SIMILAR DIETARY CATION-ANION BALANCES ACHIEVED VIA THE ADDITION OF SODIUM CHLORIDE OR POTASSIUM CHLORIDE: INFLUENCE ON SYSTEMIC ACID-BASE STATUS, MILK YIELD AND MINERAL METABOLISM IN LACTATING DAIRY COWS

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Story in Brief

Dietary cation-anion balance can be defined as meq((Na+K)-Cl)/100 g diet dry matter. The objective of this study was to evaluate the response of lactating dairy cows to altering concentrations of dietary Na, K and Cl while holding dietary cation-anion balance constant. Fifteen lactating Holstein cows were fed three diets containing sorghum silage and concentrate in a 40:60 ratio (dry matter basis), formulated to provide +32 meq ((Na+K)-Cl)/100 g diet dry matter via: 1) basal concentrations of dietary Na, K and Cl; 2) basal diet with addition of 20 meq Na and 20 meq Cl/100 g diet dry matter in the form of NaCl (1.17% of diet dry matter); and 3) basal diet with the addition of 20 meq K and 20 meq Cl/100 g diet dry matter in the form of KCl (1.56% of diet dry matter). Blood pH was reduced by addition of NaCl and KCl, although no other measures of acid-base status were significantly affected. Plasma K was higher, and plasma Mg lower, for the diets with supplemental NaCl or KCl than for basal diet. Urine mineral excretion reflected dietary mineral concentration, with the exception that Ca and Mg excretion rates were reduced on the KCl diet. Milk yield reflected dry matter intake, which was lowest with NaCl. The results from this study indicate that at a dietary cation-anion balance of +32 meq/100 g diet dry matter, actual dietary concentration of Na, K and Cl may be a more important determinant of dietary impact on systemic acid-base status than the ratio of Na and K to Cl in the diet.

(Key Words: Dietary Cation-Anion Balance, Dairy Cows, Acid-Base Status, Minerals, Sodium, Potassium, Chloride.)

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Introduction

Dietary cation-anion balance (DCAB) can be defined quantitatively as meq((Na+K)-Cl)/100 g diet dry matter (DM), and more generally as the balance of positively and negatively charged fixed ions in the diet. This balance has been shown to affect systemic acid-base status and performance in lactating dairy cows (Tucker et al., 1988), Ca metabolism in peripartum dairy cows (Block, 1984) and lactating goats (Fredeen et al., 1988), and P metabolism in young calves (Beighle et al., 1988).

Before DCAB can be utilized to manipulate acid-base status and mineral metabolism in dairy cows on a widespread basis, it will be necessary to evaluate responses to diets that have the same DCAB, but different concentrations of dietary fixed ions. Therefore, the objective of this trial was to examine the response of lactating dairy cows to diets containing similar DCAB (+32 meq), but vastly different dietary fixed ion concentrations effected by the addition of either NaCl or KCl.

Materials and Methods

Fifteen lactating Holstein cows, averaging 165 days postpartum and producing 55 lb milk daily were blocked according to age and previous milk yield. Blocks were randomly assigned to five squares in a replicated, 3 x 3 Latin square design with experimental periods 3 weeks in length. Treatments were diets containing sorghum silage and concentrate in a 40:60 ratio (DM basis) and were formulated to provide DCAB of +32 via: 1) basal concentrations of dietary Na, K and Cl (Ctrl); 2) basal diet with addition of 20 meq Na and 20 meq Cl/100 g diet DM in the form of NaCl (NaCl+20); and 3) basal diet with addition of 20 meq K and 20 meq Cl/100 g diet DM in the form of KCl (KCl+20). Since NaCl and KCl contain equimolar and equivalent proportions of cation and anion, dietary addition of these compounds allows manipulation of total mineral concentrations without altering DCAB. Total mixed diets (Tables 1 and 2) were formulated to meet established nutrient requirements of lactating dairy cows and were offered ad libitum twice daily. Samples of the total mixed diets were collected weekly, frozen, and composited at the end of the trial for subsequent nutrient analysis via commercial laboratory. Dry matter composition of the sorghum silage was determined weekly and utilized to maintain a consistent ratio of ingredients in the diet DM.

Blood and urine samples were collected at 4 h postfeeding on the morning of the last day of each experimental period. Fifteen milliliters of blood was collected via jugular venipuncture and dispensed into two evacuated, glass tubes, one containing Li heparin for subsequent plasma collection and the other, Na heparin for blood pH, pCO_2 and pO_2 analysis. Urine was collected in

Table 1. Ingredient composition of experimental diets[a].

