Review
Dietary Cation Anion Balance in the Ruminants I-Effects during Early Lactation

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ABSTRACT

Dietary cation anion balance (DCAB) is a balance between positively and negatively charged fixed dietary ions, which affect acid-base status and performance in the lactating cows. Sodium, potassium and chloride (Cl^-) have been commonly used to calculate DCAB because of their indirect participation in the osmotic pressure, acid-base balance, integrity and pumping mechanisms of cell membranes in ruminants. Sulphur (S^{-2}) is also used under certain conditions to adjust DCAB. During early lactation, increased mammary gland activity imposed high demand for nutrients on the body which cannot always be met and led to the development of milk fever and the ketosis-fatty liver complex. After parturition, increasing dietary DCAB can increase dry matter intake and water consumption. Reducing DCAB (+120 to -10) depresses blood pH (7.43-7.37) and bicarbonate (23.2-9.3 mEq/L) and increases plasma calcium (Ca^{+2}), which could be attributed to increased intestinal absorption of Ca^{+2} or increased mobilization of Ca^{+2} from bone. The impact of S^{-2} on systemic acid-base status is less than Cl^- because of lower S^{-2} absorption, but can increase the true absorption of Ca^{+2} and reduces bone accretion indicating the more bone mobilization. Dietary supplementation of Cl^- or S^{-2} that reduce DCAB (+20 to -10) results in a reduction of serum cation-anion balance (6.8-5.8 mEq/100 mL). Cows having diets with higher DCAB produces more milk, fat percentage and protein and lactose yield. Initiation of lactation results into increase urinary output. More urinary excretion of Ca^{+2}, associated with a reduction of DCAB has been reported consistently and attributed to acid stress.

Key Words: Dietary cation-Anion balance; Early lactation; Blood acid-base status; Ruminal kinetics; Milk production

INTRODUCTION

Animal body is electrically neutral. An acid-base balance is concluded as the difference between total cation and anion intake and excretion (Cheeke, 1991). Chemically, electrolyte is defined as a substance which when added to the water, produces a conductor solution. So electrolyte is a chemical that can dissociate into its specific ions. The stronger electrolyte contain more ions and less undissociated particles. The common substances that are strong, weak or non-electrolytes are presented in Table I.

Electrolytes are present in different body fluids like Sodium (Na^+), bicarbonate (HCO_3^-) and chloride (Cl^-) are mainly in extracellular fluid. Potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}) and phosphate (PO_4^{-3}) are predominately present in the intracellular fluids. The ionic composition of typical intracellular and extracellular fluid is given in Table II. The concentration of electrolytes or acid base balance is often expressed as milliequivalent (mEq) or milliosmoles (m Osm), rather than milligrams (mg). Values in mg can be converted into mEq by dividing the molecular weight and multiplying by the valency.

Electrolytes can affect acid-base status because of their respective deficit or excess in cations and anions present in the diet and their respective buffering capacity (BC). High concentrate diets decreased blood and urine pH compared with high forage diets (Roby *et al.,* 1987). Fredeen *et al.* (1988) concluded this as a difference due to electrolyte

balance because forages have a high fixed cation content and contribute more BC than grains, which have a fixed cation deficit. This concept of electrolyte balance is now termed as the dietary cation-anion balance (DCAB). The objective of this paper is to review the cations and anions used in the ruminants diets and their effect both on the production and digestive physiology of early lactating cows.

Table I. Classification of Electrolytes

Electrolytes		Non-electrolytes
Strong	**Weak**	
Hydrogen chloride	Hydrogen fluoride	Glucose
Sodium chloride	Ammonia	Sucrose
Sodium hydroxide	Acetic acid	Ethanol
Potassium fluoride	Mercuric chloride	Oxygen
	Acetone	

Table II. Ionic composition of body fluids (mEq/L)

Electrolyte	Plasma	Interstitial fluid	Intracellular fluid
Cations:			
Sodium	142	145	12
Potassium	4	4	150
Magnesium	1	1	34
Calcium	3	2	4
Anions:			
Chloride	104	117	4
Bicarbonate	24	27	12
Phosphate	2	2	40
Protein	14	0	54

