Effectiveness of potassium carbonate sesquihydrate to increase dietary cation-anion difference in early lactation cows

J. Harrison,*¹ R. White,† R. Kincaid,‡ E. Block,§ T. Jenkins,# and N. St-Pierre¶

*Department of Animal Sciences, Washington State University, Puyallup 98371

†Department of Dairy and Animal Sciences, The Pennsylvania State University, University Park 16802

‡Department of Animal Sciences, Washington State University, Pullman 99164

§Church and Dwight Co. Inc., North Harrison St., Princeton, NJ 08543

#Department of Animal and Veterinary Sciences, Clemson University, Clemson, SC 29634

¶Department of Animal Sciences, The Ohio State University, Columbus 43210

ABSTRACT

The effect of additional dietary potassium in early lactation dairy cows was evaluated with the addition of potassium carbonate sesquihydrate, which increased dietary K from 1.3 to 2.1% of dry matter (DM) from wk 3 to 12 of lactation. Cows fed potassium carbonate sesquihydrate in the form of DCAD Plus (Church & Dwight Co. Inc., Princeton, NJ) had increased DM intake, milk fat percentage and yield, energy-corrected milk, and efficiency of milk production per unit of DM intake. Milk fat of cows fed higher dietary K had a lower concentration of *trans* fatty acids, suggesting a role for potassium carbonate sesquihydrate in the rumen in the biohydrogenation processes converting linoleic to stearic acid. Cows fed the diet with 2.1% K had greater apparent balance of K, and no effects were noted on the concentration of blood Mg or amount of fecal Mg. The data support the feeding of greater amounts of K in the early lactation cow.

Key words: potassium, milk fat, fatty acids, biohydrogenation

INTRODUCTION

Potassium (K) is the third most abundant mineral in the body, and the animal's requirement for K is highest of all mineral cations. Potassium is involved with acid-base balance, nerve transmission, muscle contraction, and maintenance of normal cardiac and renal function, and it is the major intracellular electrolyte (National Research Council, 2001). Within the context of dairy nutrition, K is traditionally associated with alleviating the effects of heat stress and is 1 of the 4 minerals used in calculating DCAD (West et al., 1991). A negative

DCAD parturient can decrease the incidence of hypocalcemic parturient paresis (Block, 1984).

During lactation, a positive DCAD can increase blood-buffering capacity (West et al., 1992). Sodium (Na) or K supplementation can be used to increase DCAD; however, excess amounts of rumen buffer or DCAD >50 mEq/100 g can decrease DMI, because of reduced palatability, and decrease milk production (Chan et al., 2005). The chemical form of the supplement influences the buffering ability as well. Carbonates have a greater buffering capacity compared with bicarbonates on a weight basis. Potassium carbonate sesquihydrate has been shown to have greater buffering capacities and greater production responses compared with potassium bicarbonate and sodium bicarbonate (West et al., 1986, 1987b).

When lactating cows are exposed to heat stress, DMI decreases, and excess panting and sweating occurs, which can lead to an increased K requirement (West et al., 2003). Potassium carbonate sesquihydrate can be used as an effective rumen buffer to stabilize rumen pH, increase DMI, and increase ruminal VFA production and acetate to propionate ratio (West et al., 1986, 1987a,b). Recent work suggests that extracellular K status can affect the contraction activity of abomasal muscles, suggesting a role in displaced abomasums (Türck and Leonhard-Maerk, 2010).

Research over the past 10 yr indicates that the early lactation cow has a greater requirement for K than previously suggested (Silanikove et al., 1997; Bannink et al., 1999; National Research Council, 2001; Nennich et al., 2005). Previous publications suggest a negative K balance in early lactation cows (Silanikove et al., 1997; Bannink et al., 1999; Nennich et al., 2005). Positive K balance in early lactating cows was observed by Delaquis and Block (1995) when K was fed at >1.8% of diet DM. Our objective in this study was to evaluate the requirement for K in the early lactation dairy cow and to determine the efficiency of milk production and

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¹Corresponding author: jhharrison@wsu.edu

K balance when cows were fed K above the levels suggested by National Research Council (2001).