Ingredient:	Diet Ctrl	 NaCl+20	 KCl+20
Sorghum silage	40.26	40.26	40.26
Dried sorghum distillers grain	30.56	30.56	30.56
Ground corn	13.46	13.46	13.46
Soybean meal	11.91	11.91	11.91
Dynamate[b]	.22	.22	.19
Potassium chloride	.....	.....	1.56
Trace mineralized salt[c]	.38	1.55	.38
Limestone	.70	.70	.71
Dicalcium phosphate	.37	.37	.37
Potassium bicarbonate	.30	.30	.31
Magnesium oxide	.10	.10	.10
Calcium chloride (95%)	.19	.19	.18
Silicon dioxide	1.55	.38	.01

[a] Listed as percentage on DM basis.

[b] Double sulfate of K and Mg.

[c] Contains NaCl 92%, Mn .250%, Fe .200%, Cu .033%, I .007%, Zn .005%, Co .0025%.

polyethylene vials via manual stimulation of the vulva and analyzed for pH. One, 4 ml aliquot of urine was collected for analysis of creatinine, Cl and P, while an additional 10 ml aliquot was acidified with .3 ml concentrated HCl. Blood plasma and acidified urine were then frozen for subsequent mineral analysis. Blood plasma and urine Na, K, Ca and Mg were analyzed via atomic absorption spectrophotometry, Cl via potentiometric titration, and inorganic P via spectrophotometry. Statistical analysis was via a general linear model which included variation due to square, cow within square, period within square, treatment, treatment x square, and residual.

Results and Discussion

Blood pH (Table 3) was reduced ($P<.03$) by the NaCl and KCl diets, although no other measures of acid-base status were affected. Gastrointestinal absorption of monovalent mineral ions from the diet influences systemic acid-base status. Absorption of cation occurs in exchange for the secretion of free

Table 2. Nutrient composition of experimental diets[a].

Nutrient[b]	Diet Ctrl	 NaCl+20	 KCl+20
DM	46.40	47.00	46.70
CP	19.10	18.40	18.40
NE_l, Mcal/kg	1.63	1.65	1.65
ADF	25.40	24.30	23.40
NDF	42.50	36.60	36.50
Ca	.67	.69	.69
P	.48	.47	.46
Mg	.42	.41	.42
Na	.20	.67	.22
K	1.32	1.29	2.17
Cl	.35	1.05	1.07
S	.48	.49	.47
Fe, ppm	310	329	297
Zn, ppm	37	32	35
Cu, ppm	9	11	8
Mn, ppm	70	107	74
Mo, ppm	2	2	2
(Na+K)-Cl, meq/100 g diet DM	32.6	32.5	34.9

[a] Listed as percentage on DM basis.

[b] Nutrient composition from laboratory analyses.

proton (H^+) into the gastrointestinal tract (GT) lumen, while anion absorption is accompanied by the secretion of bicarbonate ion (HCO_3^-). The net result is that cation absorption increases systemic base generation and anion absorption increases systemic acid generation. Therefore, the ratio of monovalent cation to anion in the diet (DCAB) could reasonably be expected to influence blood acid-base status, an idea which has been confirmed previously (Tucker et al., 1988). In the present study, vastly different dietary mineral concentrations were utilized in the three diets to achieve a similar DCAB of +32 meq/100 g diet DM. Although each diet contained the same DCAB, blood pH differed among treatments, indicating that at the dietary mineral concentrations utilized, the ratio of Na and K to Cl was not a reliable indicator of dietary impact on acid-base status.

Plasma Na (Table 4) was unaffected by diet, plasma K was highest for KCl+20, and plasma Cl tended to reflect dietary Cl concentration, although this

Table 3. Least squares means and orthogonal contrasts for blood acid-base status response to experimental diets.

Blood	Diet 1 Ctrl	Diet 2 NaCl+20	Diet 3 KCl+20	SE	P 1 vs 2 and 3	P 2 vs 3
pH	7.395	7.387	7.383	.0033	.0245	NS[a]
pCO_2, mm Hg	44.9	45.2	46.8	.65	NS	NS
pO_2, mm Hg	32.7	34.3	33.1	.96	NS	NS
HCO_3^-, meq/L	27.8	27.4	28.1	.32	NS	NS
Standard HCO_3-, meq/L	26.2	25.8	26.1	.20	NS	NS
Total CO_2, mmol/L	29.2	28.8	29.5	.33	NS	NS
Base excess, blood, mmol/L	2.96	2.39	2.91	.275	NS	NS
Base excess, extracellular fluid, mmol/L	2.79	2.35	2.85	.318	NS	NS

[a] P >.10.