Cation-anion balance. "Fixed ions" refer to bioavailable ions that are not metabolized. These include Na^+, K^+ and Cl^- and determine acid-base balance in biological fluids (Stewart, 1978). Some researchers also included sulfur (S^{-2}) in this calculation (Dishington, 1975; Block, 1984). Although S^{-2} is not a fixed ion, but sulphates directly acidify biological fluids and can change acid-base balance if included at high dietary concentrations (Cole & Zlotkin, 1983). The term S^{-2} need not to be added in the equation, unless sulphates are deliberately added to diets. The anion, Cl^- should be balanced in a ration against the cations, Na^+ and K^+, to optimize the physiological functions of the animal. These particular minerals (Na^+, K^+, Cl^-) have been chosen to calculate DCAB because of their indirect participation in osmotic balance, acid-base balance, integrity and pumping mechanisms of cell membranes.

Dietary cation-anion balance can be defined as the balance of positively and negatively charged fixed (non-metabolizable) ions in the diet which affects systemic acid-base status (Tucker *et al.,* 1988), and Ca^{+2} metabolism of dairy cows (Block, 1984; Oetzel *et al.,* 1988; Gaynor *et al.,* 1989) and Goats (Fredeen *et al.,* 1988) and phosphorus (P) usage of young dairy calves (Beighle *et al.,* 1988). In addition, it could explain some of the differences in response to dietary buffers observed with corn silage (CS) Vs. alfalfa haylage (AH) based diets (Erdman, 1988). The relationship of DCAB with animal performance has also been investigated in non-ruminant species (Cohen & Hurwitz, 1974), and several equations have been developed. However, there is uncertainty about which ions should be included and which equation should be used in calculation of the DCAB (Block, 1984). The most commonly used equation for non-ruminants relies on almost complete dietary availability of Na^+, K^+ and Cl^- (Cohen & Hurwitz, 1974). Following the concepts of Mongin (1981) for poultry and Dishington (1975) for dairy cows, the DCAB is calculated as mEq (Na^+ + K^+) - Cl^-/100 g diet DM but this completely ignores the effects of S^{-2}. In ruminant research, S^{-2} either has been disregarded (Fredeen *et al.,* 1988), partly ignored (Tucker *et al.,* 1988), or included (Block, 1984; Beighle *et al.,* 1988) in the DCAB equation as mEq [(Na^+ + K^+) - (Cl^- + S^{-2})]/100 g diet DM. The major anions used in adjusting DCAB are Cl^- and S^{-2}. S^{-2} is less absorbed from gut due to which it is less effective acidifying agent compared to Cl^-. Tucker *et al.* (1991a) suggested equations adjusted for differences between S^{-2} and Cl^- in acid generating potential and are used to describe DCAB of diets. Reinhardt *et al.* (1988) generated an equation (Ca^{+2} + .3P + Na^+ + K^+) - (Cl^- + S^{-2}) which encompasses almost all factors which predispose a cow to milk fever on the left side of the equation, whereas useful anions for milk fever prevention were on the right side of the equation. Goff *et al.* (1991) argued that no one equation is entirely correct. Certain questions remain unanswered. Traditionally, a low Ca diet has been advocated for prevention of milk fever. However, Oetzel *et al.* (1988) suggested that a high dietary Ca concentration could be desirable with anionic diet.