MATERIALS AND METHODS

This study was approved by the Institutional Animal Care and Use Committee at Washington State University (IACUC protocol # 03689-001).

Experimental Design and Treatments

Twenty-six multiparous and 4 primiparous cows were assigned to the study at approximately 15 DIM and fed through 85 DIM in a 10-wk continuous design trial. The cows were blocked by lactation number, expected calving date, and predicted transmitting abilities to 1 of the 2 dietary treatments. The formulated concentration of K for the control diet was 1.2% of DM and increased to 2.0% of DM using potassium carbonate sesquihydrate (DCAD Plus, Church & Dwight Inc., Princeton, NJ) for the **DCAD+** treatment. Animals were determined to not be under heat stress; the trial was conducted between August and December of 2007.

Animals and Feeding

Cows were housed in a freestall facility bedded with composted manure. The dry cow ration consisted of (DM basis): 9.7% corn silage, 47.3% grass hay, 19.0% triticale silage, and 24% concentrate mix. The prepartum DCAD, defined as mEq/100 g DM $[(Na + K) - (Cl + S)]$, was formulated at about 6 mEq/100 g. Lactating rations were formulated using CPM-Dairy version 3.1 (Tedeschi et al., 2008). The ration ingredients on a DM basis (%) were alfalfa hay, 13.4%; corn silage, 12.1%; blue grass straw, 8.6%; whole cottonseed, 6.2%; distillers dried grains with solubles, 10.3%; and grain mix, 49.4%, and they were mixed without grain in a mixer wagon. The grain was mixed into a TMR and fed using a Calan Super Data Ranger (American Calan, Northwood, NH). All grain mixes (control and DCAD+) were made at the Washington State University feed mill. Grain composition is shown in Table 1. Cows were fed individually using Calan gates once per day between 1000 and 1200 h. Feed was offered in 5 to 10% excess of the previous day's intake. Samples of TMR, Orts, and individual ingredients were obtained every other week. Subsamples of the TMR were analyzed for DM, CP, ADF, NDF, ADL, Ca, P, K, Na, Cl, and S (Table 2) by wet chemistry (Cumberland Valley Analytical Services, Hagerstown, MD), acid insoluble ash (**AIA**; Agri King, Fulton, IL), and FA (Jenkins, 2010). Feed refusals were analyzed for DM. Actual dietary concentration of K

Table 1. Ingredients in control and DCAD+ (increased dietary K) grain mixes

Item, % of grain mix DM	Control	DCAD+
Corn	48.785	45.565
Barley	36.0	36.0
Peas, culled	6.0	6.0
Soybean meal, 47%	3.0	3.0
Sodium bicarbonate	2.2	2.2
Trace mineral salt ¹	1.0	1.0
Magnesium oxide	0.7	0.7
Limestone	2.13	2.13
Zinpro 4-Plex ²	0.1	0.1
Vitamin D premix ³	0.05	0.05
Vitamin A premix ⁴	0.025	0.025
Vitamin E premix ⁵	0.01	0.01
DCAD Plus ⁶	0	3.22

¹Contained 97.5% NaCl, 0.009% Se, 0.006% Co, 0.01% I, 0.035% Cu, 0.20% Fe, 0.18% Mn, 0.037% Mg, and 0.35% Zn.

²4-Plex, Zinpro Corp. (Eden Prairie, MN).

³Contains 8,818,400 IU of vitamin D₃ per kg.

⁴Contains 30,000 IU of vitamin A-acetate per g.

⁵Contains 500,044 IU of vitamin E per kg.

⁶Church and Dwight Co. Inc. (Princeton, NJ).

was 1.28 and 2.07% of DM for control and DCAD+ cows, respectively (Table 2).

