

Formulation of Rations with Optimal Cations and Anions for Lactation

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Summary and Conclusions

Based on published reports evaluating the effects of dietary cation-anion difference [**DCAD**: $\text{meq (K + Na - Cl - S)/100 g}$ 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 yield. Considering all of the results currently available, the magnitude and difference in lactational responses is quite small over the range +20 to +40 meq/100g DM. Less than +20 meq was quite detrimental to lactational performance and greater the +40 meq was not significantly beneficial and was even detrimental at higher DCAD concentrations. Thus, as long as the DCAD is within the +20 to +40 meq 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 of lactation; such studies under these circumstances would be useful.

When reviewing and interpreting published research reports, summaries, or especially advertisements about DCAD and supplementing cations, it is very importance 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 (**DCAD4**) which includes Na, K, Cl and

S or the three-element equation (DCAD3 such as with 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 in the four-element compared the three-element equation) in interpretation and setting of the target DCAD in 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 to 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 to increase DCAD, and similar lactational performance is expected if increased DCAD is targeted and considered beneficial. Assuming that the actual nutritional requirements (grams per day) for Na and K are met already, the fundamental formulation objective to increase DCAD should be to use the cation source that is least cost on a milliequivalent basis. Consideration also should be given to reducing the amount of supplemental cation (K or Na); this 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 our dairy farming systems are currently potential problems.

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Introduction

The DCAD has been a topic of considerable research in dairy 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 (Block, 1994; NRC, 2001). Over roughly the same period of 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): $(K + Na - Cl)/100$ g of dietary DM. In this paper, this calculation will be referred to as DCAD3, whereas DCAD4 will denote the four-element equation of meq: $(K + Na - Cl - S)/100$ g 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: $[(\%K \text{ divided by } 0.039) + (\%Na \text{ divided by } 0.023)] - [(\%Cl \text{ divided by } 0.0355) + (\%S \text{ divided by } 0.016)]$, dry basis.

The 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 (grams per day) of 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 and based on current total dietary requirements (grams per day) for K, Na, and Cl for lactating cows with milk yield (**MY**) ranging from 55 to 120 lb/day, the calculated DCAD3 is about +29 meq/100 g of dietary DM; the DCAD4 (including the dietary recommendation for total S) is about +16 meq/100 g. These values are 3 to 4 meq/100 g 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 for lactating dairy cows.

DCAD in lactation rations: Research from 1995 and earlier

The 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/100 g of dietary DM. Treatment rations were fed to mid-lactation Holstein cows. Dry matter intake (**DMI**) and 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/100 g of dietary DM; DCAD values are calculated by me from mineral element concentration values in Table 2 of the report; calculated treatment DCAD 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/day, respectively. Actual MY (unadjusted for solids content) was lower (51.9 lb/day) for cows fed -11 meq but similar (overall average = 54 lb/day) 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, or +76 meq (51.9 vs. 55.4, 57.2, and 59.0 lb/day); FCM yields of cows fed +18 and +55 meq were similar, as were those of cows fed +55 and +76 meq; however, yield was greater for cows fed the ration with +76 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 (+76 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 in three stages of lactation. Within early [25 to 50 days in milk (**DIM**)], mid (107 to 137 DIM), and late (162 to 234 DIM) stages of lactation, two DCAD4 treatments (n = 6 cows/treatment/stage) were: +6 vs. +26; +14 vs. +37; and, +20 vs. +38 meq/100 g of dietary DM, respectively. Only DMI, MY, and milk 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/day); 3.27 vs. 3.19% of body weight (**BW**); and, mid-lactation (37.4 vs. 34.3 lb/day); 3.25 vs. 3.03% of BW]; values as a percentage of BW were 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/day; 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/day in early-lactation, 40.0 vs. 41.6 lb/day in mid-lactation; and no difference was detected in late-lactation (32.8 vs. 33.7 lb/day). 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/100 g) 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) 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 milk composition from 10 experiments in which factorial arrangements of treatments included 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 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/100 g of dietary DM; this computes to a DCAD4 of -7 to +48 meq/100 g.

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/day 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/day and MY declined over 2 lb/

cow/day. 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/day and maximum DMI was just over 48 lb/cow/day. Therefore, it is not known if these results are applicable to higher yielding and/or earlier lactation cows. 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/100 g 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/100 g 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/day) 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/100 g 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/100 g DM depending on 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/100 g 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/100 g 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/day), yield of milk (overall average = 57.1 lb/cow/day), yield and concentrations of milk protein and lactose, BW gain, and body condition score (**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. The 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/100 g DM was beneficial to overall lactational performance, except for the slight rise in milk fat percentage and yield with increasing DCAD4.

