



Nutrient Intake, Acid Base Status and Growth Performance of *Thalli* Lambs Fed Varying Level of Dietary Cation-anion Difference

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ABSTRACT : Influence of -110, +110, +220 and +330 mEq/kg of dry matter (DM) dietary cation-anion difference (DCAD) on growth performance of *Thalli* lambs were examined in a randomized complete block design. Four DCAD diets were randomly allotted to four groups, with ten lambs in each group. A linear increase in nutrient intake was recorded with increasing DCAD level. The digestibilities of nutrients were higher in lambs fed -110 DCAD diet than those fed +110, +220 and +330 DCAD diets. Lambs fed +330 DCAD diet had higher nitrogen balance than those fed -110 and +110 DCAD diets. Blood pH and serum HCO_3^- increased with increasing DCAD level. Serum chloride was higher in lambs fed -110 DCAD diet, while serum (Na+K)-(Cl+S) increased linearly with increasing DCAD level. Serum calcium increased with decreasing DCAD level while serum magnesium and phosphorus remained unaffected. Lambs fed -110 DCAD diet had higher Ca balance than those fed +110, +220 and +330 DCAD diets. Urine pH increased with increasing DCAD level. Lambs fed +220 and +330 DCAD diets gained more weight than those fed -110 and +110 DCAD diets. In conclusion, increased DCAD level not only increased the dry matter intake but also improved the weight gain of growing *Thalli* lambs. (**Key Words :** DCAD, *Thalli* Lambs, Nitrogen and Calcium Balance, Growth)

INTRODUCTION

Dietary minerals are an integral part of all biological functions in the animal body. Recent advances in mineral nutrition suggest that difference between certain cations (Na and K) and anions (Cl and S), usually referred as dietary cation-anion difference (DCAD), are of more significance for animal productivity than their individual effects (Tucker et al., 1992).

The DCAD affects the acid-base status (Sanchez, 2003; Shahzad et al., 2007a). Any change in DCAD induces certain changes in blood chemistry, for example, if DCAD decreases it causes an increase in blood H^+ and a decrease in blood HCO_3^- , blood pH and urine pH (Block, 1994). Reduction in blood HCO_3^- and urine pH works as a compensatory mechanism (Block, 1994; Sanchez et al., 1997). Alteration in blood pH affects insulin secretion and its effectiveness (Schade et al., 1981; Robertson, 1987) and growth hormone (Challa et al., 1993), which can reduce dry matter intake (DMI) and thus animal growth (Fettman et al., 1984; Jackson et al., 1992; Jackson and Hemken, 1994).

Increased DMI in calves fed a high DCAD diet might be attributed to increased buffering capacity due to the alkalogenic nature of DCAD diet (Block, 1994; Shahzad et al., 2007b).

In tropical and subtropical countries like Pakistan, growing lambs are well known victims of high temperature and humidity which not only reduce their DMI but also growth performance and ultimately the profitability of the enterprise (Sarwar et al., 2003; Khan et al., 2006; Sikka and Lal, 2006). Feeding high DCAD diet to *Thalli* lambs might be an important nutritional tool to increase growth rate through increased DMI (Shahzad et al., 2007). However, scientific information regarding effects of DCAD on performance of growing sheep is limited. Therefore, the present study was planned to determine the influence of varying level of DCAD on nutrient intake and digestibility, nitrogen balance, calcium balance, growth rate and feed conversion ratio of growing *Thalli* lambs.

MATERIALS AND METHODS

The experiment was planned to determine the effects of varying level of DCAD on growth performance of *Thalli* lambs.