Sample Collection and Analysis

Cows were milked twice daily (1100 and 2300 h), and milk weights were recorded at each milking. Weekly a.m. and p.m. composite milk samples were collected and sent to Minnesota DHIA (Zumbrota, MN) for analysis (fat, protein, casein, lactose, SCC, and MUN). Additional individual a.m. and p.m. milk samples were collected at wk 2, 5, 9, and 11 (approximately 15, 40, and 65 DIM), frozen immediately, and later analyzed

Table 2. Composition of fed 2.0% K (DCAD+) or 1.2% K (control) diets

Item, % of DM	Control	DCAD+
DM	60.1	59.4
CP	16.1	16.1
Soluble protein	34.1	31.1
ADF	19.8	19.3
NDF	35.0	34.7
Ash	7.0	8.6
Ca	0.69	0.66
P	0.37	0.36
Mg	0.43	0.45
K	1.28	2.07
Na	0.65	0.65
Cl	0.52	0.52
S	0.23	0.22
Fatty acid	3.6	3.1
DCAD, ¹ mEq/100 g of DM	32	53

¹DCAD (mEq/100 g of DM) = (Na + K) - (Cl + S).

for K and Mg by atomic absorption spectrophotometry, and milk FA as described by Jenkins (2010). Fecal samples (approximately 200 g) were collected by fecal grab once per day from the rectum of cows at 2, 5, and 9 wk of lactation. Dried, ground fecal samples were analyzed for AIA (Agri King), K, and Mg by wet chemistry (Cumberland Valley Analytical Services). The assay was conducted on a Perkin Elmer 3300 XL ICP and 5300 DV ICP (Perkin Elmer, Shelton, CT) with modifications, including 0.35-g sample of ash for 1 h at 535°C, digest in open crucibles for 20 min in 15% nitric acid on a hotplate, and dilute samples to 50 mL. Blood samples (approximately 20 mL/cow) were obtained by venipuncture of the tail vein into evacuated tubes with EDTA for collection of serum at 2, 5, and 9 wk of lactation. Blood was centrifuged at $3,000 \times g$ for 20 min at 5°C. Serum was removed, allocated into duplicate polypropylene tubes, and frozen at -20°C. Serum was analyzed for glucose with a glucose oxidase-based kit (Wako, Richland, VA) and was analyzed for K and Mg by atomic absorption spectrophotometry. Urine (approximately 200 mL) was collected via manual stimulation at 2, 5, and 9 wk of lactation and pH determined immediately. Urine samples were frozen at -20°C until they were analyzed for K and Mg using atomic absorption spectrophotometry. Body weights of all cows were recorded once weekly. Urine volume was estimated using ASABE prediction equations (Nennich et al., 2006). Amount of fecal DM was estimated from TMR and fecal AIA (Van Keulen and Young, 1977).

Atomic Absorption Analysis

Concentrations of K and Mg in milk, urine, and serum were determined by means of model 603 flame atomic absorption spectrophotometer (Perkin-Elmer Corp., Norwalk, CT). Milk, urine, and serum were diluted with deionized water or lanthanum diluent as appropriate for Mg and K determinations. Concentration standards were calculated based on the general analytical methods for atomic absorption spectrophotometry (Perkin-Elmer Corp.).

Statistical Analysis

Data were analyzed as a randomized block design with repeated measurements using the MIXED procedure of SAS version 9.2 (SAS Institute, 2001). The model included the fixed effects of treatment, week, and their interaction, and the random effect of block and treatment by block. The Kenward-Roger option of the MODEL statement was used to adjust the degrees of freedom and standard error. Various error covariance

structures were investigated; we retained the structure with the smallest Bayesian information criterion. Orthogonal linear and quadratic polynomial contrasts for week and treatment by week were constructed using the IML procedure. In addition, the SLICE option in the LSMEANS statement was used to compare the 2 treatments at each week whenever the treatment by week interaction was found to be significant.

RESULTS AND DISCUSSION

The average FA content of both TMR fed during the study is summarized in Table 2. The average FA of the 2 diets was 25.1% C16:0, 0.4% C16:1, 6.1% C18:0, 23.9% C18:1, 40.0% C18:2, 0.7% C20:0, 3.0% C18:3, and 0.8% C24:0, with the amount of C18:1 + C18:2 + C18:3 being 66.9% of total FA. This would represent an estimated intake of C18:1 + C18:2 + C18:3 FA of approximately 1,150 g/d. Whole cottonseed and distillers dried grains with solubles were the primary sources of fat in the diet.

