Formulating Diets with Optimum Cation-Anion Difference for Lactating Dairy Cows

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Introduction

Dietary cation-anion difference (DCAD) has been a topic of considerable research in dairy cows nutrition for the last 2 decades (NRC, 2001). Much of the early work addressed effects of DCAD on periparturient Ca metabolism and metabolic health of transition dairy cows (NRC, 2001; Block, 1994). Over roughly the same period time, some but less research focused on the effects of DCAD on lactational performance of dairy cows. Physiological influences of DCAD on acid-base homeostasis and mineral utilization are reviewed and discussed elsewhere (Block, 1994).

Definitions. In the earlier research reports with lactating cows, DCAD was often expressed as the three-element equation: milliequivalents (meq): (K + Na – Cl)/100g of dietary DM. In this paper this calculation will be referred to as DCAD3, whereas DCAD4 will denote the four-element equation of meq:(K + Na - Cl - S)/100g of dietary DM. Whenever possible the DCAD4 is used as cited in the report or where the DCAD3 was reported the DCAD4 was calculated by me using the S concentration reported, or in a few cases assuming that S was supplemented to meet the cows' requirements (e.g., 0.2% S in dietary DM which is equal to about 13 meq of S/100 g of dietary DM). To covert dietary mineral element concentrations to meq/100 g of dietary DM the following are used: [(%K divided by 0.039) + (%Na divided by 0.023)] – [(%Cl divided by 0.0355) + (%S divided by 0.016)], dry basis.

Objectives of this paper are to review the published reports on the effects of DCAD on lactational performance of dairy cows, to consider if there is an optimal DCAD based on published information, and to consider several questions and factors related to DCAD in ration formulation to achieve optimal lactational performance.

Background and Literature Review on DCAD in Lactation

The factorial method, summing the grams of mineral element needed for maintenance, lactation, growth, and pregnancy divided by the absorption coefficient for that particular element was used to estimate the total dietary requirement (g/d) of each K, Na, and Cl (NRC, 2001). The dietary recommendation for S was set at 0.2% of ration DM because insufficient information was available to use the factorial approach. As a point of reference for the remainder of the discussion in this paper, based on current

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total dietary requirements (g/d) for K, Na and Cl for lactating cows with MY ranging from 55 to 120 lb/d the calculated DCAD3 is about +29 meq/100g of dietary DM; the DCAD4 (including the dietary recommendation for total S) is about +16 meq/100g. These values are 3 to 4 meq/100g DM greater than those calculated using NRC (1989) recommendations. There is no dietary requirement of the cow for DCAD *per se* as it is a "concentration expression", just as there are no requirements for percentages of K, Na, and Cl in rations of lactating dairy cows.

DCAD in Lactation Rations: Research from 1995 and Earlier

NRC (2001) provided a summary of much of the research done prior to 1995, directly addressing aspects of macromineral electrolytes on lactational performance of dairy cows and indirectly the effects of DCAD. The study of Tucker et al. (1988) was the first study (cool season) in which DCAD intentionally was varied to measure lactational and physiological responses. They varied DCAD3 by altering the amounts of either cation (K or Na) and the anion Cl. The DCAD3 treatment values were -10, 0, +10 and +20 meq/100g of dietary DM. Treatment rations were fed to mid-lactation Holstein cows. Dry matter intake (DMI) and milk yield (MY) increased with increasing (more positive) DCAD3. Dry matter intake and MY of cows fed the ration with +20 meq DCAD3 were greater than that of cows fed -10 meq. The experimental design and diet formulation were such that researchers were able to differentiate among influences that each element (Na, K or Cl) to vary the DCAD3 might have had on DMI and MY. No differences due to specific elements *per se* were detected. Authors stated that improvement in lactational performance of cows fed rations of greater DCAD3 was independent of the effects of the individual elements used to alter the DCAD3.

In another study (cool season) from the University of Kentucky, Ghorbani et al. (1995) varied the DCAD4 (-11, +18, +55, and +76 meq/100g of dietary DM; DCAD values are calculated by me from mineral element concentration values in Table 2 of the report; calculated treatment DCADs are different from those in the report). The DCAD treatments were fed in a basal ration (40 corn silage: 60 concentrate, dry basis) to 12 mid-lactation Holstein cows in a replicated 4 X 4 Latin square design. Dry matter intake was lower for cows fed -11 or +18 vs. +55 or +76 meq, 38.1 or 42.5 vs. 44.7 or 44.9 lb/d, respectively. Actual MY (unadjusted for solids content) was lower (51.9 lb/d) for cows fed -11 meq, but similar (overall average = 54 lb/d) among cows fed positive DCAD over the range used in the experiment. Yield of 3.5% fat-corrected milk (FCM) was lower for the -11 meq treatment compared with treatments with +18, +55 and +76 meq (51.9 vs. 55.4, 57.2 and 59.0 lb/d); FCM yields of cows fed +18 and +55 meq were similar, as were those of cows fed +55 and +77 meq; however, yield was greater for cows fed the ration with +77 compared with those fed +18 meq. Fat content of milk increased as DCAD increased when sodium bicarbonate was added and calcium chloride was removed from the ration formulations. Milk protein content was reduced for cows fed the highest (+77 meq) DCAD compared with that of cows fed the other treatments. Caution should be used in evaluating responses in this experiment because the concentration of Na (0.02%, dry basis) in the -11 meq diet was too low to meet the cows' Na requirement, and the Cl contents (0.06, 0.05, and 0.15%, dry basis) of diets with the three higher DCAD values, respectively, likely did not meet the cows' Cl requirements (NRC, 2001) at the reported feed intake rates.