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Table 1. Ingredients and chemical composition of DCAD diets for growing *Thalli* lambs

Ingredient	DCAD ¹ (mEq/kg of DM)			
	-110	+110	+220	+330
Wheat straw	20.0	20.0	20.0	20.0
Com cobs	30.0	30.0	30.0	30.0
Com grain cracked	11.0	11.0	11.0	11.0
Molasses	7.00	7.0	7.0	8.45
Wheat bran	7.78	9.55	9.70	6.70
Sunflower meal	12.0	12.0	12.0	12.0
Canola meal	6.0	6.0	6.0	6.0
Vegetable oil	2.0	1.5	1.5	2.0
Urea	1.0	1.0	1.0	1.2
DCP ²	1.0	1.0	1.0	1.0
Salt	0.50	0.50	0.50	0.50
CaCl ₂	1.42	0.45	0	0
NaHCO ₃	-	-	0.30	1.15
Chemical composition				
ME (Mcal/kg)	2.24	2.24	2.24	2.24
CP ³	14.1	14.0	14.0	14.1
NDF ⁴	35.70	35.3	36.1	36.52
ADF ⁵	18.2	17.4	19.3	18.0
NFC ⁶	27.2	27.8	27.8	27.6
Ca	1.15	0.72	0.56	0.56
P	0.57	0.58	0.58	0.55
Na	0.29	0.29	0.37	0.60
K	1.47	1.49	1.5	1.51
Mg	0.27	0.28	0.28	0.27
Cl	1.69	0.92	0.67	0.64
S	0.22	0.22	0.22	0.22

¹ Dietary cation anion difference ((Na+K)-(Cl-S)).

² Dicalcium phosphate, ³ Crude protein, ⁴ Neutral detergent fiber.

⁵ Acid detergent fiber, ⁶ Non-fermentable carbohydrate.

The DCAD is the difference between milliequivalents of cation (Na, K) and anions (Cl, S) in the whole feed. The following equation was used for DCAD calculation (Tucker et al., 1992).

$$\text{DCAD} = (\text{Na} + \text{K}) - (\text{Cl} + \text{S}) \text{ mEq/kg DM}$$

Four diets were formulated to have -110, +110, +220 and +330 mEq/kg DM DCAD. The -110, +110, +220 and

+330 DCAD levels were attained by using CaCl₂ and NaHCO₃. All diets were formulated to be iso-nitrogenous and iso-caloric using NRC (2001) values for energy and protein (Table 1). Forty growing *Thalli* lambs, of about 3-4 months of age with an average weight of 20.7 kg, were randomly allocated to four dietary treatments in a randomized block design, with ten lambs in each group. The experiment lasted for 70 days, first 10 days were adaptation period while the last ten days of each month were the collection period.

Lambs were housed on a concrete floor in separate pens and no mechanical means were used to control the house temperature. The diets were mixed daily and fed *ad libitum* twice (0300 and 1400 h) a day but at 10% weighback during the collection period.

During each collection period, feed intake was recorded daily and representative samples were taken for analysis. The lambs were weighed weekly. Faeces were collected daily, dried at 55°C, bulked and mixed at the end of each collection period. Urine samples were acidified with 50% H₂SO₄ and stored at -20°C for laboratory analysis (Nisa et al., 2004). Feed and faecal samples were analyzed for acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), Na, K, Cl, Ca, P, Mg, and S using methods described by AOAC (1990). Blood samples were collected from the jugular vein into evacuated blood tubes and serum was harvested to analyze Na, K, Cl, S, Ca, Mg and P by the methods devised by AOAC (1990). Blood samples were also collected in heparinized syringes to determine pH (AOAC, 1990), and serum bicarbonate (HCO₃) content was determined as described by Harold (1976). Nitrogen and calcium balance was determined using equations as described by NRC (2001).

Statistical analysis

The data were analyzed using a Randomized Complete Block Design. In cases of significance means were separated by Duncan's Multiple Range Test (Steel and Torrie, 1984). The contrasts were determined by using the SPSS (version 10.0.1).

