Influence of dietary cation–anion difference in finishing diets fed to Holstein steers during periods of high ambient temperature on feedlot performance and digestive function

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ABSTRACT
One hundred twenty-six Holstein steers (457.1 ± 27.5 kg BW) were used in a 127-d experiment to evaluate the influence of dietary cation–anion difference (DCAD) on growth performance and carcass characteristics. Treatments consisted of steam-flaked corn-based diets supplemented to provide DCAD of 34, 84 or 134 mEq/kg diet DM. There was no treatment effect (P > .20) on ADG, DMI, gain efficiency or dietary NE. Six Holstein steers (196 ± 3 kg) with cannulas in rumen and proximal duodenum were used in a replicated 3 × 3 Latin Square design to evaluated treatment effects on digestion characteristics. The DCAD did not affect (P > .20) ruminal or total digestion of OM, NDF, starch and N, or ruminal pH and VFA molar proportions. It is concluded that increasing DCAD of Holstein steers fed a conventional steam-flaked corn-based diet under conditions of high ambient temperature will not enhance growth performance.

1. Introduction
The anion–cation difference (DCAD) is represented as the possible negative or positive charge produced by nonmetabolizable dietary ion mixtures (Tucker et al. 1988). In its simplest form, DCAD is the difference in concentration of the major cations (Na + K) and anions (Cl + S) per kg of diet DM (Block 1984; Beighle et al. 1988). Diets with low or negative DCAD decrease blood and urine pH, and increase blood Ca solubility (Apper-Bossard et al. 2006). Heat stress increases respiratory CO2 loss (respiratory alkalosis), and Na and K loss (coupled with bicarbonate ions) via elevated sweat and urine production. In principle, corrections in blood acid–base balance and associated electrolyte losses may be achieved through modification of the DCAD. Diets formulated with DCAD of 250 mEq/kg DM have been recommended for optimal growth in chickens (Mongin 1981) and pigs (Austic and Calved 1981; Patience et al. 1987), and 200–370 mEq/kg DM for optimal milk yield in lactating dairy cattle (Tucker et al. 1988; West et al. 1991). The DCAD is usually manipulated by the addition of weak buffers such as NaHCO3, KHCO3 and K2CO3. In ruminants, dietary modifications of this nature may, of themselves, directly alter ruminal pH, with associated effects on ruminal microbial efficiency, digestion and DMI. Changes in dietary salt concentrations to bring about modifications in DCAD may also directly affect diet palatability or acceptability, and hence, DMI. The influence of DCAD modifications on performance of feedlot cattle has received limited attention. Colgan and Mader (2007) evaluated effects of DCAD on ability of cross-bred yearling feedlot steers to cope with moderate (average maximum temperature, 29.4°C; average relative humidity, 74%) summer heat stress during the final 67 d on feed. Increasing DCAD of dry rolled corn-based finishing diet from 91 to 294 mEq/kg did not affect ADG, DMI or gain efficiency. Ross et al. (1994) evaluated effects of DCAD on 84-d feedlot performance of cross-bred steers fed a cracked corn-based finishing diet (climatic conditions or season were not specified). Increasing DCAD from approximately 40 to 350 mEq/kg decreased DMI and ADG, but did not affect gain efficiency.

The role of DCAD on growth performance of calf-fed Holstein steers has not been directly assessed. During periods of high ambient temperature characteristic of the desert Southwest (USA), DMI, and hence, ADG and gain efficiency of Holstein steers are markedly depressed. This depression is most apparent during the late finishing phase (Torrentera et al. 2017). The objective of this study was to evaluate the potential benefit of increasing DCAD in finishing diets on performance of Holstein steers when the late finishing phase coincides with the summer period of very high ambient temperature.

2. Materials and methods
All procedures involving animal care and management were in accordance with and approved by the University of California, Davis, Animal Use and Care Committee.