Table 4. **Least squares means and orthogonal contrasts for mineral response to experimental diets.**

	Diet				P	
Plasma, meq/L	1 Ctrl	2 NaCl+20	3 KCl+20	SE	1 vs 2 and 3	2 vs 3
Na	143.1	144.3	143.8	.77	NS[a]	NS
K	4.50	4.63	4.95	.090	.0246	.0315
Cl	101.2	102.0	103.6	.86	NS	NS
Ca	5.25	5.27	5.35	.031	NS	.0831
Mg	2.17	2.04	2.04	.023	.0001	NS
P, mg/L	70.3	73.4	72.6	3.10	NS	NS
Cation-anion balance[b]	4.64	4.69	4.51	.128	NS	NS
Urine mineral excretion, mg urine mineral/mg urine creatinine						
Na	2.10	7.91	3.18	.646	.0004	.0001
K	8.27	7.94	18.04	.695	.0001	.0001
Cl	3.29	10.12	11.26	.721	.0001	NS
Ca	.297	.379	.193	.0390	NS	.0035
Mg	.647	.648	.591	.0201	NS	.0584
P	.427	.628	.503	.0936	NS	NS

1 P >.10.

2 Expressed as meq((Na+K)-Cl)/100 ml plasma.

response was most evident for KCl+20. Plasma Ca tended to be higher ($P<.09$) for KCl+20 than NaCl+20. Supplemental KCl stimulates parathyroid hormone release, which could account for the elevation in plasma Ca. The reduction ($P<.001$) in plasma Mg on KCl+20 can likely be attributed to the high K concentration of that diet, since high dietary K inhibits Mg absorption from the reticulorumen. The plasma Mg response to NaCl+20 is more difficult to explain, and is in disagreement with O'Connor et al. (1988), who reported that the addition of 1% NaCl to the diet DM had no influence on plasma Mg.

Renal excretion of Na, K and Cl closely corresponded to dietary concentrations of these elements. Urinary Ca excretion tended to be higher for NaCl+20 and lower for KCl+20 than for Ctrl. The increased urinary Ca excretion is likely attributable to competition between Na and Ca for reabsorption from glomerular filtrate, while the reduction in Ca excretion observed with KCl+20 in the present study is in agreement with Deetz et al. (1982). They reported that ruminal infusion of KCl increased plasma parathyroid hormone which would subsequently increase renal conservation of Ca. The reduction in Mg excretion effected by KCl+20 is likely a result of reduced gastrointestinal absorption of Mg effected by high dietary K.

Milk yield and composition (Table 5) were generally unaffected by diet, although milk fat percentage, fat yield and protein yield tended to be higher ($P<.10$) for Ctrl than NaCl+20 and KCl+20. These responses can likely be attributed to lower DM intake ($P<.001$) for NaCl+20 and KCl+20.

In conclusion, dietary addition of 20 meq of Na and Cl, or K and Cl while holding DCAB constant at +32 meq/100 g diet DM resulted in a reduction in blood pH, but it had no significant effects on other measures of systemic acid-base status. Certain metabolic disorders (e.g., acidosis, parturient paresis) should, by nature of the disorder, respond to dietary manipulation of systemic acid-base status. This relationship has already been well documented for parturient paresis, which has been virtually eliminated by feeding a low DCAB during the dry period (Block, 1984). However, before DCAB can be utilized with confidence to control acid-base status, confirmation of the response of acid-base status to various points on the DCAB scale encountered in practical dairy feeding situations is essential. In addition, the variable response of acid-base status to a specific DCAB achieved via vastly different mineral concentrations in the present study indicates that the close association of DCAB and acid-base status demonstrated previously by Tucker et al. (1988) may only be operational within specific ranges of dietary Na, K, and Cl concentrations. This would make the practical application of DCAB more complicated, but would not preclude its use as a tool for controlling metabolic disorders associated with alterations in systemic acid-base status.

Table 5. Least squares means and orthogonal contrasts for milk yield, composition and dry matter intake response to experimental diets.

	Diet				P	
Milk	1 Ctrl	2 NaCl+20	3 KCl+20	SE	1 vs 2 and 3	2 vs 3
Yield, kg	22.7	21.4	22.1	.47	NS[a]	NS
Fat, %	3.55	3.68	3.46	.076	NS	.0574
Fat yield, kg	.80	.78	.76	.015	.0784	NS
Protein, %	3.23	3.21	3.23	.016	NS	NS
Protein yield, kg	.73	.69	.71	.015	.0984	NS
Lactose, %	5.08	5.07	5.10	.024	NS	NS
Solids-not-fat, %	8.94	8.91	8.96	.023	NS	NS
Dry matter intake, kg	18.5	16.5	17.4	.30	.0007	.0424

[a] P >.10.

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