Table 2. Influence of varying levels of DCAD on nutrient intakes and their digestibilities in growing *Thalli* lambs

	DCAD ¹ diets (mEq/kg of DM)				SE	Effect
	-110	+110	+220	+330		
DMI ² (g/d)	1,120 ^c	1,230 ^b	1,390 ^{ab}	1,430 ^a	82.45	L ^o
Dig. (%)	63.02 ^a	62.55 ^b	62.44 ^b	62.11 ^b	0.17	L
CPI ³ (g/d)	157.92 ^c	172.20 ^b	194.60 ^{ab}	201.63 ^a	15.39	L
Dig. (%)	72.11 ^a	71.77 ^b	71.67 ^b	71.55 ^b	0.11	NS ⁷
NDFI ⁴ (g/d)	399.84 ^c	434.19 ^b	501.79 ^{ab}	522.24 ^a	41.59	L
Dig. (%)	61.02 ^a	60.66 ^b	60.32 ^b	60.30 ^b	0.12	NS
ADFI ⁵ (g/d)	203.84 ^c	214.03 ^b	250.20 ^{ab}	257.40 ^a	17.8	L
Dig. (%)	55.22 ^a	54.32 ^b	54.77 ^b	54.87 ^b	0.21	NS

Means within the same row having different superscripts differ significantly (p<0.05).

¹ Dietary cation anion difference ((Na+K)-(Cl-S)). ² Dry matter intake, ³ Crude protein intake.

⁴ Neutral detergent fiber intake, ⁵ Acid detergent fiber intake, ^o Linear, ⁷ Nonsignificant.

Table 3. Influence of varying levels of DCAD on nitrogen balance in growing *Thalli* lambs

	DCAD ¹ diets (mEq/kg of DM)				SE	Effect
	-110	+110	+220	+330		
Nitrogen intake (g/d)	25.27 ^c	27.55 ^b	31.14 ^{ab}	32.26 ^a	3.59	L ²
Faecal nitrogen (g/d)	11.50	12.75	14.21	14.70	1.01	
% of intake	45.51	46.28	45.63	45.57	0.42	
Apparent absorption (g/d)	13.17 ^c	14.8 ^b	16.94 ^{ab}	17.56 ^a	3.13	L
% of intake	54.49	53.72	54.37	54.43	0.61	
Urinary nitrogen (g/d)	0.104 ^c	0.116 ^b	0.135 ^{ab}	0.145 ^a	0.37	NS ³
Nitrogen balance (g/d)	13.66 ^c	14.68 ^b	16.79 ^{ab}	17.41 ^a	1.16	L
% of intake	54.08	53.29	53.91	53.95	0.11	

Means within the same row having different superscripts differ significantly ($p < 0.05$).

¹ Dietary cation anion difference ((Na-K)-(Cl-S)). ² Linear. ³ Nonsignificant.

Table 4. Influence of varying levels of DCAD on blood pH and serum mineral levels in growing *Thalli* lambs

	DCAD ¹ diets (mEq/kg of DM)				SE	Effect
	-110	+110	+220	+330		
Blood pH	7.303 ^u	7.325 ^c	7.381 ^b	7.417 ^a	0.005	L ²
Urine pH	6.81 ^d	7.43 ^c	7.68 ^b	7.88 ^a	0.25	L
HCO ₃ (mmol/L)	22.15 ^d	23.62 ^c	26.45 ^b	27.75 ^a	1.10	L
Na (mEq/L)	121.1	122.2	122.6	123.4	0.16	
K (mEq/L)	4.41	4.45	4.46	4.61	0.1	
Cl (mEq/L)	97.12 ^a	94.22 ^b	93.35 ^{bc}	92.12 ^c	1.1	L
S (mEq/L)	1.46	1.47	1.48	1.49	0.1	
Serum (Na+K)-(Cl+S) (mEq/L)	26.93 ^d	30.96 ^c	32.23 ^b	34.40 ^a	1.10	L
Ca (mg/dl)	9.55 ^a	9.42 ^b	9.21 ^c	9.11 ^d	0.11	L
Mg (mg/dl)	2.50	2.23	2.30	2.30	0.13	
P (mg/dl)	7.31	7.32	7.32	7.32	0.07	

Means within the same row having different superscripts differ significantly ($p < 0.05$).