In another cool season experiment, Delaquis and Block (1995) measured lactational performance and physiological responses of 12 Holstein cows each in three stages of lactation. Within early (25 to 50 DIM), mid (107 to 137 DIM), and late (162 to 234 DIM) stages of lactation two DCAD4 treatments (n = 6 cows/treatment per stage) were: +6 vs. +26; +14 vs. +37; and, +20 vs. +38 meq/100g of dietary DM, respectively. Only DMI, MY and composition responses are addressed here. Daily DMI of cows increased with high vs. low DCAD4 treatments within early-lactation [(35.6 vs. 33.4 lb/d); 3.27 vs. 3.19% of BW; and, mid-lactation (37.4 vs. 34.3 lb/d); 3.25 vs. 3.03% of BW]; values as a percentage of BW are calculated by me from results in the report. In late-lactation, DMI for low and high DCAD4 were not different (37.0 vs. 39.2 lb/d; 2.82 vs. 2.95 % of BW). Milk yield responses were similar to DMI responses with cows on low and high DCAD4 treatments yielding 40.3 vs. 42.9 lb/d in early-lactation, 40.0 vs. 41.6 lb/d in mid-lactation; no difference was detected in late-lactation (32.8 vs. 33.7 lb/d). Significant, but generally small differences were noted in milk protein and lactose percentages and yields due to increasing DCAD4 in early and mid-lactation. The DMI and MY responses in early- and mid-lactation to increasing DCAD4 are not surprising. The lowest DCAD in both stages was quite low (+5.5 [early] or +14.0 [mid] meq/100g) for lactation diets and would be expected to decrease performance based on reports of Tucker et al. (1988) and Sanchez et al. (1994a, b). Although lactational responses to increasing DCAD4 were noted in early- and mid-lactation in this experiment, overall DMI and MY of cows were atypical of modern Holstein cows. Thus, the stage of lactation data and differences noted in this experiment do not provide much insight as to whether early-lactation cows (most generally presumed to have higher MY and metabolic and nutrient demands) may benefit from higher DCAD4.

Based on a series of lactation performance experiments conducted during the 1980s in Florida with mid-lactation Holstein cows, Sanchez et al. (1994a, 1994b) conducted regression analysis to evaluate DMI and MY responses to varying DCAD. The database (1022 cow-period treatment means from 326 mid-lactation cows) included results of individual cow-period DMI and MY and composition from10 experiments in which factorial arrangements of treatments including two or more dietary concentrations of mainly K, Na, Cl, Mg, Ca and P; S was formulated and supplemented (as sulfate-salt) as needed to achieve 0.2% S, dry basis among all treatments and experiments. Dietary concentrations of the macromineral elements ranged from below to above NRC (1989) recommendations. The DCAD3 over all 10 experiments ranged from +6 to +61 meq/100g of dietary DM; this computes to a DCAD4 of -7 to +48 meq/100g.

Figure 1 displays the overall MY (unadjusted for solids-content), 4% FCM yield and DMI responses of cows over the experimental range of DCAD4. Responses were clearly curvilinear indicating that some optimal DCAD existed. For both DMI and MY, maximum daily rates were at DCAD4 = +25 meq/100 g of dietary DM. However, magnitude of the differences from lowest to highest responses between +7 and +44 meq of DCAD4 was quite small; about 0.55 lb/d for DMI and MY. Many (if not most) lactation rations for mid-lactation dairy cows fall within this DCAD4 range. However, when DCAD4 ranged from +25 up to +48 meq/100 g of dietary DM, DMI declined about 1.1 lb/cow per d and MY declined over 2 lb/cow per d. When the empirical regression equations describing optimal DCAD for maximal DMI and MY were evaluated against independent data from the literature (Tucker et al., 1988; West et al., 1991; 1992), reasonable agreement was found (Sanchez et al., 1994a). Greatest average MY of cows in this regression analysis was less than 51 lb/cow per d and maximum DMI was just over 48 lb/cow per d. Therefore, it is not known if these results are applicable to higher yielding and(or) earlier lactation cows, or not. Additionally, because of the desired dietary treatment concentrations of K, Na and Cl in the original experiments, the distribution of much of the data is well above the former (NRC, 1989) or current (NRC, 2001) recommended concentrations of these macromineral elements to meet requirements. Thus, relatively high DCAD values are associated with much of the data. How these regression responses would compare with a dataset in which the preponderance of data more closely bracketed DCAD concentrations approximating recommended NRC (2001) concentrations for K, Na, Cl, and S is not known.

Similar evaluations with sufficient data to model optimal DCAD on lactational performance of early-lactation and high yielding dairy cows has not been reported. Also, the question of whether or not it makes any difference whether K or Na is used to increase DCAD has not been answered adequately for cows at any stage of lactation. The studies of Tucker et al. (1988) and West et al. (1991) indicate that increasing either K or Na concentration (typically by adding a bicarbonate or carbonate salt of Na or K), either of which changes DCAD, resulted in similar lactational responses.

During Heat Stress Conditions. Esbanosa et al. (1984) found that increasing the DCAD3 from -14 to +35 meq during Texas heat stress increased feed intake and MY. Of course, it is now known that feeding negative DCAD compared with positive DCAD is deleterious for lactating cows regardless of the climatic conditions. Subsequently, West et al. (1991) reported similar improvements in DMI and MY, when different amounts of either K or Na were used to achieve the same DCAD3 (West et al., 1992).

Sanchez et al. (1994b) conducted additional regression analysis using the large dataset described previously. Specifically, the optimal DCAD was evaluated at which maximal DMI and 4% FCM yield were achieved during warm and cool seasons. Results of these regression analyses are in Figure 2. For both DMI and 4% FCM yield optimal DCAD4 was about +22 meq for the warm season and about +30 meq/100g of dietary DM for the cool season. Over the range of DCAD values in the dataset DMI and 4% FCM yield were 10 to 17% less in warm weather than cool weather.

DCAD in Lactation Rations: Research after 1995

Roche and coworkers working in Australia and New Zealand studied the DCAD of rations for late pregnant nonlactating (Roche et al., 2003c; 2002) and lactating dairy cows (Roche et al., 2003a,b) in pasture-based systems. In their first lactation experiment, early-lactation cows were fed individually a ration typical for early-lactation in southeastern Australia of 11 lb of dry rolled barley plus ad libitum pasture forage (cut-and-carry for the experiment). The DCAD4 was varied by drenching individual cows twice daily after milking with appropriate amounts of magnesium sulfate, magnesium chloride, and(or) sodium bicarbonate (Roche et al., 2003b). The final DCAD concentrations of the experimental treatments were +21, +52, +102, and +127 meq/100g of total dietary DM, with five cows receiving each treatment. As DCAD increased from +21 meq, DMI declined (tendency: $P < 0.1$), average daily body weight gain, and milk protein production declined; however, concentrations of milk fat, protein, and lactose were unaffected by varying DCAD. There was a non-significant trend (55.9, 54.1, 54.3, 51.0 lb/cow per d) for reduction in MY as DCAD4 increased from +21, +52, +102, and +127 meq, respectively. Milk protein yield declined nearly 20% as DCAD4 increased from +21 to +127 meq/100g of dietary DM.