The DCAB is also defined by Ross *et al.* (1994a) as the mEq of (Na^+ + K^+ + Ca^{+2} + Mg^{+2}) - mEq of (Cl^- + P + S^{-2})/kg of diet. On the other hand, Mongin (1981) described that dietary electrolyte balance (DEB) may be expressed using only the monovalent ions in the equation (Na^+ + K^+ - Cl^-) because of the differences in function and absorption of monovalent and divalent ions. There is uncertainty of which ions to include and which equation to use in calculation of DCAB. Dishington (1975) used mEq (Na^+ + K^+) - (Cl^- + S^{-2}), Lomba *et al.* (1978) used mEq (Na^+ + K^+) - (Cl^- + S^{-2}); mEq (Na^+ + K^+) - (Cl^- + S^{-2} + P) and Ender and Dishington (1970) examined mEq (Na^+ + K^+) - (Cl + S) and mEq (Ca^{+2} + Mg^{+2} + K^{+2} + Na^+) - (P + S^{-2} + Cl^-). Lomba *et al.* (1978) suggested that the inclusion of P improved the relation between dietary ions and Ca digestibility. A brief summary of various DCAB used along with their values, ions manipulated, forage to concentrate ratio, along with the physiological state of the animal are given in Table III.

Diets containing 25 mEq of DEB/100 g of dietary DM have been recommended for optimum growth by chicks (Mongin, 1981), whereas dairy cows required 20-37.5 mEq/100 g of dietary DM for maximum feed intake and milk production (Tucker *et al.,* 1988; West *et al.,* 1991).

Acid-base parameters of blood, urine, and milk include the blood pH; HCO_3^- concentration, or partial pressure of CO_2 (pCO_2); urine volume, urinary hydrogen (H^+) and HCO_3^- excretions; concentration of HCO_3^- and H^+ and total daily secretion in the milk. Blood pH is determined by pCO_2 and HCO_3^- concentration. The relationship among these acid-base parameters is described by the Henderson Hasselbalch equation:

$$pH = pKa + \log [HCO_3]/[CO_2]$$

Where pK is $-\log_{10} K \alpha$ (apparent dissociation constant of the carbonic acid-bicarbonate system) and α is the solubility coefficient for CO_2. Therefore, any change in HCO_3^- concentration or pCO_2 will result in blood pH change.

Sources. A "buffer" is defined as a salt of a weak acid or oxide or hydroxide which neutralizes acids present in feedstuffs or acids produced during nutrient digestion and metabolism. A true buffer should lessen the decrease in pH without causing a pH increase whereas a compound which neutralizes acid, but also elevates pH, would be classified as an alkalizing agent. Sodium bicarbonate ($NaHCO_3$) is one of the most common buffers and first used in dairy cattle feeding experiments in the early 1960's. This buffer was fed with the concentrate portion (80-90%) of the diet at 2.6-4.6% of the DM. Although it elevated milk fat percent, but also reduced dietary dry matter intake (DMI). Refined Na sesquicarbonate ($NaHCO_3$ and Na_2CO_3), is another buffer, sold under the label "S-Carb[®]". "Alkaten[®]"is unrefined Na-sesquicarbonate (contains 6% inert materials) and is slightly lower in Na^+. A newly manufactured dietary buffer (Rumen Mate[®]), contains sylvite (KCl) and northupite

Table III. List of the DCAB's used commonly with their formulae, elements manipulated, forage to concentrate ratio, and physiological stage

Treatment	Forage: Concentrate	Formula used mEq/kg of DM	DCAB	Elements Manipulated	Stage	Days ± parturition	Author
Hi-Bal (+limestone)	10%SS:56AH:34C	(Na+K)-(Cl+S)	+9.35		DP	-21	Tucker et al. (1992a)
Lo-Bal (+CaCl₂)			-3.41				
Fresh	AH:SS:WC:C		+5.99		EL		
EA	AH based (51%)	(Na+K)-(Cl+S)	+258.1		EL	+25 to +50	Delaquis and Block (1995b)
EB			+55.5				
MA	AH based (49%)		+372.7		ML	+107 to +137	
MB			+140.2				
LA	AH based (56%)		+374.6		DP	+162 to +234	
LB			+199.8				
0	CS based	Na+K-Cl	+2.1	NH₄Cl	GS		Ross et al. (1994b)
15			+16.6	Na₂CO₃			
30			+35.6				
45			+46.7				
DCAB (0%)	Corn based	Na+K-Cl	+2.1	NH₄Cl	GS		Ross et al. (1994a)
(15%)			+15.2	NaHCO₃			
(30%)			+27.2				
(45%)			+46.2				

NOTE: C= concentrate; SS= sorghum silage; AH= alfalfa haylage; WC= whole cottonseed; EA= early lactation with high DCAB; EB= early lactation with low DCAB; MA= mid-lactation with high DCAB; MB= mid-lactation with low DCAB; LA= late-lactation with high DCAB; LB= late-lactation with low DCAB; EL= Early lactation; ML= mid-lactation; DP= dry period.