¹ Dietary cation anion difference ((Na-K)-(Cl+S)). ² Linear.

RESULTS

Nutrient intake and digestibilities

Maximum (1.430 g/d) and minimum (1.120 kg/d) DMI was recorded in lambs fed +330 and -110 mEq/kg DCAD diet, respectively (Table 2). Lambs fed +330 consumed 27.68% more feed than those fed -110 mEq/kg DCAD diet. Lambs fed +110 and +220 DCAD consumed 1.230 and 1.390 g/d, respectively. However, DMI in lambs fed +220 and +330 mEq/kg DCAD diets remained unaltered.

A constant increase in CP and NDF intakes was observed with increasing DCAD level of the diet. Lambs fed +330 and -110 mEq/kg DCAD diets consumed maximum (201.63 g/d) and minimum (157.92 g/d) CP, respectively. Lambs fed +110 and +220 mEq/kg had 172.20 and 194.60 g/d CP intake, respectively. Increase in nitrogen balance was also noticed with increasing DCAD level of the diet (Table 3). Nitrogen balance was maximum (17.41 g/d) and minimum (13.66 g/d) in lambs fed the +330 and -110 DCAD diet, respectively. The NDF intake was maximum (522.24 g/d) and minimum (399.84 g/d) in lambs fed +330 and -110 mEq/kg DCAD diets, respectively. A similar trend was observed for ADF intake (Table 2). The digestibilities of DM, NDF and CP increased in lambs fed -110 compared to those fed +110, +220 and +330 mEq/kg DCAD diets.

However, nutrient digestibilities in lambs fed +110, +220 and +330 DCAD diets remained unaltered (Table 2).

Blood pH and HCO₃

Blood pH was maximum (7.417) in lambs fed +330 while minimum (7.303) in those fed -110 mEq/kg DCAD diet, respectively (Table 4). Lambs fed +110 and +220 mEq/kg DCAD diet had a blood pH of 7.325 and 7.381, respectively. A constant increase in serum HCO₃ was noticed with increasing DCAD of the diet (Table 4). Maximum (27.75 mmol/L) and minimum (22.15 mmol/L) HCO₃ was recorded in lambs fed +330 and -110 mEq/kg DCAD diet, respectively. Lambs fed +110 and +220 mEq/kg DCAD diet had 23.62 and 26.45 mmol HCO₃/L blood, respectively (Table 4).

Serum minerals

Serum Ca increased with decreasing level of DCAD. Lambs fed -110 and +330 mEq/kg DCAD diets had maximum (9.55 mg/dl) and minimum (9.11 mg/dl) serum Ca, respectively (Table 4). Serum Cl also followed a similar trend. Lambs fed -110 and +330 mEq/kg DCAD diet had maximum (97.12 mEq/L) and minimum (92.12 mEq/L) serum Cl, respectively. Serum phosphorus, sodium and potassium remained unaltered by DCAD level.

Table 5. Influence of varying levels of DCAD on Ca balance in growing *Thalli* lambs

	DCAD ¹ diets (mEq/kg of DM)				SE	Effect
	-110	+110	+220	+330		
Intake (g/d)	12.88 ^a	8.86 ^b	7.78 ^b	7.78 ^b	1.45	L ²
Faeces						
Excretion (g/d)	6.12 ^a	4.18 ^b	3.68 ^b	3.72 ^b	2.15	L
% of intake	47.51	47.18	47.30	47.81	0.10	
Apparent absorption (g/d)	6.76 ^a	4.68 ^b	4.10 ^b	4.06 ^b	1.41	L
% of intake	52.48	52.82	52.69	52.18	0.44	
Urine						
Excretion (mg/d)	166 ^a	141 ^b	123 ^c	118 ^c	10.22	L
Apparent retention (g/d)	6.59 ^a	4.54 ^b	3.98 ^b	3.94 ^b	1.96	L
% of intake	51.19	51.23	51.12	50.98	1.89	

Means within the same row having different superscripts differ significantly ($p < 0.05$).