In their most recent experiment, Roche et al. (2003a) evaluated lactational performance of early-lactation cows in a pasture-based system. In New Zealand, the DCAD of the ration may range from 0 to +100 meq/100g DM depending upon the particular pasture and fertilization scheme. However, the effects of different DCAD concentrations on lactational performance and acid-base status were not adequately characterized. Holstein-Friesian cows (n = 36) were grazed together and forage intake was estimated for individual cows. Average basal concentrations of K, Na, Cl, S (% of DM) and DCAD4 were 3.74, 0.30, 1.10, 0.36, and +55 meq/100g DM during the 5-week study. One of four experimental treatments was delivered twice daily by drenching individual cows randomly assigned to receive supplements containing varying amounts of sodium bicarbonate, and magnesium and calcium chlorides to alter DCAD4. The actual final DCAD4 treatments (from pasture intake plus drench) were +23, +45, +70, and +88 meq/100g DM; these values, based on re-calculation, are different than those listed in the abstract (personal communication with J. R. Roche, 2003). Dry matter pasture intake (overall average = 37.4 lb/cow per d), yield of milk (overall average = 57.1 lb/cow per d), yield and concentrations of milk protein and lactose, BW gain, and BCS change were all not affected by increasing DCAD4. There were small significant linear increases in milk fat percentage (3.96 to 4.22%) and fat yield (10% increase overall) with increasing DCAD. Systemic acid-base status was affected as reflected by increases in blood pH, bicarbonate, base excess, and urine pH as DCAD increased. Authors concluded that overall lactational performance of early-lactation cows was not affected over this wide range of DCAD4 in this pasture-based system. There certainly was no suggestion that increasing DCAD4 above +23 meq/100g DM was beneficial to overall lactational performance, except for the slight rise in milk fat percentage and yield with increasing DCAD4.

Sanchez et al. (2003) reported in an abstract some results of five field trials (each in a separate herd) conducted by splitting the high herd cows into two groups (n/treatment group = 85 to 145) in four commercial dairies and one university herd. Trials were conducted in non-heat stress conditions. In each dairy, two different DCAD4 were fed to each group with one DCAD treatment as Control and the other some higher DCAD (Treatment) resulting from removal of Cl (in one trial), addition of K (in three trials), or additional of K and Na (in one trial). The magnitude of increase in DCAD between Control and Treatment for the five trials was +6, +8, +5, +10, and +6 meq/100 g of dietary DM. Because these were field trials, cows were group-fed so information is not available about DMI for statistical analysis. The actual MY or FCM yields were not reported (e.g., the high group average pre-trial or treatment averages after application of Control and Treatment); however, the magnitude of difference between DCAD treatments within each farm was listed in the abstract. In two of the five trials there was an increase in actual MY (unadjusted for solids content) with increasing DCAD; in these two trials the Control DCAD was 18 or 19 meq and it was increased to 25 or 26 meq/100g DM, respectively. In three trials no response in MY to increasing DCAD was detected; in these cases the Control DCAD was 38, 25 and 33 meq/100g DM, respectively, before being raised to a higher value with K and(or) Na supplementation. In one of the five trials, fat yield was increased (0.4 lb/cow per d) by increasing DCAD from 25 to 35 meq/100g DM (milk fat% was not reported in the abstract). Fat-corrected MY also was increased by 5.6 lb/cow per d in this trial in which DCAD was increased by supplementing some combination of K and Na salts; unadjusted MY actually was 2 lb/cow per d less with the higher DCAD Treatment in this trial. In the two other trials, FCM yield was increased by 3.0 (by reducing dietary Cl) or 3.3 (by adding K) lb/cow per d by increasing DCAD. In the other two of the five trials unadjusted MY, fat yield, and FCM yield were not affected by increasing the DCAD from 38 to 43 meq or 33 to 39 meq/100g dietary DM; %K of ration DM was increased from 1.52 to 1.80% in one trial, and from 1.50 to 1.70% in the other trial.

Summary of five trials reported by Sanchez et al. (2003) suggests that: **1)** increasing DCAD by removing Cl, or adding Na or(and) K was efficacious especially in situations when the Control DCAD was in the range of 18 to 25 meq/100g DM (low end of the range of these five trials); and, **2)** lactational responses were not detected when supplementing additional cations when the Control DCAD was greater than 25 meq/100 g of dietary DM.

Recently, Hu and Murphy (2004) presented a meta-analysis of 12 studies from published research reports involving 17 trials in which DCAD was varied in rations for lactating dairy cows. Depending upon variable evaluated data from between 35 and 54 dietary treatments were evaluated by regression analysis using mixed model statistical procedures. Average MY for the entire data set was 51 lb/cow per d and ranged from 33 to 79 lb/cow per d. The majority of data are from mid-lactation dairy cows. The overall average DCAD3 (as reported) was +26 and ranged from -19 to +64 meq/100g of dietary DM. The average dietary S% among all diets was 0.33% and ranged from 0.11 to 0.91%, dry basis; but, it is not possible from the report to relate specific S contents with specific DCADs reported by the authors. Therefore, to provide a DCAD4 for comparison a S content of 0.2% or the NRC (2001) recommendation was assumed when referencing a DCAD4 below.

For the entire dataset, DMI was maximal when DCAD4 was +28 meq/100g of dietary DM. Highest MY (unadjusted for solids content) by regression analysis was found when DCAD4 equaled +22 meq, whereas 4% FCM yield was greatest at +37 meq. The magnitude of the difference in 4% FCM yield determined by regression analysis between DCAD4 of +25 and +60 meq was quite small, about 1.5 lb/cow per d over the entire range. Interestingly, because DCAD is considered a major factor affecting systemic acid-base status, Hu and Murphy (2004) evaluated the relationship between DCAD and blood pH. Normal physiologic blood pH is tightly controlled in the range of 7.38 to 7.42. Based on their regression analysis, cows fed DCAD4 from +7 to +27 meq/100g of dietary DM had blood pH within that normal range.

The results of the work of Hu and Murphy (2004) using a different database (all different experiments) compared with that of Sanchez et al. (1994a), provide similar conclusions about the DCAD4 for overall optimum lactational performance of mid-lactation dairy cows. The one exception being at somewhat higher DCAD for maximal FCM yield in the Hu and Murphy (2004) analysis compared with the analysis of Sanchez et al. (1994a).