$(MgCO_3.Na_2CO_3.NaCl)$, with substantial amounts of K^+, Mg^{+2}, Na^+ and Cl^- (Staples & Lough, 1989). Composition of these supplemental buffers and alkalinizing agents are given in Table IV.

Physiological stages. The nutrient requirement of the animals change with the change in their physiological stages. The diets supplying constant levels of DCAB will not help optimize the livestock productivity. Thus formulating rations for livestock, keeping in view their physiological needs, seems imperative to enhance livestock productivity.

Early lactating cows. Parturition and the onset of lactation impose tremendous physiological challenges to the homeostatic mechanisms of the cow. During early lactation, the metabolic demands imposed on the cow by the formation of colostrum far exceed the demands of the fetus. The production of 10 kg of colostrum on the calving day requires 11 Mcal of energy, 140 g of protein, 23 g of Ca^{+2}, 9 g of P and 1g of Mg^{+2}, either supplied from the diet or be brought to the mammary gland from body stores. The high demand for nutrients imposed on the body by the increased activity of the mammary gland cannot always be met, resulting in the development of metabolic diseases like milk fever and ketosis. In early lactation, high producing dairy cows often have less DMI and generally are in negative energy balance. Increasing the proportion of concentrates above 60% of the ration DM to provide higher energy density may result in anorexia, rumen acidosis, reduction in forage digestibility, milk fat depression and possible increase in the incidence of abomasal displacement, milk fever and ketosis (Clark & Davis, 1980). The effects of the addition of dietary buffers, especially $NaHCO_3$ to the rations of dairy cows remain controversial; performance responses vary from improved to depressed.

Table IV. Relative Composition (%) of Several Supplemental Buffers and Alkalinizing Agents for Ruminant Animals

Item	Compound				
	NaHCO₃	S-Carb®	Alkaten®	Rumen Mate®	MgO
NaHCo₃	100.0	37.0	34.8	-	-
Na₂CO₃	-	47.0	43.8	-	-
MgO	-	-	-	-	71-96
Water of hydration	-	16.0	14.9	-	-
Other minerals	-	-	1.0	-	-
Inert material	-	-	6.1	-	-
Sodium	27.4	30.4	28.5	8.8	-
Magnesium	-	-	-	16.6	43-58
Potassium	-	-	-	14.5	-
Chloride	-	-	-	10.8	-
Sulfur	-	-	-	3.6	-

Note: S-Carb = Refined Na sesquicarbonate (NaHCO₃ & Na₂CO₃); Alkaten = Unrefined Na sesquicarbonate (6% inert material) and; Rumen Mate = Sylvite (KCl) and Northupite (MgCO₃.Na₂CO₃.NaCl)

a) Dry matter intake. Dry matter intake increased with the addition of $NaHCO_3$ (Staples & Lough, 1989), but Erdman *et al.* (1982) observed no change in consumption. During early lactation, increasing DCAB significantly increased dietary DMI (Tucker *et al.*, 1991a; West *et al.*, 1991; Delaquis & Block, 1995). Similarly Tucker *et al.* (1988) quoted that daily DMI of the diet decreased as DCAB decreased from +20 to -10, however, Canale and Stokes (1988) did not observe any effect of forage source on DMI during early lactation. The dietary protein affects acid-base balance partly because of its amino acid (AA) profile

(Asplund *et al.*, 1980), especially the S^{-2} containing AA. If the ingredients affect acid-base balance, the response to dietary buffers and to DCAB depends on ration composition. But Delaquis and Block (1995c) observed that the ingredients of a ration did not necessarily have any impact on the acid-base status of the cow.