¹ Dietary cation anion difference ((Na+K)-(Cl-S)). ² Linear.

Table 6. Influence of varying levels of DCAD on weight gain in growing *Thalli* lambs

	DCAD ¹ diets (mEq/kg of DM)				SE
	-110	+110	+220	+330	
Weight gain (g/d)	126 ^c	138 ^b	155 ^a	159 ^a	26.5
Feed conversion ratio	8.88	8.91	8.96	8.99	0.11

Means within the same row having different superscripts differ significantly ($p < 0.05$).

¹ Dietary cation anion difference ((Na+K)-(Cl+S)).

A slight increase in serum Mg was observed with decreasing DCAD level of diets (Table 4). A linear increase in serum DCAD (Na+K-Cl+S) was noticed with increasing DCAD level of the diet. Lambs fed +330 had higher serum DCAD (34.40 mEq/L) than those fed -110 mEq/kg DCAD diet (26.93 mEq/L). Serum sulphur was not affected by altering the DCAD level of the diet.

Urinary pH

A linear increase in urine pH was observed with increasing DCAD level of the diet (Table 4). The minimum (6.81) and maximum (7.88) urine pH was determined in lambs fed -110 and +330 mEq/kg DCAD diet, respectively. Lambs fed +110 and +220 DCAD diet had a urine pH 7.43 and 7.68, respectively.

Calcium balance

Urinary Ca increased with decreasing DCAD of the diet (Table 5). Maximum (166 mg/d) and minimum (188 mg/d) urinary Ca excretion was recorded in lambs fed the -110 and +330 mEq/kg DCAD diet, respectively. Moreover, Ca absorption was significantly increased in lambs fed -110 DCAD diet compared to those fed +110, +220 and +330 DCAD diets. Higher Ca intake and retention was observed in lambs fed -110 than in those fed +110, +220 and +330 DCAD diets (Table 5).

Growth performance

An increasing weight gain was observed with increasing DCAD level of the diet in growing lambs (Table 6). Lambs fed +330 and -110 DCAD diet had maximum (159 g/d) and

minimum (126 g/d) weight gain, respectively. Lambs fed +110 and +220 DCAD diet gained 138 and 155 g daily, respectively. Feed conversion ratio remained unchanged across all diets (Table 6).

DISCUSSION

Nutrients intake and their digestibilities

Increased DMI in lambs fed high DCAD diets (+220 and +330) might be attributed to improved blood HCO₃, buffering capacity (Sanchez and Beede, 1994) and rumen pH (Tucker et al., 1991). Higher HCO₃ not only increased ruminal buffering capacity but also ruminal fluid dilution and flow of undegraded starch (Russel and Chow, 1993). Increased DMI with increasing the DCAD has also been reported by other workers (Tucker et al., 1991; West et al., 1991; Delaquis and Block, 1995). Hu and Murphy (2004) examined the potential empirical relationships between DCAD and DMI and reported 400 mEq/kg DCAD for maximum DMI in lactating cows. However, in contrast to the present study, Roche et al. (2005) reported that DMI did not increase with increasing DCAD level of the diet in lactating cows. Similarly, Fredeen et al. (1988a) also reported that DMI did not increase in lactating goats fed a diet with a DCAD level of 900 mEq/kg DM. The lack of difference in DMI in their study might be due to the high DCAD range (230 to 900 mEq/kg DM).

Reduced DMI in lambs fed -110 diet may be attributed to poor palatability of this diet due to high anionic salt (CaCl₂) content. Calcium chloride, being unpalatable, might have reduced the feed consumption. Tucker et al. (1988) also reported decreased feed intake in cows fed -100 diet

compared to those fed +100 and +200 mEq/kg DCAD diets. They used CaCl_2 (1.3%) to attain the -100 DCAD, while in the present study CaCl_2 (1.75%) was also used to attain a DCAD level of -110 mEq/kg DM. Decreased DMI with reducing DCAD level of the diet has also been reported by West et al. (1991; 1992).