During Heat Stress Conditions. Researchers in Georgia continued to evaluate the possible effects of DCAD on lactational performance during warm weather (Wildman et al., 2002, 2003, 2004; West, 2003). In one study mid-lactation (188 DIM) cows were fed rations for 80 d with DCAD4 of 30 vs. 45 meq/100g dietary DM, factored with varying dietary ratios of K-to-Na of 2-to-1, 3.5-to-1, or 5-to-1. No main effects of or interactions among DCAD or K-to-Na ratios on DMI, energy-corrected MY, or milk fat or protein percentages were detected. Based on blood and urine measurements taken during the study, authors suggested that sufficient blood buffering capacity existed even with the lower DCAD4 (+30 meq) dietary treatment because additional cation and bicarbonate were excreted in urine.

In another Georgia study, late-lactation cows (225 DIM) were used in a 6-week study during hot weather with a 2 x 2 factorial arrangement of DCAD3 (+25 vs. +50 meq/100g dietary DM) and dietary crude protein (CP) concentrations (15 vs. 17%, dry basis). There was a tendency for a DCAD3 X CP interaction on average daily MY with +50 meq DCAD resulting in lower MY (61.2 lb/cow per d) than +25 meq (69.8 lb/cow per d) with 17% CP ($P < 0.09$), but this difference was not detected with 15% CP. No differences between treatments were observed for DMI or milk protein percentage; milk fat percentage increased with greater DCAD3 and by higher CP%.

Following on previous work, Wildman et al. (2004) reported an additional study in which the DCAD3 was +25 or +50 meq/100g of dietary DM. Eight mid-lactation Holstein cows were used in a replicated 4 x 4 Latin square in late summer and fall. The DCAD treatment was factored with treatments of 33 vs. 42% undegraded intake protein (as percentage of CP). There was no main effect of DCAD3 on DMI or FCM yield. However, there was an interaction of DCAD3 with UIP content in that cows had greater DMI and FCM yield at higher compared with lower UIP when fed higher DCAD3 (+50 meq). However, there were no benefits to increasing UIP within treatments with +25 meq DCAD3.

K, Na, Cl, S Concentrations and DCAD of Selected Feeds

A fairly common comment from the field nowadays is that the K% of many forages is quite high and also that the Cl% is often times higher than previously assumed based on "book" values. It also has been suggested that the concentrations of Cl have increased appreciably compared with previous values. Certainly it has become more common to analyze Cl content of feeds since increased attention is paid to DCAD in ration formulation. Table 15-3 of NRC (2001) provides mineral element composition from recent laboratory analyses with estimates of variability within feed.

Fertilization using KCl (potash) on grass (including corn for silage) and legume fields for mechanically harvested hay and haylage and for pasture is common to stimulate plant growth and to increase stand longevity in cold climates. There also is the idea that perhaps the concentrations of K and Cl in forages are correlated.

To examine and hopefully better understand the profiles of the macromineral elements of the DCAD equation we requested and were provided feed analyses data from four commercial feed testing laboratories in the U.S. The total original database (called New database henceforth) included 95,490 individual feed samples with complete or partial analyses. For this report, partial chemical analyses of 12 forages and 5 concentrate feeds commonly used in dairy rations are presented for comparison and evaluation (Table 1). Presented are comparable macromineral, fiber component, and crude protein analyses [mean, N = number of analyses in mean, and standard deviation (±SD)] as determined from the New database and reported in NRC (2001); where available comparable data from NRC (1989) and (1978) also are listed.

Several general observations can be made from the information in Table 1. Even with large numbers of forage sample analyses (e.g., from about 1,000 to over 30,000) for each feed there still are appreciable differences in mean concentrations of some elements among the New database, NRC (2001), NRC (1989), and NRC (1978). This fact accentuates the need for nutrient analyses of the specific individual forages being used in each dairy farm. Without chemical analyses of the forages unique to the farm there would not seem to be much reason or benefit to trying to achieve a specific targeted "optimal" DCAD in formulation. One easily could be off by 10 to 20 meq/100g, or more, for the total diet if using book values vs. actual analyses. In general, as one would expect the DCAD is appreciably more positive for the forages listed than the concentrate feeds (Table 1).

In comparison to values for NRC (2001), overall many of the Na values for forages in the New database are higher. The reason for this is not known. The K, Na, Cl, S and DCAD contents for corn silage are quite similar among sources of analyses. However, the concentrations of Cl in the NRC (2001) table for legume (alfalfa) hay and grass hay are quite a lot higher than found in the New database. Other major differences in mineral element concentrations exist among the different sources of analytical information. This again, emphasizes the need for actual laboratory analyses if DCAD is an important consideration in ration formulation. To obtain accurate information about mineral element concentrations, analyses must be done by wet-chemistry analysis and not by near infrared reflectance spectroscopy (NIRS) (Shenk and Westerhaus, 1994).

Another evaluation of interest with respect to the DCAD of feeds is to better understand what macromineral elements/values in the DCAD equation have the most influence on the calculated DCAD for specific feeds in the New database. Table 2 presents the proportion of the total variation in calculated DCAD value that is associated with each macromineral element in the equation for each feed. For example, based on the evaluation of data in the New database for oatlage, K is responsible for 49% of the variation of the calculated DCAD value, whereas, Na and Cl have smaller (27 and 22%, respectively) influences; the influence of S is quite small. In contrast in oat hay, K has relatively minor influence (17%), whereas, Na and Cl have appreciable and greater influences on the calculated DCAD. Overall, S does not account for much of the variation in calculated DCAD except for wet brewers grains. This information may be useful in crop fertilization and ration formulation to assist in targeting certain feeds for certain management groups and classes of cows if consideration of or targeting to a particular DCAD is an objective. <u>The values listed in Table 2 ARE NOT coefficients to be placed in front of each element in the DCAD equation.</u>

Ration Formulation and DCAD: Questions and Considerations

Is there an optimal DCAD for rations of lactating dairy cows? As a point of reference, the DCAD4 resulting from formulating rations to meet NRC (2001) requirements for K, Na, Cl and S is about +16 meq/100g dietary DM. Based on available published research reports from 1984 through 2004 and meta-analyses (Hu and Murphy, 2004; Sanchez et al., 1994a,b) evaluating a number of lactational performance and physiological variables, the optimal DCAD for lactation rations is in the range of +25 to +30 meq/100g of dietary DM. The one exception is that FCM yield was maximum at +37meq/100g in the meta-analysis of Hu and Murphy (2004). Though, showing relatively small differences, DMI and MY responded in a curvilinear fashion with the gradual decline beginning when DCAD4 exceeded about +30 meq/100 g of dietary DM (Figures 1 and 2). This may be a palatability issue (vs. metabolic issue) associated with the supplemental salts in these totally mixed rations. A similar depression in DMI was not noted when salts were drenched to elevate DCAD beyond +23 meq/100g DM (Roche et al., 2003).