b) Ruminal kinetics. Addition of $NaHCO_3$ to the diet tended to attenuate the increase in ruminal fluid acidity (0-6 h post-feeding), whereas H^+ tended to be lower. Although dosing $NaHCO_3$ via ruminal cannula had an immediate effect on ruminal fluid acidity (Tucker *et al.*, 1992b). The reduction in H^+ accompanying intraruminal infusion of $NaHCO_3$ disappeared within several hours after infusion (Tucker *et al.*, 1992b). Whereas, ruminal fluid H^+ increased for the control diet until 4-6 h post-feeding, probably the result of higher concentrations of fermentation acids (Tucker *et al.*, 1992b). This pattern is typical of unbuffered high concentrate diets fed twice daily. Cows receiving buffers in their diets had higher ruminal fluid BC at 0 h, but BC fell by approximately 15 mEq/L by 6 h post-feeding and was lower than control diet (Hogue *et al.*, 1991; Tucker *et al.*, 1992b). Sodium bicarbonate dosed intraruminally at 2 h post-feeding was the most effective in maintaining ruminal fluid BC during 4 to 6 h post-feeding interval during which ruminal fluid acid content typically is highest (Hogue *et al.*, 1991).

c) Water metabolism. The increase in free water consumption with AH can be explained by the smaller quantity obtained from the feed itself. Delaquis and Block (1995a) noticed that cows offered AH had a significantly higher apparent absorption of water than CS. The cows consuming AH absorbed more K^+, Cl^- and S^{-2} and had a higher concentration of Cl^- in plasma 4 h post-feeding, which could have affected plasma osmolarity. Under most conditions, the kidneys maintained blood osmolarity and responded to volume changes. This increase in water absorption would, in turn expand volume, inhibiting the secretion of antidiuretic hormone (Ganong, 1989) and consequently reducing reabsorption of water and increasing urine volume in early and mid-lactation but not in late-lactation. However, the increased amount of water absorbed apparently was completely excreted in the urine (Delaquis & Block, 1995). Higher DCAB increased water consumption in early and mid-lactation (Delaquis & Block, 1995). Lactation imposes a large acceleration in the water metabolism in dairy cows in terms of water turn over (Shalit *et al.*, 1991). The increase in the milk free water balance probably reflects a response to an increase in energy metabolism during lactation (Woodford *et al.*, 1984).

d) Blood acid-base status. In early lactation, experiments utilizing CS as the main dietary forage, S-Carb® proved effective as a dietary buffer by increasing yield of 4% FCM as reviewed by Staples and Lough (1989). The average increase in 4% FCM was 1.7 kg/cow/day. Poos-Floyd and Coyle (1986) found little response in 4% FCM when S-Carb® was fed at >1.25% level. Sodium bicarbonate feeding

proved to be equally effective as S-Carb® feeding (Jordan & Aguilar, 1985). Cows consuming S-Carb® had more dietary DMI and produced milk with a higher fat content (Jordan & Aguilar, 1985). The feeding of S-Carb® also resulted in higher milk fat percentage than $NaHCO_3$ feeding. This is because S-Carb® has some alkalizing as well as buffering potential, as it contains Na_2CO_3 as well as $NaHCO_3$.

Alkaten® and $NaHCO_3$ were equally effective in increasing 4% FCM, although percent milk fat was lower in first calf heifers consuming buffer supplemented CS diets (Staples & Lough, 1989). However, Coppock *et al.* (1986) found that during early lactation, the performance of cows consuming Alkaten® was similar to control cows and inferior to those fed $NaHCO_3$.

There are no effects of dietary AH and CS on blood pH; HCO_3 concentration or pCO_2 (Delaquis & Block, 1995c). The lack of difference between acid-base status of AH and CS was surprising because the acidity of CS is generally given as an explanation for the greater benefit of $NaHCO_3$ supplementation when CS rather than haylage is used as the forage source (Escobosa *et al.*, 1984). Generally CS have lower DCAB than AH; thus, the addition of a buffer would increase the dietary DCAB.