In the present study, increased digestibilities of DM, NDF and CP in lambs fed -110 DCAD diet might be attributed to increased rumen retention time of nutrients due to reduced DMI. A positive correlation between nutrient digestibility and rumen retention time is well documented (Sarwar et al., 1996; Nisa et al., 2004; Nisa et al., 2006). However, Tucker et al. (1991) reported that altered DCAD level did not alter the digestibility of DM, NDF and CP in lactating cows. Similarly, Delaquiz and Block (1995) also reported that DCAD did not affect the digestibility of nutrients. A plausible explanation for these observations might be that in these latter studies S was used to acidify the diet while in the present study Cl was used to acidify the diet. Higher N balance in lambs fed the +220 and +330 DCAD diets might be due to increased DMI compared to those fed -110 and +110 mEq/kg DCAD diets. However, Delaquiz and Block (1995) reported unaltered N balance due to DCAD alteration. This contrast might be attributed to small differences in N intake (463.9 versus 439.09 g/d) due to DCAD variation (258 versus 55 mEq/kg DM). It is speculated that although the narrow DCAD range altered the acid base status of the lactating cows yet it was not sufficient to alter the N balance (May et al., 1987; Welbourne et al., 1988).

Blood pH and HCO_3

Reduction in blood pH with reducing DCAD level might be attributed to increased Cl content of the diet. Lambs fed at DCAD level of -110 mEq/kg had high Cl (1.61%) due to anionic salt (CaCl_2). The Cl absorption takes place in the posterior segment of the intestine, when it was in excess of Na, in exchange for HCO_3 to maintain electrical neutrality, resulting in reduced blood HCO_3 and increased H^+ concentration. Eventually, higher DCAD increased the blood HCO_3 and reduced H^+ , the reverse was true for a low or negative DCAD diet (Block, 1994). The phosphate and ammonia buffer system functions for hydrogen ion excretion. Hydrogen ions combine with phosphate or ammonia after entering the renal tubules and a HCO_3 ion is formed that enters the extracellular fluids to further buffer acid therein (Guyton, 1976). The findings are not surprising because maintaining blood pH is critical to normal body functions, a principal goal of homeostatic mechanisms. The negative DCAD (high Cl) diet might have overcome the ability of the kidneys to excrete sufficient hydrogen ion to maintain a constant blood pH, resulting in slight systemic acidosis. A high DCAD diet tends to have

high blood pH due to more HCO_3 production and H^+ excretion (Tucker et al., 1992). These findings were consistent with West et al. (1991) who reported decreased blood pH (7.32) in cows fed -166 compared to those (7.42) fed 312 mEq/kg DCAD diet. However, the increased pH was within the normal range (Stewart, 1983). Roche et al. (2005) also observed an increased blood HCO_3 with increasing DCAD level.

Serum minerals

Increased serum Ca in lambs fed -110 DCAD diet might be attributed to increased calcium absorption from the alimentary tract (Lomba et al., 1978) and increased calcium mobilization from bones (Joyce et al., 1997), due to mild metabolic acidosis induced by negative DCAD diet. Slight metabolic acidosis, induced by a negative DCAD diet, increased the recognition ability of receptor tissues not only for the parathyroid gland but also for $1, 25(\text{OH})_2 \text{D}_3$. Thus, a negative DCAD diet might have increased serum Ca directly by mobilization of calcium from bones and indirectly through increased absorption from the intestine due to increased synthesis of $1, 25(\text{OH})_2 \text{D}_3$ (Block, 1994). This is also supported by Gaynor et al. (1989) who observed higher plasma hydroxyproline, an index of bone resorption, in cows fed a diet rich in anions (Cl or S). Increased plasma Ca in animals fed a negative DCAD compared to those fed a high DCAD diet has also been reported by Espino et al. (2003).