This entire body of information on the effects of DCAD on lactational performance and clear definition of an optimal DCAD(s) suffers from lack of adequate research with high yielding cows. Nearly all of the experiments were done with mid- to late-lactation cows. Few research results are reported comparing different DCAD with truly high producing and(or) early-lactation dairy cows. Doubtless, this is the physiological state where one could most justify the hypothesis that higher DCAD might be efficacious to support homeostasis in the face of higher metabolic acid production associated with elevated lactation.

Can DCAD be too high or too low? A number of experiments cited in this paper in which a relatively wide range in DCAD was studied demonstrated that DCAD can be too high or too low. Based on the entire body of information it seems certain that DCAD4 of greater than +40 meq or less than +20 meq/100 g of dietary DM should be of concern. The DCAD4 of rations based on NRC (2001) nutrient requirements (about +16 meq/100g DM) could benefit from small additions of cation sources such as feed-grade sodium bicarbonate or potassium carbonate. As DCAD4 approached zero or negative values among reported studies lactational performance was affected deleteriously.

To increase DCAD, is Na or K the better choice? The practical choices to increase DCAD are sodium bicarbonate or potassium carbonate. Sodium carbonate and potassium bicarbonate also have been evaluated sparingly in experiments, and in general did not appear sufficiently efficacious or are considered too expensive for feeding to dairy cows. There is no clear-cut evidence in the published reports to support that sodium bicarbonate is superior to potassium carbonate to increase DCAD and lactational performance of dairy cows, or visa versa. Most typically in dairy rations in the U.S., Na is more likely to be marginally deficient compared with K, which may indicate its consideration as first selection in formulation to increase DCAD. Doubtless, to increase DCAD the fundamental formulation question boils down to which cation source is the *best buy (best value) on a milliequivalent basis, not on a weight basis.* And secondly which element, Na or K is most likely to be (marginally) deficient to lactating cows and result in less excretion which can not be captured and recycled effectively via crops or other means.

Is optimal DCAD different in cool vs. hot weather? Based on the available published reports from Florida and Georgia (Sanchez et al., 1994b; Wildman et al. 2002, 2003, 2004) there is no convincing evidence that DCAD should be increased during heat-stress conditions compared with non-heat stress. Overall optimal lactational performance during hot weather occurred within the range of +25 to +30 meq/100g of dietary DM.

Does rate (level) of MY affect the optimal DCAD for lactation? The highest average MY of any treatment in the reports reviewed was 69 lb/cow per d. Therefore, this question has not been adequately addressed to controlled research. Additional information would be useful. In a study by Mooney and Allen (2002), 40 higher yielding Holstein cows (average MY during the experiment = 85 lb/cow per d) were fed dietary treatments supplemented with sodium bicarbonate, sodium chloride, potassium bicarbonate, or potassium chloride. There were no differences in feed intake or MY among cows fed any of the dietary treatments.

Keys to Practical Ration Formulation

1. Analyze the K, Na, Cl and S contents of all feed ingredients used in ration formulation by wet-chemistry analysis to insure accuracy. The contents of these elements are variable within feed type, especially for forages within and among

farms, and are heavily influenced by fertilization practices and other agronomic and weather-related factors.

2. In ration formulation, the first step should be to meet the requirements for K, Na, Cl (g/d) and S (%) (NRC, 2001).
3. Next, check the DCAD4 of the resulting formulation. If it falls between +25 and +30 meq/100g dietary DM the DCAD is within the optimal range, based on published reports. Additionally, based on published reports if the DCAD4 is within +16 to +40 meq quite small (negligible) differences in DMI or MY would be expected.
4. If the DCAD4 is considered too low and needs to be increased, the primary driver of how much cation must be added to achieve a particular "DCAD target" is largely basal diet Cl content, and to a lesser extent S content. Many common feeds may have relatively high Cl concentrations (Table 1). It is important to note that 0.1 percentage units of S in the diet has about twice the impact to affect the DCAD value as does 0.1 percentage units of Cl. However, common basal feed ingredients typically contain considerably more Cl than S.
5. If the basal DCAD4 is low, the first formulation strategy to increase DCAD might be to remove some Cl or S (i.e., high Cl-containing or high S-containing supplements or feeds).
6. Once anion removal is accomplished as much as practically possible, the DCAD4 of the basal ration can be increased by supplementation with feed grade sodium bicarbonate or potassium carbonate. There is no published research conclusively indicating that one cation is superior to the other to increase DCAD for lactating dairy cows. That is, a milliequivalent of K or Na is essentially equal to adjust DCAD, assuming that the nutrient requirement (g/cow per d) of each element has been met. Therefore, the one selected to increase DCAD should be that source that provides a milliequivalent of cation at the least cost.
7. Finally, there are no “requirements” for concentrations or Na, K, Cl, or DCAD. It is important to remember that high producing cows typically consume more feed than lower producing or later lactation cows. Therefore, even fed the same DCAD, higher producing cows consume more equivalents of cations (Na and K) to help maintain homeostasis.

Conclusions and Summary

Based on the entire body of published reports evaluating effects of dietary cation-anion difference [DCAD: meq (K + Na – Cl – S)/100 g of dietary DM] on lactational performance of dairy cows a value in the range of +25 to +30 meq is effective and sufficient to achieve maximum feed intake and milk production. Considering all the results currently available, the magnitude and difference in lactational responses is quite small over the range +20 to +40 meq/100g DM. Thus, as long as the DCAD is within this range little (or no) benefit is expected by supplementing additional cation (e.g., Na or K). In large part, published results are from experimentation with dairy cows in mid- to late-lactation. There are few reports of experiments with very high yielding and(or) cows in the first trimester; such studies under these circumstance would be useful.

When reviewing and interpreting published research reports, summaries, or advertisements it is very important to consider the following. 1) Is the DCAD correctly calculated in the report? This is not always the case. 2) Is the DCAD reported or cited that for the four-element equation which includes Na, K, Cl and S, or the three-element equation (e.g., Na, K and Cl)? This can make considerable difference (between 13 and 19 meq/100 g of dietary DM for diets with 0.2 to 0.3%S for the four-element compared the three-element equation) in interpretation and setting the target DCAD for formulation. 3) What is the actual or predicted feed intake associated with the particular DCAD and concentrations of Na, K, Cl and S being studied or targeted? Quoted concentrations of DCAD, Na, K, Cl and S as ”requirements” are risky in practical application in dairy nutrition without accurate information about feed intake.