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**Experiment 1: Influence of dietary cation–anion balance in finishing diets during a period of high ambient temperature on growth performance, dietary energetics and carcass characteristics**

**Experimental location**
This trial was conducted at the Desert Research Center of the University of California, Davis, during the period of (May–September) (127-d feeding trial). The Desert Research Center is located in the Imperial Valley, California (32° 47′ 31″ N and 115° 33′ 47″ W). It is about 16 m below sea level and under Sonoran desert conditions (BW classification according to Köppen). This region is characterized as dry and arid with extreme temperatures in summer (≥42°C), and an average annual precipitation of 85 mm.

**Weather measurement and THI estimation**
Climatic variables (ambient temperature, relative humidity, solar radiation, black globe temperature and wind speed) were obtained every 30 min from an on-site weather station (UC Agriculture Field station) throughout the experimental period. The temperature humidity index was calculated using the following formula: 
\[ \text{THI} = 0.81 \times T + \text{RH} \left( T - 14.40 \right) + 46.40 \]
(Mader et al. 2006).

**Animal management**
One hundred twenty-six calf-fed Holstein steers (457.1 ± 27.5 kg BW) were used in a 127-d experiment to evaluate the influence of increasing levels of dietary cation–anion balance (DCAD) during the seasonally hot months of May through September on growth performance and carcass characteristics. Steers were blocked by weight and randomly assigned within weight groupings to 18 pens (7 steers per pen). Pens were 43 m² with 22 m² overhead shade, automatic waterers and 2.4 m fence-line feed bunks.

**Treatments**
Three dietary DCAD levels were evaluated: 34, 84 and 134 mEq/kg diet DM, where DCAD = (Na + K)−(Cl + S). Dietary DCAD levels were obtained by supplementation of a steam-flaked corn-based finishing diet with 0, 5 or 10 g KHCO₃/kg DM, respectively (Table 1). Steers were allowed ad libitum access to feed and water. Fresh feed was added twice daily. On day 35, steers were implanted Synovex-Plus® (Zoetis Inc., Kalamazoo, MI). Water. Fresh feed was added twice daily. On day 35, steers were implanted Synovex-Plus® (Zoetis Inc., Kalamazoo, MI).

**Estimations of performance and dietary energy**
Energy gain (EG, Mcal/d) was calculated by the equation: 
\[ \text{EG} = \text{ADG} \times 0.0557 \times (NRC 1984). \]
Maintenance energy (EM, Mcal/d) was calculated by the equation: 
\[ \text{EM} = 0.084 \times W^{0.75} \text{(Lofgreen and Garrett 1968).} \]
From the derived estimates of energy required for maintenance and gain, the NEm and NEg values of the diet were obtained using the quadratic formula: 
\[ x = \frac{(-b \pm \sqrt{b^2 - 4ac})}{2a}, \text{ where } a = -1.716EM, b = 0.877EM + 1.716DMI + EG \] and 
\[ c = -0.877DMI, \text{ and } \text{NEg} = 0.877, \text{ NEm} = -1.716 \text{ (Zinn and Shen 1998).} \]

**Statistical analyses**
For calculating steer performance, initial and final full weights were reduced 4% to account for digestive tract fill. Pens were used as experimental units (six pens per treatment). Data were analysed as a randomized complete block design experiment (Hicks 1973) using the GLM procedure (SAS Inst. Inc., Cary, NC). The effects of increasing levels of DCAD in diet on response variables were tested for linear and quadratic components by means of polynomial contrasts, with contrast coefficients adjusted for unequal spacing.

| Item | DCAD, mEq/kg DM |
|------|----------------|
| 34   | 0.00 | 5.00 | 10.0 |
| 84   | 0.00 | 5.00 | 10.0 |
| 134  | 0.00 | 5.00 | 10.0 |

- **Table 1. Composition of experimental diets fed to steers (Experiments 1 and 2)**
- **Table 2. Nutrient composition, g/kg DM basis**

**Experiment 2, influence of dietary cation–anion balance in finishing diets on digestion characteristics**

**Animals and sampling**
Six Holstein steers (196 ± 3 kg) with cannulas in rumen and proximal duodenum were used in a replicated 3 x 3 Latin Square Design to evaluate treatment effects on characteristics of digestion. Diets were the same as in Experiment 1 with the addition of 0.4% chromic oxide as a digestion marker. Steers were maintained in individual pens with access to water at all times. Diets were fed at 08:00 and 20:00 daily. Dry matter intake was restricted to 22 g feed/kg BW.