A summary of milk production, intakes, and BW are presented in Table 3. Body weight did not differ between treatments ($P = 0.64$) but increased over time ($P < 0.0001$). Dry matter intake was significantly ($P < 0.04$) affected by the interaction of treatment and week (Table 3, Figure 1), indicating a greater persistency of DMI after 4 wk of feeding the DCAD+ diet. Cows fed the DCAD+ diet tended ($P < 0.20$) to have greater milk yield; and ECM and 3.5% FCM were significantly affected with linear contrast (Table 3), indicating greater persistency of FCM production (Table 3, Figure 2) with an average increase in ECM of about 3.0 kg and FCM of about 4.0 kg. Hu et al. (2007) reported increases in 4% FCM and milk components when DCAD was increased from -3 to 47 mEq/100 g of DM. Average milk fat percentage was increased by 0.37% ($P < 0.01$) when cows were fed the DCAD+ diet. Yield of milk fat followed a similar pattern as noted for ECM and FCM. It is noteworthy that the increase in fat test was observed even when milk fat was relatively elevated in the control cows (Table 3). Feeding DCAD Plus has previously been shown to increase milk fat content and production in cows with milk fat test of 2.4 to 3.1% and in diets supplemented to 1.5% K of total diet (West et al., 1986, 1987a). Cows fed K carbonate had improved milk fat test when compared with cows fed Na bicarbonate (West et al., 1986), suggesting that K carbonate may improve milk fat by mechanisms other than rumen buffering. Urine pH for cows fed the control and DCAD+ diets averaged 8.25 across the weeks of the study and did not differ due to diet. Sanchez and colleagues (1994) predicted that 3.5% FCM yield and

Figure 1. Average daily DMI for cows fed 2.0% (◆) or 1.2% (■) K. Color version available in the online PDF.

DMI were maximized when DCAD ((Na + K – Cl) mEq/100 g of DM) was between +30 and +50. In the current study, feeding a DCAD of 53 mEq/100 g of DM (Na + K – Cl – S) increased milk production, DMI, and fat content and production.

Average percentage of milk protein was less in cows fed the DCAD+ diet but average yield of milk protein did not differ (Table 3). Lactose, MUN, and SCC were similar between treatment groups (Table 3). Efficiency of milk production when expressed as kilograms of 3.5% FCM/kg of DMI or kilograms of ECM/kg of DMI was improved ($P < 0.08$) by 0.08 to 0.11 kg of milk/kg of DMI (Table 3) when cows were fed the DCAD+ diet. The observation of positive responses to DMI and 4% FCM is consistent with the meta-analysis of Hu and Murphy (2004), which predicted an increase in 4%

Figure 2. Average daily 3.5% FCM for cows fed 2.0% (◆) or 1.2% (■) K. Color version available in the online PDF.

FCM yield as DCAD increased to 50 mEq/100 g of DM.

Milk FA Profile

Table 4 summarizes the evaluation on milk fat samples from this study. Milk samples from half of the cows in each treatment group were obtained at wk 2, 5, 9, and 11. The cows selected for characterization of milk FA represented a range from low to high milk production. The added dietary potassium carbonate

Table 3. Body weight, DMI, milk, and milk composition for cows fed 2.0% K (DCAD+) or 1.2% K (control) diets

Item	Treatment (Trt)			$P <$				
	Control	DCAD +	SEM	Trt	Week	Trt × Week	Linear	Quadratic
BW, kg	671	672	24	0.84	0.0001	0.31	0.05	0.13
DMI, kg/d	26.0	26.7	0.9	0.35	<0.0001	0.04	0.13	0.13
Milk, kg/d	39.5	41.6	1.6	0.2	0.0001	0.60	0.52	0.50
ECM, kg/d	41.7	44.8	1.8	0.21	0.25	0.10	0.03	0.69
3.5% FCM, kg/d	42.8	46.7	1.9	0.14	0.14	0.12	0.05	0.79
Fat, kg/d	1.58	1.77	0.80	0.10	0.08	0.06	0.07	0.93
True protein, kg/d	1.16	1.15	0.42	0.94	0.001	0.16	0.02	0.13
Milk composition								
Fat, %	4.01	4.38	0.10	0.01	0.0001	0.12	0.46	0.51
True protein, %	2.95	2.78	0.05	0.01	0.0001	0.12	0.01	0.02
Casein, %	2.42	2.29	0.04	0.03	<0.0001	0.14	0.03	0.02
Lactose, %	4.88	4.92	0.06	0.61	<0.0001	0.003	0.001	0.28
MUN, mg/dL	10.4	10.7	0.30	0.45	<0.0001	0.15	0.18	0.43
SCC, 1,000/mL	244	282	142	0.85	0.42	0.52	0.10	0.58
Feed efficiency, kg of 3.5% FCM/kg of DMI	1.68	1.79	0.04	0.03	0.0001	0.14	0.77	0.21
Feed efficiency, kg of ECM/kg of DMI	1.63	1.71	0.04	0.08	0.0001	0.14	0.08	0.49