To evaluate and implement formulation strategies to achieve a target DCAD several points are important. If the objective is increase DCAD4 this might be done by reducing Cl and(or) S contributed by specific basal ingredients or supplements. After that consideration, the cations Na and K are equally efficacious for addition to increase DCAD and expect similar lactational performance. Assuming the requirements for Na and K are met already, the fundamental formulation objective to increase DCAD should be to use the source that is least cost on a milliequivalent basis for additional cation. Consideration also should be given to reducing the amount of supplemental cation (K or Na) which is excreted in greater amounts by the cow, and must be effectively recycled via crops or other means. Excessive K, Na, Cl and S in dairy farming systems are a potential problem.

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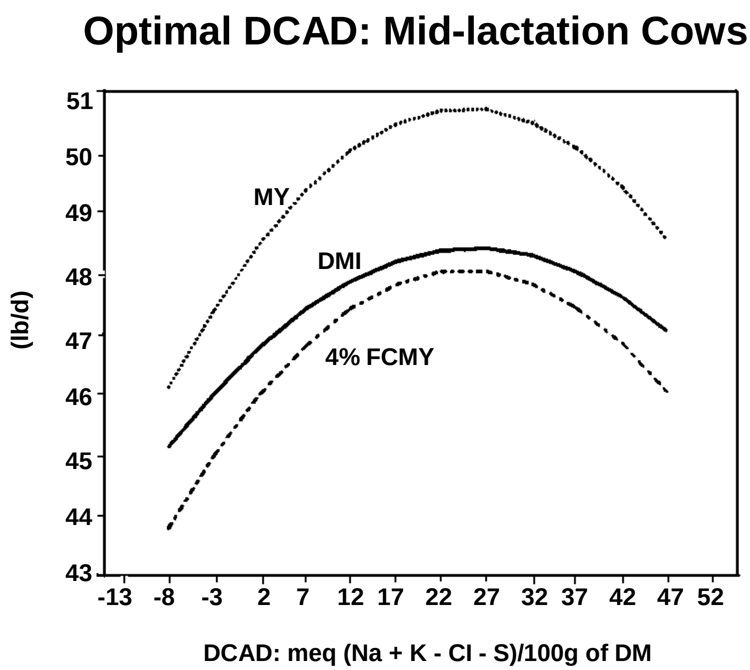

Figure 1. Milk yield (MY), 4% fat-corrected MY (4% FCMY), and DMI responses to mid-lactation Holstein cows to varying DCAD4 (from: Sanchez et al., 1994a).

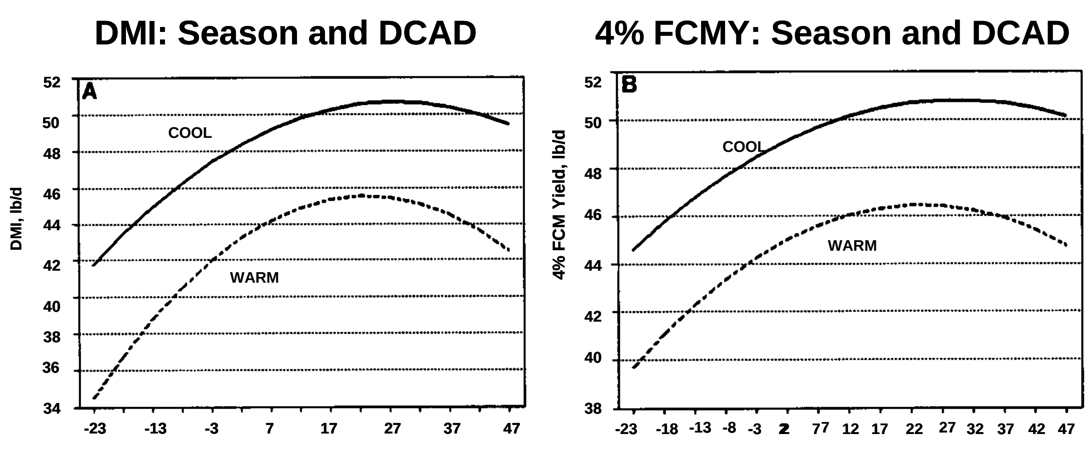

Figure 2. Dry matter intake and 4% fat-corrected milk yield (4% FCMY) of mid-lactation Holstein cows fed varying DCAD4 during cool and warm seasons in Florida.

Table 1. Macromineral element concentrations, dietary cation-anion difference (DCAD), fiber components and crude protein concentrations of selected feeds: comparison of composition from New feed database, NRC (2001), NRC (1989), and NRC (1978), dry basis.[a]

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD [b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	ADF% N ±SD	NDF% N ±SD	CP% N ±SD
Forages											
Corn silage:											
New	1.09	0.04	0.27	0.11	13.9	0.26	0.23	0.18	25.59	43.22	8.67
database	30207	9701	8917	14958	3972	31214	31030	30812	30746	20151	30848
	0.24	0.06	0.12	0.02	6.16	0.07	0.03	0.04	3.35	5.00	8.67
NRC 2001	1.20	0.01	0.29	0.14	14.21	0.28	0.26	0.17	28.1	45.0	8.8
	1033	6991	468	27		1033	1033	1033	1033	1033	1033
	0.30	0.01	0.10	0.02		0.10	0.04	0.04	3.3	5.3	1.2
NRC 1989	0.96	0.01	-	0.15		0.23	0.22	0.19	28.0	51.0	8.1
NRC 1978	1.05	0.01	-	0.08		0.27	0.20	0.28	31.0		8.0
Legume (alfalfa) hay:											
New	2.40	0.14	0.59	0.28	28.5	1.47	0.28	0.30	30.55	39.24	21.15
database	11243	6407	4625	6236	3047	11857	12137	11985	11813	8246	11772
	0.58	0.47	0.30	0.06	14.71	0.29	0.05	0.07	3.77	5.52	2.46
NRC 2001	2.53	0.01	0.74	0.25	28.7	1.52	0.26	0.30	31.2	39.6	20.2
	11212	4242	565	4250		11212	11272	11212	12195	12178	12218
	0.49	0.12	0.39	0.05		0.27	0.05	0.06	4.6	6.3	2.6
NRC 1989	2.52	0.14	0.38	0.28	42.4	1.41	0.22	0.33	31.0	42.0	18.0
NRC 1978	2.08	0.15	0.38	0.30	30.3	1.25	0.23	0.30	38.0		17.2
Legume (alfalfa) haylage:											
New	2.71	0.19	0.64	0.26	33.4	1.33	0.33	0.29	34.59	42.67	21.09
database	12230	5785	3243	4424	2075	12618	12796	12802	12546	6936	12539
	0.58	0.45	0.28	0.05	13.86	0.27	0.05	0.06	4.08	5.15	2.41
NRC 2001	2.87	0.06	0.62	0.24	43.6	1.34	0.32	0.27	37.0	45.7	20.0
	8479	2729	374	3255		8479	8479	8479	8562	8567	8576
	0.59	00.09	0.33	0.04		0.26	0.06	0.05	4.8	6.5	3.0