Increased serum Na and decreased serum Cl as DCAD increased were anticipated because of increased dietary concentrations of these minerals as DCAD increased and decreased, respectively. Decreased serum Cl with increasing the DCAD level is also supported by Roche et al. (2003) who observed a linear reduction in plasma Cl with an increased DCAD diet. Jackson et al. (2001) also reported higher (96.7 mEq/L) plasma Cl in lambs fed 0 mEq/kg than those fed 200 mEq/kg DCAD diets (94.3 mEq/L).

Moreover, slight variation in serum Na (138.2-139.31 mEq/L) and K (4.45-4.52 mEq/L) might be attributed to dietary alteration of these minerals as excess dietary Na and K were excreted through the kidney (Hu and Murphy, 2004). Similar results were reported by West et al. (1991) who stated that increased DCAD level (-116 to 312 mEq/kg) did not significantly affect the serum Na (141.64, 142.50 mEq/L) and K (4.91, 4.70 mEq/L) concentrations. A slight decreasing trend of serum sulphur with increasing DCAD level might be attributable to dietary concentration. Moreover, S balance is regulated renally not intestinally, thus increased intake increased the blood serum S (Krijgheld et al., 1979). These findings are in concordance with Delaquiz and Block (1995).

A linear increase in serum DCAD (Na+K-Cl+S) in the present study was also supported by other researchers

(Tucker et al., 1988; West et al., 1991; Hu and Murphy, 2004) who observed non-significant change in serum Na or K but an increased serum Cl with decreased DCAD level. The inverse relation between blood Cl and serum HCO_3^- concentration has been demonstrated in an imperial model by Hu and Murphy (2004). Moreover, Cl is absorbed in exchange for HCO_3^- to maintain the neutrality of body and results in decreased HCO_3^- and blood pH (Block, 1994). There was no significant effect of DCAD level on serum phosphorus. A slight reduction in serum Mg in lambs fed -110 mEq/kg DCAD level might be due to the high Ca content of the diet which reduced Mg absorption (Chicco et al., 1973).

Urinary pH

Increased urinary pH with increasing DCAD level might be attributed to higher blood HCO_3^- and lower urine net acid excretion, implying that the acid load of the animals decreased rapidly as DCAD increased (Hu and Murphy, 2004). Alteration in urine pH reflects alteration in blood pH and the kidneys minimize this change by making the urine pH alkaline, by excreting more HCO_3^- and conserving H^+ , or acidic, by excreting more H^+ and conserving more HCO_3^- (Roche et al., 2003). Waterman et al. (1991) also reported increased anions (Cl or S) or decreased cations (Na and K) reduced urine pH sharply. Moreover, reduced urine pH with increased dietary anions (Cl and S) has been reported by many workers (Jackson et al., 1992; Jackson and Hemken, 1994; Pehrson et al., 1999). The urine pH had been used as an indicator of metabolic acid or alkali load (Sanchez et al., 2003). Increased urine pH (8.09) was recorded in dairy calves fed a 200 DCAD diet compared to those (6.80) fed 0 mEq/kg DCAD diets (Jackson et al., 2001). However, urine pH has a threshold limit as low as 4.5, induced by a negative DCAD diet (Roche et al., 1999). An increased urinary pH is considered an indicator of blood pH, implying that the acid load of the lactating cows decreased dramatically as cation anion difference increased (Hu and Murphy, 2004).