Table 4. Fatty acid (% of total FA) composition of milk fat from cows fed 2.0% K (DCAD+) or 1.2% K (control) diets

Item, % of total FA	Treatment (Trt)			<i>P</i> <		
	Control	DCAD+	SE	Trt	Week	Trt × Week
C4:0	4.37	4.48	0.13	0.55	0.0003	0.09
C6:0	1.16	1.11	0.04	0.31	0.0001	0.001
C8:0	2.63	2.4	0.15	0.05	0.0001	0.003
C10:0	0.25	0.27	0.02	0.09	0.0001	0.07
C11:0	2.93	2.71	0.14	0.19	0.0001	0.003
C12:0	9.17	8.89	0.30	0.4	0.0001	0.005
C14:0	0.635	0.56	0.06	0.35	0.0001	0.01
C14:1	1.00	0.95	0.05	0.19	0.0001	0.24
C15:0	1.00	0.95	0.05	0.25	0.0001	0.16
C16:0	25.2	25.8	0.56	0.22	0.0001	0.98
C16:1	1.47	1.32	0.05	0.03	0.0001	0.41
C17:0	0.64	0.65	0.02	0.4	0.0001	0.07
C18:0	12.6	14.2	0.48	0.02	0.0001	0.06
<i>trans</i> -6, <i>trans</i> -8 C18:1	0.36	0.31	0.02	0.03	0.91	0.3
<i>trans</i> -9 C18:1	0.29	0.26	0.01	0.07	0.75	0.51
<i>trans</i> -10 C18:1	0.68	0.40	0.09	0.03	0.59	0.46
<i>trans</i> -11 C18:1	1.43	1.05	0.17	0.11	0.33	0.65
<i>trans</i> -12 C18:1	0.61	0.55	0.027	0.09	0.27	0.64
C18:1	21.6	21.8	0.62	0.84	0.0001	0.02
C18:2	3.31	3.18	0.151	0.48	0.41	0.83
C18:3	0.46	0.46	0.015	0.89	0.0001	0.53
C20:0	0.18	0.18	0.008	0.51	0.97	0.35
<i>cis</i> -9, <i>trans</i> -11 CLA ¹	0.44	0.34	0.033	0.03	0.47	0.46
<i>trans</i> -10, <i>cis</i> -12 CLA	0.09	0.09	0.005	0.93	0.35	0.41
C21:0	0.11	0.09	0.009	0.24	0.68	0.37
<i>trans</i> -9, <i>trans</i> -11 CLA	0.12	0.10	0.007	0.12	0.83	0.81
C22:0	0.12	0.10	0.009	0.2	0.53	0.29
C22:1	0.18	0.16	0.008	0.28	0.16	0.77
C24:0	0.08	0.09	0.005	0.09	0.13	0.77
Other	5.46	5.19	0.097	0.06	0.007	0.72

¹Conjugated linoleic acid.