The experiment consisted of 3 experimental periods of 14 d each; 10-d diet adjustment followed by 4-d collection. During the collections, duodenal and fecal samples were taken from each steer, twice daily over a period of 4 successive days as follows: day 1, 07:50 and 13:50; day 2, 09:00 and 15:00; day 3, 10:50 and 16:50; and day 4, 12:00 and 18:00. Individual samples consisted of approximately 500 mL duodenal chyme and 200 g (wet basis) fecal material. Samples from each steer and within each collection period were composited for analysis. During the final day of each collection period, ruminal samples were obtained from each steer at approximately 4 h after feeding for ruminal pH, and subsequently, 2 mL of freshly prepared 25%
Metaphosphoric acid was added to 8 mL of strained ruminal fluid. Samples were then centrifuged (17,000× g for 10 min) and supernatant fluid stored at −20°C for VFA analysis.

Sample analysis and calculations
Upon completion of the trial, ruminal fluid was obtained from all steers and composited for isolation of ruminal bacteria via differential centrifugation (Bergen et al. 1968). Feed, duodenal and fecal samples were oven dried at 105°C until no further weight was lost, ground in a lab mill (Micro-Mill; Bel-Arts Products, Pequannock, NJ) and stored in tightly sealed glass jars for further analysis. Samples were subjected to all or part of the following analysis: DM (oven drying at 105°C until no further weight loss); ash; ammonia N; Kjeldahl N (981.10; AOAC 1986); aNDFom (Van Soest et al. 1991); purines (Zinn and Owens 1986); chromic oxide (Hill and Anderson 1958); starch (Zinn 1990). Microbial OM (MOM) and N (MN) leaving the abomasum minus ammonia-N and MN and, thus, includes any endogenous contributions.

Methane production was calculated based on the theoretical fermentation balance for observed molar distribution of VFA and OM fermented in the rumen (Wolin 1960). Primary assumptions are that VFA, CO₂ and methane are the sole end products of fermentation and that glucose represents the fermentable substrate (OM fermented is expressed as glucose equivalent).

Data analysis and statistics
Data were analysed as a replicated 3 × 3 Latin Square Design (Hicks 1973) using the GLM procedure (SAS Inst. Inc., Cary, NC). The effects of increasing levels of DCAD in diet on response variables were tested for linear and quadratic components by means of polynomial contrasts with contrast coefficients adjusted for unequal spacing.

### Results and discussion

#### Experiment 1
There was no precipitation during the study. Relative humidity averaged 38%. Minimum and maximum ambient temperatures
Table 3. Treatment effects on characteristics of ruminal and total tract digestion (Experiment 2).  