In early lactation, blood pH responded to DCAB at 2 h post-feeding (Delaquis & Block, 1995). Reducing DCAB depresses blood pH and HCO_3^- (Tucker *et al.*, 1991ab), but the difference in blood pH was no longer significant at 4 h post-feeding (Delaquis & Block, 1995). Blood concentration of HCO_3 was significantly reduced by low DCAB (Tucker *et al.*, 1991b) pre-feeding and at 4 h post-feeding (Delaquis & Block, 1995), whereas blood pCO_2 was unaffected (Tucker *et al.*, 1991a).

The impact of S^{-2} on systemic acid-base status might be less than Cl^- because of lower S^{-2} absorption as well as the variety of organic and inorganic forms in which S^{-2} may be absorbed and used by the body. Apparent absorption of Cl^- by ruminants may exceed 95% (Church & Fontenot, 1979), whereas apparent absorption of S^{-2} has ranged from 51.8-60.8% (Spears *et al.*, 1985). However, Tucker *et al.* (1991a) reported similar effects of Cl^- and S^{-2} on acid-base status and indicated that the contribution of dietary S^{-2} on acid-base status should not be ignored.

Plasma Ca^{+2} was increased by anion supplementation (Block, 1984; Oetzel *et al.,* 1988; Tucker *et al.*, 1991b) in contrast with the results of Gaynor *et al.* (1989). This might be attributed to increased intestinal absorption of Ca^{+2} or increased mobilization of Ca^{+2} from bone (Block, 1984). Takagi and Block (1988) reported that reducing DCAB:S increased true absorption of Ca^{+2} and reduced bone accretion in sheep, whereas Block (1984) reported increased plasma hydroxyproline indicating increased bone mobilization. Plasma Mg^{+2} and P concentrations were not affected by Cl^- or S^{-2} supplementation. Oetzel *et al.* (1988) and Gaynor *et al.* (1989) reported that during the peripartum period plasma Mg^{+2} was higher for cows receiving anionic

vs. cationic diets, but serum P was not affected in either study. In contrast, Block (1984) reported increased serum P during the peripartum period for cows receiving anionic diets. Factors involved in Mg^{+2} homeostasis have not been clearly identified, although extracellular Mg^{+2} concentration is regulated by renal excretion (Guyton, 1986). If lowering the DCAB resulted in an increase in PTH release, P would be mobilized from bone, but the threshold for reabsorption of phosphate by the renal tubules would also be reduced (Guyton, 1986), thus resulting greater P loss in urine and plasma P concentrations may not be affected.

Reducing DCAB from +20 to -10 resulted in a reduction in serum cation-anion balance (CAB) from 6.8 to 5.8mEq/100 ml (Tucker *et al.,* 1988). Similar findings were also reported by Tucker *et al.* (1991a) when plasma CAB was reduced by dietary supplementation of Cl^- or S^{-2}.

e) Milk and milk components. Increased milk production is reported by Canale and Stokes (1988) with 1.25% $NaHCO_3$ addition to a ration (silage based) but Erdman *et al.* (1982) observed decrease in milk production when $NaHCO_3$ was added to a ration (hay based). Erdman (1988) further suggested that dietary buffers were more efficient when added to CS than to a ration based on AH. During early lactation, milk production of cows receiving $NaHCO_3$ was not different from those receiving both $NaHCO_3$ and MgO. Whereas, Stokes *et al.* (1986) showed that there was no apparent advantage of feeding both $NaHCO_3$ and MgO in a 70% concentrate:30% hay crop silage diet. Milk yield and fat percent were almost identical between cows consuming diets supplemented with $NaHCO_3$ alone and diets supplemented with $NaHCO_3$ plus MgO, respectively.