sesquihydrate decreased unsaturated and *trans* FA and increased C18:0 in milk. The data indicate less *trans* FA in milk when cows were fed additional K in the form of potassium carbonate sesquihydrate. Bauman and Lock (2006) suggested that an altered fermentation may occur in the rumen, in which the biohydrogenation of FA from linoleic to stearic resulted in more *trans* FA, with *trans*-10 C18:1 being a marker for the altered FA pathway. Although many *trans* FA were not significantly changed by dietary treatment, *trans*-10 C 18:1 was reduced when potassium carbonate sesquihydrate was fed. Data presented in Table 4 support this contention and support that one mechanism for the increase in milk fat production in this study was ruminally based. This contention is supported by observations of Jenkins et al. (2010, 2011), in which it was demonstrated in vitro that K plays a role in the biohydrogenation of FA in the rumen using continuous culture artificial rumen fermenters. The fermenter studies demonstrated that added potassium carbonate sesquihydrate reduced *trans*-10 FA. The data of Jenkins et al. (2010) suggest that when dietary K is increased, either the activity of the alternate pathway of biohydrogenation is reduced

or the activity of the desirable pathway is increased, or both, as unsaturated FA are hydrogenated to 18:0.

Potassium Balance

Intake of K and fecal excretion of K (g/d) were greater for DCAD+ cows ($P < 0.001$), with average intakes of K at 321 and 530 g/d for control and DCAD+, respectively (Table 5). However, urine and milk K were similar (Table 5). Intake of K increased over time ($P < 0.001$) as did fecal K ($P = 0.02$). Treatment averages for K balance were positive for all weeks and higher in DCAD+ cows and increased over time ($P < 0.0001$; $P < 0.08$, linear effect). Although our approach to estimating K balance was different from that of Delaquis and Block (1995), both studies observed positive balance of K when K was fed at $>1.3\%$ of diet DM. As intake of K was increased in the DCAD+ diet, fecal K increased. This observation is in contrast to that of West et al. (1987a), who observed that as dietary K increased, more K was excreted renally. One primary difference between our work and that of West et al. (1987a) was the hot weather to which cows were ex-

Table 5. Potassium balance of cows fed 2.0% K (DCAD+) or 1.2% K (control) diets

Item	Control						DCAD+						P < ¹	
	Wk 2	SEM	Wk 5	SEM	Wk 9	SEM	Wk 2	SEM	Wk 5	SEM	Wk 9	SEM	Trt	Week
Intake	296	22	323	22	343	22	445	22	583	22	563	22	0.0001	0.0038
Feces ²	31	4	36	4	37	4	32	5	45	5	53	5	0.07	0.42
Urine ²	120	18	136	15	126	15	113	19	142	16	151	16	0.52	0.36
Milk	41	4	42	4	43	4	48	5	41	4	41	4	0.79	0.62
Balance ³	107	33	142	30	152	29	247	33	311	30	303	29	0.001	0.40
														0.82

¹Trt = treatment.

²Urine volume was estimated using the prediction equation (kg/d) = (DCAD, mEq/100 g × 0.337) + 13.2 (Nennich et al., 2006). DCAD+ = 27.4 kg, control = 22 kg.

³Balance = intake K – fecal K – milk K.

posed in the previous study. The intake of Mg was not different between treatments, at 113 and 110 g/d for control and DCAD+ diets, respectively. We observed no effect on apparent absorption of Mg, as fecal Mg was 92 and 88 g/d for control and DCAD+, respectively.

Serum K, Mg, and Glucose

The addition of K in the form of DCAD+ had no effect on serum concentrations of glucose, K, or Mg. The average concentration of serum glucose across wk 2, 5, and 9 was 52 and 49 mg/dL for control and DCAD+, respectively. The average concentration of serum K across wk 2, 5, and 9 was 6.25 and 6.21 mEq/L for control and DCAD+, respectively. The average concentration of serum Mg across wk 2, 5, and 9 was 2.09 and 2.10 mg/L for control and DCAD+, respectively.

CONCLUSIONS

Potassium carbonate sesquihydrate increased DMI, milk fat percentage and yield, ECM, and efficiency of milk production per unit of DMI, suggesting that the K requirement of the early lactation cow appears to be greater than that currently recommended by National Research Council (2001). The observed reduction of *trans* FA in milk fat when cows are fed higher dietary K suggests that one role of K may be in affecting the biohydrogenation pathways in the rumen. Although the current study demonstrates these effects with potassium carbonate sesquihydrate, a specific effect of K separate from carbonate cannot be established.

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