Sanchez et al. (2002) 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 dairy farms 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 addition 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/100 g 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/100 g DM 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/day) by increasing DCAD from 25 to 35 meq/100 g DM (milk fat% was not reported in the abstract). Fat-corrected MY also was increased by 5.6 lb/cow/day in this trial in which DCAD was increased by supplementing some combination of

K and Na salts; unadjusted MY actually was 2 lb/cow/day 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/day by increasing DCAD. In the other two of the five trials, unadjusted MY, fat, and FCM yields were not affected by increasing the DCAD from 38 to 43 meq or 33 to 39 meq/100 g dietary DM; K (5 of DM) was increased from 1.52 to 1.80% in one trial and from 1.50 to 1.70% in the other trial.

In summary, the five trials reported by Sanchez et al. (2003) suggest 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/100 g DM (low end of the range of these five trials); and 2) lactational responses were not detected with 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 on the 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/day and ranged from 33 to 79 lb/cow/day. The majority of data were from mid-lactation dairy cows. The overall average DCAD3 (as reported) was +26 and ranged from -19 to +64 meq/100 g of dietary DM. The average dietary S concentration 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 concentrations with specific DCAD reported by the authors. Therefore, to provide a DCAD4 for comparison, a S concentration of 0.2% or the NRC (2001) recommendation was assumed when referencing a DCAD4.

For the entire dataset, DMI was maximal when DCAD4 was +28 meq/100 g 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/day 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/100 g 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) and 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 days with DCAD4 of 30 vs. 45 meq/100 g 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 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/100 g dietary DM) and dietary crude protein (**CP**) concentrations (15 vs. 17%, dry basis). There was a tendency for a DCAD3 X CP interaction for MY, with +50 meq DCAD resulting in lower MY (61.2 lb/cow/day) than +25 meq (69.8 lb/cow/day) 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 percentage.

Following on previous work, Wildman et al. (2004) reported an additional study in which the DCAD3 was +25 or +50 meq/100 g of dietary DM. Eight mid-lactation Holstein cows (180 DIM) 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% rumen undegradable protein (**RUP**; as a percentage of CP). There was no main effect of DCAD3 on DMI or FCM yield. However, there was an interaction of DCAD3 with RUP content in that cows had greater DMI and FCM yield at higher compared with lower RUP when fed higher DCAD3 (+50 meq). However, there were no benefits to increasing RUP within treatments for +25 meq DCAD3.

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

A fairly common comment from the field nowadays is that the K percentage of many forages is quite high and also that the Cl percentage is oftentimes 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 the 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 analysis 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 CP analyses [mean, N = number of analyses in mean, and standard deviation ($\pm$ SD)] as determined from the New database and reported in NRC (2001), where available comparable data from NRC (1989; 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 and NRC (1978; 1989; 2001). 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/100 g, or more, for the total diet if using book values versus 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 concentrations for corn silage were quite similar among sources of analyses. However, the concentrations of Cl in the NRC (2001) 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 for 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 for a particular DCAD is an objective. The values listed in Table 2 ARE NOT coefficients to be placed in front of each element in the DCAD equation.

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/100 g dietary DM. Based on available published research reports from 1984 through 2004 and meta-analyses (Sanchez et al., 1994a,b; Hu and Murphy, 2004) evaluating a number of lactational performance and physiological variables, the optimal DCAD for lactation rations is in the range of +25 to +30 meq/100 g of dietary DM. The one exception is that FCM yield was maximum at +37 meq/100 g 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 (versus 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/100 g DM (Roche et al., 2003).

This entire body of information on the effects of DCAD on lactational performance and a 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/100 g 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 for 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/100 g 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/day. Therefore, this question has not been adequately addressed by 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/day) 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 (grams per day) and S (percentage) (NRC, 2001).
3. Next, check the DCAD4 of the resulting formulation. If it falls between +25 and +30 meq/100 g dietary DM, the DCAD is within the optimal range based on published reports. Additionally, 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 influenced by basal diet Cl concentration, and to a lesser extent S concentration. 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 (grams per cow per day) of each element has been met. Therefore, the one selected to increase DCAD should be the source that provides a milliequivalent of cation at the least cost.

7. Finally, there are no “requirements” for concentrations of 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.

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

Table 1. (Con'td.)

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

Table 1. (Con'td.)

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

Table 1. (Con'td.)