| Item                  | DCAD, mEq/kg DM | 34   | 84   | 134  | Linear | Quadratic | SEM  |
|-----------------------|-----------------|------|------|------|--------|-----------|------|
| Steer replications    |                 | 3    | 3    | 3    |        |           |      |
| Intake, g/d           |                 |      |      |      |        |           |      |
| DM a                  | 4309            | 4309 | 4309 |      |        |           |      |
| OM a                  | 4045            | 4045 | 4045 |      |        |           |      |
| NDF                   | 647             | 647  | 647  |      |        |           |      |
| N                     | 83              | 83   | 83   |      |        |           |      |
| Starch                | 2011            | 2011 | 2011 |      |        |           |      |
| Flow to the duodenum, g/d |             |      |      |      |        |           |      |
| OM                    | 2275            | 2275 | 2275 |      | 0.91  | 0.83  | 104  |
| NDF                   | 418             | 394  | 394  |      | 0.67  | 0.43  | 30   |
| N                     | 98.4            | 94.3 | 95.5 |      | 0.71  | 0.70  | 4.2  |
| Microbial N           | 58.3            | 55.7 | 56.2 |      | 0.71  | 0.75  | 3.0  |
| Non-ammonia N         | 94.8            | 91.0 | 91.9 |      | 0.71  | 0.73  | 4.2  |
| N                     | 36.5            | 35.3 | 35.7 |      | 0.81  | 0.77  | 1.7  |
| Ruminal digestion, g/kg |             |      |      |      |        |           |      |
| OM                    | 582             | 582  | 571  |      | 0.76  | 0.87  | 19   |
| NDF                   | 354             | 391  | 359  |      | 0.63  | 0.47  | 43   |
| N                     | 704             | 688  | 673  |      | 0.58  | 0.99  | 28   |
| Feed N                | 563             | 577  | 572  |      | 0.81  | 0.77  | 21   |
| Microbial efficiencyb | 25.6            | 24.0 | 24.3 |      | 0.71  | 0.75  | 1.9  |
| Protein efficiencyc   | 1.14            | 1.09 | 1.10 |      | 0.71  | 0.73  | 0.05 |
| Fecal excretion, g/d  |                 |      |      |      |        |           |      |
| DM                    | 876             | 868  | 915  |      | 0.63  | 0.63  | 46.8 |
| OM                    | 770             | 752  | 795  |      | 0.77  | 0.68  | 45.3 |
| NDF                   | 328             | 315  | 341  |      | 0.79  | 0.52  | 25.1 |
| Starch                | 24.7            | 35.4 | 52.0 |      | 0.25  | 0.86  | 10.5 |
| N                     | 22.9            | 29.7 | 307  |      | 0.63  | 0.97  | 1.4  |
| Total tract digestion, g/kg |          |      |      |      |        |           |      |
| DM                    | 660             | 664  | 652  |      | 0.71  | 0.73  | 3.0  |
| OM                    | 770             | 752  | 795  |      | 0.77  | 0.68  | 45.3 |
| NDF                   | 328             | 315  | 341  |      | 0.79  | 0.52  | 25.1 |
| N                     | 988             | 944  | 920  |      | 0.22  | 0.82  | 13   |
| Non-ammonia N         | 699             | 680  | 678  |      | 0.47  | 0.71  | 14   |
| N                     | 672             | 659  | 654  |      | 0.63  | 0.97  | 17   |

a Dry matter intake was restricted to 22 g feed/kg BW.  
b Microbial N, g/kg OM fermented.  
c Non-ammonia N flow to the small intestine as a fraction of N intake.

averaged 20.5 and 38.8°C, respectively. The daily average and maximum THI were 76.2 ± 3.7 and 82.6 ± 2.9, respectively (Figure 1). In accordance with nominal coding (Normal THI < 74; Alert 75 < THI < 78; Danger 79 < THI < 83; and Emergency THI > 84; Mader et al. 2006), cattle experienced ‘alert’ or greater ambient conditions throughout the course of the study.