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD [b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	ADF% N ±SD	NDF% N ±SD	CP% N ±SD
Grass hay:											
New database	1.87 3516 0.58	0.17 2026 0.40	0.54 1091 0.26	0.18 1976 0.06	21.8 694 13.38	0.51 3735 0.19	0.24 3777 0.07	0.21 3787 0.07	38.76 3725 3.98	61.51 2631 6.36	11.16 3727 3.20
NRC 2001	2.83 21 0.65	0.03	0.74	0.28	35.3	1.01 21 0.32	0.31 21 0.06	0.26 21 0.08	31.5 21 2.0	49.6 21 1.8	18.4 21 3.1
Grass haylage:											
New database	2.45 784 0.69	0.21 591 0.46	0.66 552 0.32	0.24 547 0.07	34.8 440 16.78	0.55 837 0.20	0.32 853 0.07	0.23 851 0.06	35.64 830 4.75	51.87 587 7.47	14.73 825 3.33
NRC 2001	2.64 95 0.73	0.01	0.45 2	0.25 3 0.02	39.66	0.89 95 0.26	0.36 95 0.06	0.26 95 0.07	35.7 95 1.9	54.4 95 1.6	17.6 95 3.0
Barlage:											
New database	1.33 1785 0.94	0.66 1464 0.72	0.82 1248 0.31	0.20 1300 0.04	23.5 1162 16.48	0.42 1802 0.12	0.30 1784 0.06	0.18 1777 0.04	32.77 1770 4.49	47.03 1406 5.95	13.22 1786 2.41
NRC 2001	2.43 420 0.78	0.13 214 0.23	0.72 11 0.54	0.17 97 0.04	36.9	0.48 525 0.19	0.30 525 0.06	0.18 420 0.05	34.5 528 4.9	56.3 387 7.0	12.0 528 2.6
Oat hay:											
New database	1.91 313 0.89	0.56 244 0.62	0.89 225 0.55	0.19 210 0.05	31.8 170 20.36	0.37 314 0.14	0.25 320 0.06	0.18 315 0.05	35.72 275 3.57	55.07 166 4.91	10.78 280 2.67
NRC 2001	2.01 403 0.71	0.33 403 0.28	1.08 51 0.51	0.14 180 0.06	26.6	0.37 403 0.22	0.22 403 0.07	0.17 403 0.06	36.4 419 4.5	58.0 419 6.3	9.1 422 2.9

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD [b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	ADF% N ±SD	NDF% N ±SD	CP% N ±SD
Oatlage:											
New database	2.58 506 1.01	0.66 355 0.94	0.81 256 0.40	0.21 338 0.05	36.8 221 21.44	0.49 506 0.16	0.32 522 0.07	0.21 511 0.05	38.21 502 4.14	56.03 388 5.89	13.50 533 3.00
NRC 2001	2.89 615 0.77	0.24 207 0.30	1.34 28 0.91	0.19 194 0.05	34.7	0.52 615 0.21	0.31 615 0.07	0.20 615 0.05	38.9 631 4.2	60.6 632 5.7	12.9 634 1.6
Triticale silage:											
New database	3.05 203 0.91	0.12 116 0.22	0.94 76 0.56	0.21 93 0.05	36.6 52 20.53	0.49 210 0.21	0.35 207 0.07	0.18 211 0.05	36.45 213 4.85	55.71 147 6.77	14.48 211 3.61
NRC 2001	3.01 107 0.88	0.05 40 0.08		0.21 25 0.06		0.57 107 0.30	0.33 107 0.07	0.19 107 0.06	39.6 107 5.7	59.7 107 8.3	13.8 107 4.0
Wheatlage:											
New database	2.33 937 0.72	0.13 475 0.23	0.68 189 0.36	0.19 257 0.04	29.9 141 16.85	0.39 926 0.14	0.30 939 0.07	0.16 947 0.04	36.91 935 4.10	55.74 501 5.86	13.07 948 2.88
NRC 2001	2.28 459 0.69	0.07 249 0.13	0.83 36 0.49	0.17 179 0.05	27.34	0.38 223 0.16	0.29 459 0.08	0.16 459 0.05	37.6 470 4.9	59.9 471 7.4	12.0 471 3.0
NRC 1989	1.39	0.07	0.07	0.24	21.7	0.27	0.27	0.62	-	-	11.9
NRC 1978	1.39	0.07	0.07	0.24	21.7	0.27	0.27	0.62	-	-	11.9

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD [b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	ADF% N ±SD	NDF% N ±SD	CP% N ±SD
Sorghum silage:											
New	1.57	0.08	0.58	0.13	22.2	0.44	0.21	0.26	35.55	54.86	8.07
database	771	263	136	240	97	796	779	777	817	622	718
	0.54	0.13	0.30	0.04	12.10	0.17	0.05	0.07	5.92	8.42	1.55
NRC 2001	2.57	0.03	0.56	0.15	41.9	0.64	0.24	0.31	40.7	63.3	10.8
	131	63	5	53		131	131	131	139	139	140
	0.97	0.05	0.22	0.05		0.41	0.07	0.08	5.1	7.2	3.2
NRC 1989	2.25	0.02	-	0.06		0.46	0.21	0.44	42.0	68.0	10.8
NRC 1978	2.56	0.02	-	0.06		0.48	0.19	0.49			11.1
Ryelage:											
New	3.15	0.04	0.87	0.25	42.0	0.45	0.43	0.18	34.48	54.50	17.06
database	1265	629	172	185	113	1270	1275	1294	1258	498	1264
	0.65	0.04	0.38	0.06	17.46	0.13	0.09	0.04	4.39	5.08	3.23
NRC 2001	3.34	0.05	0.90	0.20	49.7	0.43	0.42	0.16	34.9	57.8	16.1
	1155	563	24	240		1155	1155	1155	1173	1174	1175
	0.66	0.08	0.51	0.05		0.16	0.08	0.10	4.9	6.3	3.1
Concentrates											
Barley:											
New	0.46	0.14	0.16	0.14	5.4	0.08	0.40	0.15	6.79	17.91	13.35
database	131	115	76	110	72	130	130	130	176	179	179
	0.23	0.21	0.05	0.02	4.61	0.03	0.06	0.02	1.62	3.04	1.60
NRC 2001	0.56	0.02	0.13	0.12	4.0	0.06	0.39	0.14	7.20	20.8	12.4
	287	229	31	139		319	321	287	727	331	795
	0.12	0.02	0.07	0.01		0.02	0.06	0.02	2.8	8.6	2.1
NRC 1989	0.47	0.03	0.18	0.17	-2.4	0.05	0.38	0.15	7.0	19.0	13.5
NRC 1978	0.45	0.03	0.20	0.18	-4.1	0.05	0.37	0.15	7.0		13.9