Feedstuff	%K		%Na		%Cl		%S		DCAD ^b		%Ca		%P		%Mg		%ADF		%NDF		%CP	
	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD
High moisture ear corn:																						
New database	0.47		0.01		0.13		0.10		2.5		0.05		0.28		0.12		9.32		19.61		8.73	
	931		166		29		245		20		976		1187		1176		1150		543		1157	
	0.07		0.01		0.04		0.01		2.26		0.03		0.04		0.02		2.52		4.48		0.82	
NRC 2001	0.48		0.01		0.07		0.09		5.1		0.05		0.28		0.12		9.4		21.0		8.4	
	2608		470		54		907				2608		2608		2608		2673		2675		2684	
	0.07		0.03		0.03		0.01				0.03		0.03		0.01		3.7		6.9		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		0.02		0.09		0.10		2.6		0.03		0.32		0.12		3.89		10.10		9.50	
	3366		533		183		1726		88		3430		4461		4493		3409		2447		4494	
	0.05		0.04		0.06		0.01		2.29		0.03		0.04		0.01		1.22		1.60		0.86	
NRC 2001	0.43		0.01		0.05		0.10		3.8		0.03		0.30		0.12		3.6		10.3		9.2	
	4633		439		107		1317				4633		4633		4633		4728		4729		4761	
	0.06		0.01		0.01		0.01				0.03		0.03		0.03		1.6		2.7		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		1.14		-0.8		0.03		0.31		0.13		3.0				10.0	
Soybean meal:																						
New database	2.21		0.02		0.08		0.41		31.7		0.38		0.75		0.32		7.94		12.07		51.96	
	211		286		58		298		423		417		411		411		346		317		932	
	0.19		0.02		0.07		0.03		5.38		0.08		0.06		0.02		2.33		3.38		2.84	
NRC 2001	2.41		0.03		0.13		0.39		35.0		0.35		0.70		0.29		6.2		9.8		53.8	
	246		237		96		142				256		256		243		248		248		549	
	0.25		0.25		0.65		0.05				0.10		0.08		0.03		10.0				49.9	
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	

Table 1. (Con'td.)

Feedstuff	%K		%Na		%Cl		%S		DCAD ^b		%Ca		%P		%Mg		%ADF		%NDF		%CP	
	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD	N	±SD
Wet brewers grains:																						
New database																						
	0.13		0.03		0.07		0.35		-21.8		0.99		0.64		0.22		22.76		47.25		30.97	
	381		259		90		185		76		5		380		397		416		290		471	
	0.10		0.05		0.07		0.07		4.37		0.26		0.10		0.05		2.55		5.30		4.68	
NRC 2001																						
	0.47		0.01		0.12		0.33		-11.5		0.35		0.59		0.21		23.1		47.1		28.4	
	427		13		1		190				427		427		427		686		685		1127	
NRC 1989																						
	0.26		0.01				0.06				0.22		0.10		0.26		3.8		6.8		4.0	
	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	

^aIf data were not available from NRC (1989; 1978) rows were not included for that feed in the table. ADF = acid detergent fiber, NDF = neutral detergent fiber, CP = crude protein, N = number of samples, and SD = standard deviation.

^bDCAD = meq: (K + Na - Cl - S)/100 g of DM.

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

Feedstuff	K	Na	Cl	S
	----- R^2 -----			
Forages				
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

^aDCAD = $\text{meq}(\text{K} + \text{Na} - \text{Cl} - \text{S})/100$ g of dietary DM. The values listed in Table 2 ARE NOT coefficients to be placed in front of each element in the DCAD equation.