Calcium balance

Increased urinary Ca excretion in lambs fed -110 diets might be due to slight metabolic acidosis, induced by a negative DCAD diet. This metabolic acidosis might have increased Ca resorption from bones and intestinal Ca absorption (Schonewille et al., 1994; Roche et al., 2003) due to increased synthesis of $1,25(\text{OH})_2 \text{D}_3$ (Goff et al., 1991). Acidosis maintains a high Ca flux through the exchangeable pool without affecting the pool size (Fredeen et al., 1988). The reduced urinary Ca excretion in lambs fed high DCAD diets might be due to a gradual vanishing effect of metabolic acidosis. Ruminant kidneys are highly sensitive to blood acid base status and increase the

excretion of Ca during acidosis, independent of the hormonal action usually associated with Ca metabolism (Stacy and Wilson, 1970). These results are in concordance with West et al. (1992) who observed an increased urinary Ca: creatinine (0.30 versus 0.09) excretion with increased (120 vs. 465 mEq/kg) level of DCAD. Alteration in fecal Ca excretion might be attributed to dietary concentration of this mineral. In the present study, increased Ca retention in lambs fed -110 diet might also be attributed to higher dietary intake of this mineral. Moreover, increased Ca absorption in lambs fed -110 DCAD diet also supported the assumption that metabolic acidosis induced by low or negative DCAD diet might have increased $1,25(\text{OH})_2 \text{D}_3$ synthesis which increased Ca absorption. In contrast to these findings, Schonewille et al. (1994) reported nonsignificant effect on Ca absorption when extra Ca was supplemented in non-pregnant dry cows fed Cl rich diet. Calcium intake was almost 1.8 times higher when extra Ca was supplemented in cows fed an anionic diet but the amount of Ca absorbed was similar. This difference may be attributed to the fact that they used non-pregnant dry cows while in the present study, growing lambs were used, the latter have different Ca dynamics due to growth and development. Above all, it is more important to produce slight metabolic acidosis in order to regulate increased Ca absorption rather than Ca level.

Growth performance

Increased weight gain in lambs fed +220 and +330 DCAD diets might be attributed to increased DMI. Reduced DMI in lambs fed a -110 DCAD diet might be attributed to slight metabolic acidosis, induced by negative DCAD level. During growth, metabolic activities take place at a rapid rate resulting in more CO_2 production, which tends to make the intra cellular environment acidic because CO_2 acts as an acid (carbonic acid) after combining with water. This slightly acidic situation does not allow the cell and its organelles to work at optimum capacity and might have reduced cellular activities resulting in poor growth rate in lambs fed -110 DCAD diet. By comparison a high DCAD, being alkalogenic creates slight alkalosis in the intra cellular environment which reduces the extent of cellular acidity produced by CO_2 , generated by metabolic activities and thus allows the cell to work at its optimum potential (Block, 1994). Similar findings were reported by Jackson et al. (1992) who observed a quadratic increase in the average daily gain in growing calves fed DCAD diets of -170.9, 40.5, 220.5, and 380.3 mEq/Kg of DM. This may be due to a quadratic increase in DMI with increasing DCAD level of the diet. Fettman et al. (1984) studied the effect of Cl supplementation in the ration of dairy cows. They reported increased weight gain in calves fed 0.10% Cl diet compared to those fed 0.45% Cl. The increased weight gain in calves

fed a low Cl (0.10%) diet might be due to increased feed consumption. Wheeler (1981) also reported an increased weight gain in steers fed a DCAD diet of 100 mEq/kg of DM due to increased feed consumption. Jackson and Hemken (1994) observed that calves fed 13 mEq/100 g DM diet gained 0.14 kg/d more weight than those fed diets containing -18 mEq/100 g of DM. Average daily gain was higher in calves fed a DCAD diet of 130 mEq/kg DM. Decreased growth rate in lambs fed low or negative DCAD might be due to metabolic acidosis induced by these diets. Moreover, when the acid balance of the diet deviates toward acidosis, apart from the homeostatic welfare, most metabolic pathways cannot work under optimum conditions and are more involved in homeostatic regulation than growth (Mongin, 1980).

In conclusion, growing *Thalli* lambs fed high (+220 and +330 mEq/kg) DCAD diets gained more weight than those fed low (-110 mEq/kg) DCAD diets.

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