Feedstuff	**%K** **N** **±SD**	**%Na** **N** **±SD**	**%Cl** **N** **±SD**	**%S** **N** **±SD**	**DCAD** [b] **N** **±SD**	**%Ca** **N** **±SD**	**%P** **N** **±SD**	**%Mg** **N** **±SD**	**ADF%** **N** **±SD**	**NDF%** **N** **±SD**	**CP%** **N** **±SD**
High moisture ear corn:											
New database	0.47 931 0.07	0.01 166 0.01	0.13 29 0.04	0.10 245 0.01	2.5 20 2.26	0.05 976 0.03	0.28 1187 0.04	0.12 1176 0.02	9.32 1150 2.52	19.61 543 4.48	8.73 1157 0.82
NRC 2001	0.48 2608 0.07	0.01 470 0.03	0.07 54 0.03	0.09 907 0.01	5.1	0.05 2608 0.03	0.28 2608 0.03	0.12 2608 0.01	9.4 2673 3.7	21.0 2675 6.9	8.4 2684 1.0
NRC 1989	0.53	0.02	0.05	0.16	3.0	0.07	0.27	0.14	7	28	9.0
NRC 1978	0.56	0.05		0.22		0.05	0.26	0.17			9.3
High moisture shelled corn:											
New database	0.41 3366 0.05	0.02 533 0.04	0.09 183 0.06	0.10 1726 0.01	2.6 88 2.29	0.03 3430 0.03	0.32 4461 0.04	0.12 4493 0.01	3.89 3409 1.22	10.10 2447 1.60	9.50 4494 0.86
NRC 2001	0.43 4633 0.06	0.01 439 0.01	0.05 107 0.01	0.10 1317 0.01	3.8	0.03 4633 0.03	0.30 4633 0.03	0.12 4633 0.03	3.6 4728 1.6	10.3 4729 2.7	9.2 4761 0.9
NRC 1989	0.35	0.01	0.05	0.14	-0.8	0.02	0.32	0.14	3.0	9.0	10.0
NRC 1978	0.35	0.01	0.05	0.14	-0.8	0.03	0.31	0.13	3.0		10.0
Soybean meal:											
New database	2.21 211 0.19	0.02 286 0.02	0.08 58 0.07	0.41 298 0.03	31.7 42 5.38	0.38 417 0.08	0.75 411 0.06	0.32 411 0.02	7.94 346 2.33	12.07 317 3.38	51.96 932 2.84
NRC 2001	2.41 246 0.25	0.03 237 0.25	0.13 96 0.65	0.39 142 0.05	35.0	0.35 256 0.10	0.70 256 0.08	0.29 243 0.03	6.2 248 3.0	9.8 248 5.6	53.8 549 2.1
NRC 1989	1.98	0.03	0.08	0.37	26.6	0.30	0.68	0.30	10.0		49.9
NRC 1978	2.21	0.31	0.03	0.49	38.6	0.36	0.75	0.30	10.0		49.6

Feedstuff	%K N ±SD	%Na N ±SD	%Cl N ±SD	%S N ±SD	DCAD [b] N ±SD	%Ca N ±SD	%P N ±SD	%Mg N ±SD	ADF% N ±SD	NDF% N ±SD	CP% N ±SD
Wet brewers grains:											
New database	0.13 381 0.10	0.03 259 0.05	0.07 90 0.07	0.35 185 0.07	-21.8 76 4.37	0.99 5 0.26	0.64 380 0.10	0.22 397 0.05	22.76 416 2.55	47.25 290 5.30	30.97 471 4.68
NRC 2001	0.47 427 0.26	0.01 13 0.01	0.12 1	0.33 190 0.06	-11.5	0.35 427 0.22	0.59 427 0.10	0.21 427 0.26	23.1 686 3.8	47.1 685 6.8	28.4 1127 4.0
NRC 1989	0.09	0.23	0.17	0.32	-12.5	0.33	0.55	0.16	23.0	42.0	25.4
NRC 1978	0.09	0.28	0.13	0.34	-10.4	0.29	0.54	0.15	23.0		26.0

[a] If data were not available from NRC (1989; 1978) rows were not included for that feed in the table.
[b] DCAD = meq:(K + Na – Cl – S)/100g of DM.

Table 2. Proportion (%) of total variation (R^2) of calculated dietary cation-anion difference associated with each variable (cation or anion) in the DCAD equation for various feeds in the database[a].

Feedstuff	K	Na	Cl	S
Forages:		R^2		
Corn silage	59	20	18	2
Legume (alfalfa) hay	56	10	25	8
Legume (alfalfa) haylage	61	4	31	4
Grass hay	52	19	22	7
Grass haylage	67	4	25	4
Barlage	22	54	22	2
Oat hay	17	38	44	1
Oatlage	49	27	22	2
Triticale silage	53	5	41	1
Wheatlage	68	12	19	1
Sorghum silage	58	4	36	2
Ryelage	61	2	34	3
Concentrates:				
Barley	14	71	8	6
High moisture ear corn	68	3	17	12
High moisture shelled corn	59	11	16	14
Soybean meal	70	2	16	12
Wet brewers grains	22	4	11	63

[a]DCAD = meq(K + Na – Cl –S)/100g of dietary DM. The values listed in Table 2 ARE NOT coefficients to be placed in front of each element in the DCAD equation.