Daily milk production and percentage of milk components were similar among cows offered the diets containing DCAB +482 and +387 (Delaquis & Block, 1995). Similar findings were also supported by Canale and Stokes (1988). However, Delaquis and Block (1995b) reported increased milk production by cows fed diets supplying higher DCAB levels and were consistent with other workers (Tucker *et al.*, 1988; Tucker *et al.*, 1991a; West *et al.*, 1991). However the fat remained unaffected by DCAB at all stages of lactation (Tucker *et al.,* 1988; Delaquis & Block, 1995) but Escobosa *et al.* (1984), Tucker *et al.* (1991a) and West *et al.* (1991) reported a higher fat percentage in milk as DCAB was increased. These different results can be attributed to the stage of lactation and the range of DCAB used in different experiments. The ranges of DCAB in reports (Tucker *et al.*, 1991a; West *et al.*, 1991) were lower than in the experiment conducted by Delaquis and Block (1995a); thus the initial acid-base status of the cows probably tended toward a more acidic profile in the lower DCAB than in the higher ones. Acidosis affects fat metabolism (Hood *et al.*, 1990), but cows in the experiment of Delaquis and Block (1995b), even when they consumed the lower DCAB diets, did not suffer from metabolic or respiratory acidosis; their blood pH and HCO_3^- concentration were normal.

Protein and lactose yields were significantly increased by higher DCAB (Delaquis & Block, 1995) and was due to increased milk production. Daily milk yield was reduced by lowering DCAB:S from +15 to +0 with either Cl^- or S^{-2}. Milk fat percent and yield and protein yield were highest for cows fed the diet having DCAB:S (+15) but protein percent remained unaltered (Tucker *et al.*, 1991a). It may be due to improved ruminal nutrient digestibility, although S^{-2} concentrations for all diets were above the requirement of 0.25% as listed by the National Research Council (NRC, 1988). An increased DCAB might have increased mammary gland metabolic rate, augmenting the quantity of protons secreted, or the milk might used as a mode of excreting extra protons generated. These observations did not establish whether free proton secretion in the milk is required for milk production or used to maintain electrical neutrality or appeared in the milk because a higher DCAB allowed a higher metabolic rate and increased production of protons. The possibility that DCAB changed the free H^+ content of milk by alteration of the BC alone cannot be eliminated because BC of the milk was not monitored. The 3 major buffers of milk are phosphate, citrate, and protein (Delaquis & Block, 1995). The increased concentration of free H^+ and milk volume resulted into increased total secretion of H^+ into milk, but had no effect on HCO_3^-, as DCAB increased during early lactation. The H^+ secreted in milk could have originated from the blood or from metabolism within the mammary epithelial cells (Peaker, 1983). Total secretion of free H^+ in milk of cows consuming higher DCAB was higher than the cows consuming lower DCAB.

Lactation affects kidney function in ruminants. Initiation of lactation resulted into increased urinary output (Shalit *et al.*, 1991). Urea was the main component contributing to urine osmolality, but the concentrations of Na^+, Cl^- and K^+ were extremely low (Shalit *et al.*, 1991). After peak lactation, urea concentration in urine was reduced, and electrolyte concentration was slightly increased. The low electrolyte concentration (particularly Na^+ & Cl^-) in the very early phase of lactation may reflect either electrolyte deficiency, or the need to excrete urea, or both. If protein is consumed in higher quantities or rumen ammonia concentrations are excessive due to high dietary NPN or due to higher rumen degradable protein intake in that period, there is a need to excrete large amounts of urea, because kidney concentration capacity is limited, Na^+, K^+ and Cl^- contents in urine were reduced (Shalit *et al.*, 1991).

f) Ion balance in urine. Supplementation of diets of rats with Cl^- or S^{-2} to evaluate effects on urinary net acid excretion, Whiting and Cole (1986) indicated that if differences in apparent absorption of Cl^- and S^{-2} were considered, the 2 anions produced similar increases in urinary net acid excretion and would be expected to have similar effects on systemic acid-base status. The data of Tucker *et al.* (1991a) also supported the concept of similar acidogenicity for Cl^- and S^{-2} and further elaborated that

reducing DCAB tended to increase urine H^+, but the effect of the highest concentrations of Cl^- and S^{-2} were much more pronounced (Tucker *et al.*, 1991a).