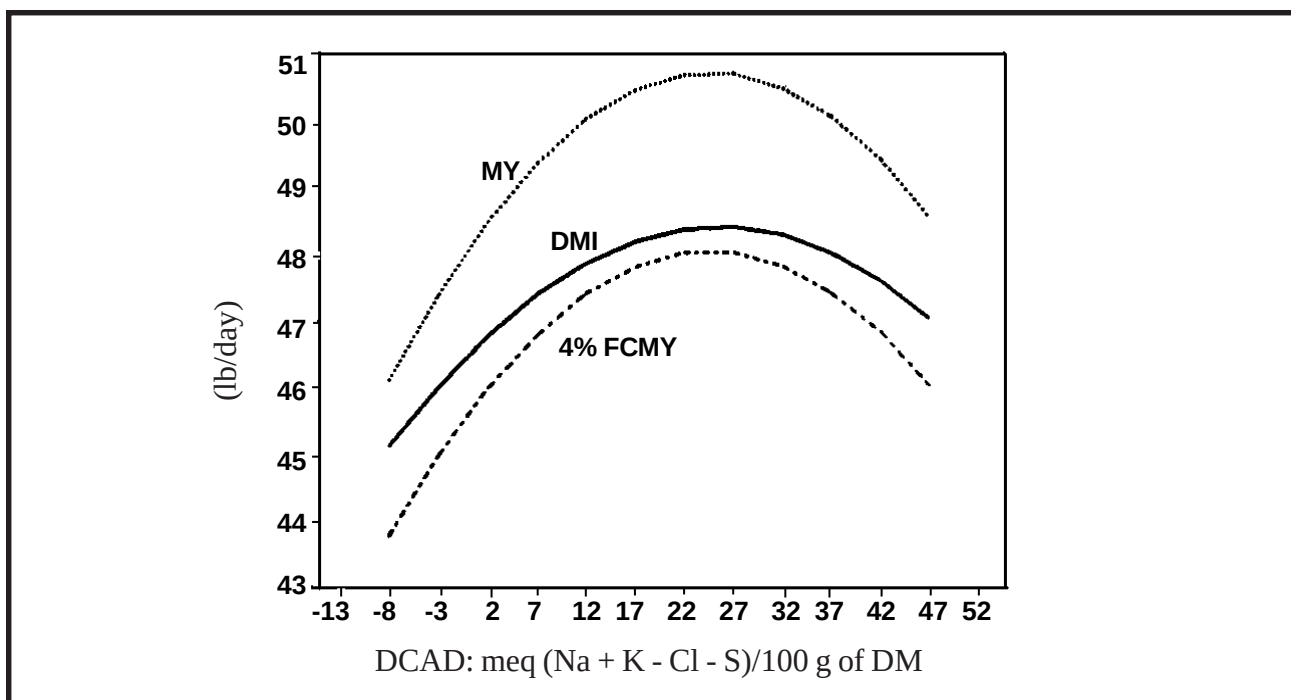


Figure 1. Milk yield (MY), 4% fat-corrected MY (4% FCMY), and DMI responses to mid-lactation Holstein cows to varying DCAD4 (DCAD = dietary cation-anion difference)

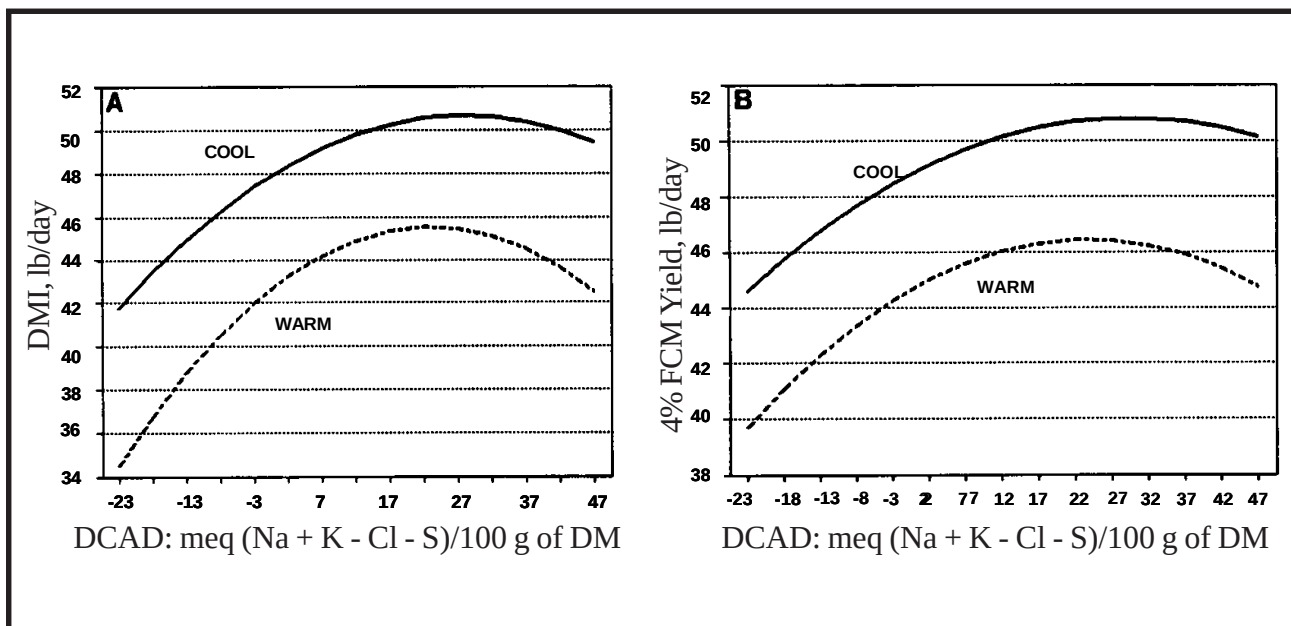


Figure 2. Dry matter intake (DMI; A) and 4% fat-corrected milk yield (4% FCMY; B) of mid-lactation Holstein cows fed varying DCAD4 (DCAD = dietary cation-anion difference) during cool and warm seasons in Florida (Sanchez et al., 1994b).