of forage-based diets to induce metabolic acidosis is almost impractical (Roche et al., 2002). An alternative would be the combination of a diet low in K with supplementation of anionic salts. Alternatives to sufficiently reduce DCAD require further research.

The results of the present study showed that even a moderate decrease in DCAD levels may cause some

changes in the acid–base status of periparturient cows. These changes were detected earlier with BAQ than with pH or NABE. As observed by Hu et al. (2007), acid–base parameters in urine are more sensitive indicators of the acid–base status of cows than are blood parameters.

CONCLUSIONS

The results of this study indicate that the decrease in DCAD in positive ranges by feeding a low-K hay may provide positive benefits to the prepartum acid–base status and the mineral balance shortly after parturition in dairy cows. Decreasing DCAD from 514 to 195 mEq/kg of DM induced a change in the prepartum acid–base homeostasis and reduced metabolic alkalosis, as indicated by reduced urinary pH, NABE, and BAQ. The BAQ indicator revealed this change earlier than did urinary pH or NABE and could prove to be a useful tool for early detection of changes in acid–base status in the periparturient cow. Feeding a low-K hay prepartum increased the daily feed intake during the first days after parturition and appeared to have a positive effect on the balance of Ca and P of dairy cows at the onset of lactation.

REFERENCES

- Albin, R. C., and D. C. Clanton. 1966. Factors contributing to the variation in urinary creatinine and creatinine-nitrogen ratios in beef cattle. *J. Anim. Sci.* 25:107–112.
- ALP. 2008. Fütterungsempfehlungen und Nährwerttabellen für Wiederkäuer. Online ed. Agroscope Liebefeld-Posieux Research Station ALP, Posieux, Switzerland. http://www.feed-alp.admin.ch/start.php?action=adv_search&cmd=list_feed Accessed Oct. 7, 2008.
- AOAC. 1995. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.
- Bender, S., and R. Staufenbiel. 2003. Methodical influence on selected parameters of the acid-base equilibrium in urine samples from dairy cows. [In German.] *Berl. Munch. Tierarztl. Wochenschr.* 116:432–435.
- Block, E. 1984. Manipulating dietary anions and cations for prepartum dairy cows to reduce incidence of milk fever. *J. Dairy Sci.* 67:2939–2948.
- Charbonneau, E., P. Y. Chouinard, G. F. Tremblay, G. Allard, and D. Pellerin. 2008. Hay to reduce dietary cation–anion difference for dry dairy cows. *J. Dairy Sci.* 91:1585–1596.
- Charbonneau, E., D. Pellerin, and G. R. Oetzel. 2006. Impact of lowering dietary cation–anion difference in nonlactating dairy cows: A meta-analysis. *J. Dairy Sci.* 89:537–548.
- Delaquis, A. M., and E. Block. 1995. Acid–base status, renal function, water, and macromineral metabolism of dry cows fed diets differing in cation–anion difference. *J. Dairy Sci.* 78:604–619.
- Gaynor, P. J., F. J. Mueller, J. K. Miller, N. Ramsey, J. P. Goff, and R. L. Horst. 1989. Parturient hypocalcemia in Jersey cows fed alfalfa haylage-based diets with different cation to anion ratios. *J. Dairy Sci.* 72:2525–2531.
- Goff, J. P. 2000. Pathophysiology of calcium and phosphorus disorders. *Vet. Clin. North Am. Food Anim. Pract.* 16:319–337.
- Goff, J. P., and R. L. Horst. 1997. Effects of the addition of potassium or sodium, but not calcium, to prepartum ratios on milk fever in dairy cows. *J. Dairy Sci.* 80:176–186.

- Hu, W., M. R. Murphy, P. D. Constable, and E. Block. 2007. Dietary cation-anion difference effects on performance and acid-base status of dairy cows postpartum. *J. Dairy Sci.* 90:3367-3375.
- Leiber, F., H. R. Wettsten, and M. Kreuzer. 2009. Is the intrinsic potassium content of forages an important factor in intake regulation of dairy cows? *J. Anim. Physiol. Anim. Nutr. (Berl.)* 93:391-399.
- Liesegang, A., C. Chiappi, J. Risteli, J. Kessler, and H. D. Hess. 2007. Influence of different calcium contents in diets supplemented with anionic salts on bone metabolism in periparturient dairy cows. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 91:120-129.
- Martens, H., and M. Schweigel. 2000. Pathophysiology of grass tetany and other hypomagnesemias. Implications for clinical management. *Vet. Clin. North Am. Food Anim. Pract.* 16:339-368.
- Mertens, D. R. 2002. Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: Collaborative study. *J. AOAC Int.* 85:1217-1240.
- Oetzel, G. R., J. D. Olson, C. R. Curtis, and M. J. Fettman. 1988. Ammonium chloride and ammonium sulfate for prevention of parturient paresis in dairy cows. *J. Dairy Sci.* 71:3302-3309.
- Roche, J. R., D. E. Dalley, P. Moate, C. Grainger, M. Hannah, F. O'Mara, and M. Rath. 2000. Variations in the dietary cation-anion difference and acid-base balance of dairy cows on a pasture-based diet in south-eastern Australia. *Grass Forage Sci.* 55:26-36.
- Roche, J. R., J. Morton, and E. S. Kolver. 2002. Sulfur and chlorine play a non-acid base role in periparturient calcium homeostasis. *J. Dairy Sci.* 85:3444-3453.
- Schonewille, J. T., A. T. Van't Klooster, H. Wouterse, and A. C. Beynen. 1997. Intrinsic potassium in grass silage and magnesium absorption in dry cows. *Livest. Prod. Sci.* 48:99-110.
- Soder, K. J., and W. L. Stout. 2003. Effect of soil type and fertilization level on mineral concentration of pasture: Potential relationships to ruminant performance and health. *J. Anim. Sci.* 81:1603-1610.
- Tucker, W. B., J. F. Hogue, G. D. Adams, M. Aslam, I. S. Shin, and G. Morgan. 1992. Influence of dietary cation-anion balance during the dry period on the occurrence of parturient paresis in cows fed excess calcium. *J. Anim. Sci.* 70:1238-1250.
- Vagnoni, D. B., and G. R. Oetzel. 1998. Effects of dietary cation-anion difference on the acid-base status of dry cows. *J. Dairy Sci.* 81:1643-1652.