Increased urinary excretion of Cl^- could have resulted from the increased intake of Cl^- (Tucker *et al.,* 1988) with AH (AH had slightly more K^+, Cl^- and S^{-2} than CS) and from the increased excretion of K^+ in the urine, which reduced the potential gradient driving Cl^- reabsorption in the proximal renal tubules (Delaquis & Block, 1995). Urinary Na^+ excretion tended to decrease with increased Cl^- supplementation. While Ca^{+2} excretion tended to be higher with Cl^- and S^{-2} supplementation (Tucker *et al.*, 1991a) as was found by Takagi and Block (1988). Increased urinary excretion of Ca^{+2}, associated with a reduction of DCAB has been reported consistently and attributed to acid stress (Fredeen *et al.*, 1988; Tucker *et al.*, 1991b; West *et al.*, 1991). The reduced ability of the kidney to reabsorb Ca^{+2} also results from acidosis (Sutton *et al.*, 1979); however, the mechanisms involved are not well understood. Mg^{+2} and P excretion were unaffected by Cl^- or S^{-2} supplementation (Tucker *et al.*, 1991a). This contrasts with the results of Gaynor *et al.* (1989) who observed that reducing DCAB from +126 to +22 increased urinary Mg^{+2} excretion. But the data of Ferdeen *et al.* (1988) revealed that reducing DCAB had no effect on urinary P excretion in pregnant or lactating goats.

Concentration and total daily excretion of HCO_3^- fell as DCAB was reduced (Delaquis & Block, 1995). The reduced blood pH or concentration of HCO_3^- caused by lower DCAB was paralleled by lower total urinary excretion of HCO_3^- (Escobosa *et al.*, 1984; Tucker *et al.*, 1991a; West *et al.*, 1991), which is a normal renal compensatory mechanism to normalize blood pH (Vander, 1991). Urinary CAB tended to decrease with decreasing DCAB. This reduction was more extensive for Cl^- than for S^{-2} supplementation. The larger response to the Cl^- diets likely can be explained by the exclusion of S^{-2} when calculating urinary CAB (Tucker *et al.*, 1991a). The trend for the fractional excretion of Cl^- to increase in early lactation as DCAB was reduced could be related to an increased activity of the Cl^- and HCO_3^- exchanger present in the proximal tubules because lower urinary HCO_3^- concentration was also associated with lower DCAB (Delaquis & Block, 1995). A reduced ability of the kidneys to form new HCO_3^- is not likely the cause of the lowered HCO_3^- in the urine of cows because this mechanism is triggered only when urinary reabsorption of filtered HCO_3^- is almost complete (Vander, 1991).

The fact that HCO_3^- is reabsorbed with Na^+ suggested that as the need for HCO_3^- reabsorption was reduced with higher DCAB, more Na^+ or energy was available for organic solute and Cl^- reabsorptions, both of which are largely dependent on Na^+ (Berry & Rector, 1991). The same mechanism could have been in the GIT, where most Na^+ is absorbed with SO_4^{-2}, thereby limiting Na^+ availability for absorption of AA and glucose (Hopter, 1987). The transport

systems of the mammary epithelial cells might also been competing for Na^+.

CONCLUSION

During early lactation, buffer feeding and higher DCAB can increase the DMI and water intake. But most of the increase water intake losses in increase urine volume. Reducing DCAB depressed blood pH and HCO_3^-, but the difference in pH is not sustained upto 4 hours post-feeding. Among anions, impact of S^{-2} on systemic acid-base status is less than Cl^- because of lower S^{-2} absorption. Anion supplementation elevates the plasma Ca^{+2} by increasing bone mobilization or intestinal absorption of Ca^{+2}. Higher DCAB increase milk production, % fat and protein and lactose yield. Increasing anions especially Cl^- in diet can increase urinary excretion of Cl^- and K^+ and decrease urinary Na^+. Low DCAB elevates urinary excretion of Ca^{+2}, which is attributed to acid stress. Total excretion of HCO_3^- fell with reduced DCAB and it was due to the reduced blood pH or concentration of HCO_3^-.

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