During the late finishing phase (last 127 d on feed), and notwithstanding the elevated THI, increasing DCAD did not affect (P > .20) ADG, DMI, gain efficiency or dietary NE (Table 2). Colgan and Mader (2007) observed that addition of 2.1% KHCO3 to increase the DCAD of a dry rolled corn-based finishing diet from 91 to 294 mEq/kg did not affect ADG or gain efficiency of Angus-cross steers during their late finishing phase (average daily THI, 71.4). The addition of KHCO3 did, however, increase water intake 22% (from 2.92 to 3.61 L/kg DMI). In contrast, the addition of 1.1% NaCl did not affect water intake. Likewise, Luebbe et al. (2011) did not observe an effect of DCAD (~160 vs +200 mEq/kg DM) on growth performance of feedlot steers during a summer finishing period (June through October). In a 113-d trial conducted during the summer months of June through September, Sexson et al. (2010) observed that increasing the DCAD level from 37 to 102 mEq/kg DM in a steam-flaked corn-based finishing diet did not affect ADG. However, it increased (3.2%) estimated dietary NE. They attributed this response to a potential buffering effect of the added K2CO3, as increasing DCAD also tended to reduce the incidence of liver abscess. Ross et al. (1994) evaluated effects of DCAD on 84-d feedlot performance of cross-bred steers fed a cracked corn-based finishing diet (climatic conditions or season were not specified). Increasing DCAD from approximately 40 to 350 mEq/kg decreased DMI and ADG, but did not affect gain efficiency.

### Experiment 2

Increasing DCAD did not affect (P > .20) ruminal or total digestion of DM, OM, NDF, N or starch (P > .20; Table 3). The influence of DCAD, on site and extent of digestion of feedlot diets has received limited attention. Likewise, increasing DCAD of a steam-flaked corn-based finishing diet from 16 to 104 mEq/kg did not influence ruminal site and extent of digestion of OM, fibre, starch or N (Zinn 1991; Zinn and Borquez 1993).

There were no treatment effects (P > .20) on ruminal pH, total VFA, or molar proportions of acetate, propionate and butyrate, or estimated methane production (Table 4). Ross et al. (1994) did not observe an effect of increasing DCAD from –9 to +350 mEq/kg in a cracked corn-based finishing diet on ruminal pH and VFA molar concentrations. Likewise, Zinn and Borquez (1993) observed that increasing DCAD of a steam-flaked corn-based finishing diet from 16 to 104 mEq/kg did not influence ruminal pH, VFA molar proportions or estimated methane production. In other instances (Russell et al. 1980; Zinn 1991), the increasing DCAD (from approximately 15 to 120 mEq/kg) in high grain finishing diets increased ruminal pH and decreased propionate molar proportions.

### 4. Conclusion

During periods of high ambient temperature, increasing DCAD from 34 to 134 mEq/kg in a steam-flaked corn-based finishing diet did not appreciably influence feedlot growth performance of Holstein steers or characteristics of ruminal and total tract digestion.

Table 4. Treatment effects on ruminal pH and VFA molar proportions and estimated methane production (Experiment 2).  

| Item                  | DCAD, mEq/kg DM | 34   | 84   | 134  | Linear | Quadratic | SEM  |
|-----------------------|-----------------|------|------|------|--------|-----------|------|
| Ruminal pH            | 5.80            | 6.03 | 5.99 |      | 0.35   | 0.42  | 0.10 |
| Total VFA, mM         | 71.6            | 69.2 | 66.8 |      | 0.42   | 0.99  | 3.0  |
| Ruminal VFA, mol/100 mol |           |      |      |      |        |           |      |
| Acetate               | 61.9            | 61.9 | 59.7 |      | 0.40   | 0.61  | 1.2  |
| Propionate            | 29.1            | 28.6 | 29.5 |      | 0.91   | 0.84  | 1.9  |
| Butyrate              | 9.0             | 9.5  | 10.8 |      | 0.28   | 0.71  | 0.7  |
| Acetate/propionate    | 2.1             | 2.4  | 2.04 |      | 0.82   | 0.52  | 0.3  |
| Methaneb              | 0.51            | 0.52 | 0.50 |      | 0.76   | 0.79  | 0.02 |

a Dry matter intake was restricted to 2.2% of BW.  
b Methane production (mol/mol glucose equivalent fermented) was estimated based on the theoretical fermentation balance for observed molar distribution of VFA (Wolin 1960).
Disclosure statement
No potential conflict of interest was reported by the authors.

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