Another *New* Look at DCAD for the Prepartum Dairy Cow

William K. Sanchez, Ph.D.
Church & Dwight Co., Inc.

INTRODUCTION

Dairy nutritionists are beginning to fine-tune anionic salt feeding and macromineral nutrition recommendations according to the cation-anion difference concentration in the diet. Many papers on feeding anionic salts and dietary cation-anion difference **(DCAD)** concepts have appeared recently in the scientific literature and popular press. The objective of this paper and presentation will be to deliver the newest information on current strategies to feed and supplement the close-up dry cow to prevent hypocalcemia and associated disorders. For a broader examination of these and other related topics see recent reviews by Beede (1995), Horst et al. (1997), and the accompanying paper in this proceedings (Sanchez 1999).

DCAD AND ACID-BASE STATUS

Shohl and Sato (1923) were the first to propose that mineral interrelationships were related to acid-base status. Shohl (1939) proposed that maintenance of normal acid-base equilibrium required excretion of excess dietary cations and anions. He hypothesized that consumption of either, excess mineral cations relative to anions or excess anions relative to cations, resulted in acid-base disturbances.

Once animal nutritionists began to test this hypothesis, mineral interrelationships were found to affect numerous metabolic processes. Leach (1979) and Mongin (1980) reviewed related literature and concluded that mineral interrelationships had profound influences. They theorized that for an animal to maintain its acid-base homeostasis, input and output of acidity had to be maintained. It was shown that net acid intake was related to the difference between dietary cations and anions. The monovalent macromineral ions, Na, K and Cl were found to be the most influential elements in the expression (Mongin, 1980).

Specific Effects of Macromineral Salts on Acid-Base Status

Nutrient metabolism results in the degradation of nutrient precursors into strong acids and bases. During normal metabolism the flux of H^+ is great. In typical rations fed to dairy cattle, inorganic cations exceed dietary inorganic anions by several millequivalents (meq) per day. Carried with excess dietary inorganic cations are organic anions, which can be combusted to HCO_3^-. Therefore, a diet with excess inorganic cations relative to inorganic anions is alkaline and a diet with excess inorganic anions relative to cations is acidogenic.

NUTRITIONAL FACTORS RELATED TO CATION-ANION INTERRELATIONSHIPS

Leach (1979) and Mongin (1980) reviewed nutritional concepts related to cation-anion interrelationships. Historically, nutritionists intuitively knew it was difficult to evaluate the effect of one macromineral without considering the influences of others. Early concepts evaluated total ash, mineral ratios, and differences among two or more of the macrominerals.

Acid or Alkaline Ash

Nutritionists first investigated the alkalinity and acidity of the diet under the acid- or alkaline-ash concept (Shohl, 1939). It was recognized that human food either had an acid or alkaline ash. When food is metabolized in the body, organic anions, such as acetate, citrate, malate, etc., are oxidized. Inorganic cations originally associated with these organic anions remain. Because organic anions can buffer H^+ ions generated through metabolism, a food with a large amount of organic anions (and thus inorganic cations) was considered alkaline. The pH of the ash represented the acid or alkaline nature of human food.

Dietary Cation-Anion Difference (DCAD)

Blood pH is ultimately determined by the number of cation and anion charges absorbed into the blood. If more anions than cations enter the blood from the digestive tract, blood pH will decrease. Mongin (1980) was one of the first to propose a three-way interrelationship among dietary Na, K and Cl. He proposed that the sum of Na plus K minus Cl (in meq per 100 g diet DM) could be used to predict net acid intake. This sum commonly has been referred to as the dietary cation-anion balance (Tucker et al., 1988) or dietary electrolyte balance (West et al., 1991). However, Sanchez and Beede (1991) coined the term *cation-anion difference* to represent, more precisely, the mathematical calculation used and to avoid the erroneous connotation that mineral cations truly are balanced with mineral anions in the diet. Expressed in its fullest form, DCAD would be written as:

meq [(Na + K + Ca + Mg) - (Cl + S + P)]/ 100g of dietary DM   **Equation 1**

A problem with including the multivalent macrominerals (Ca, Mg, P, and S) in the DCAD expression for ruminants, relates to the variable and incomplete bioavailability of these ions compared to Na, K and Cl.

The expression that has been used most often in non-ruminant nutrition is the monovalent cation-anion difference expressed as:

meq (Na + K - Cl)/100 g dietary DM
                                                   Equation 2

This expression was considered superior for non-ruminant nutritionists because it comes closest to representing feed ions that are completely dissociated and solubilized from their respective salts, and absorbed into the body.

Because of the additional use of sulfate salts in prepartum rations, the expression that has gained the most acceptance in ruminant nutrition, and is the most common expression used in ration software, is:

meq [(Na + K) - (Cl + S)]100 g dietary DM)
                                                   Equation 3

Calculating DCAD

To actually calculate DCAD using Equation 3 mineral concentrations are first converted to meq as follows:

$$meq/100\ g = \frac{(milligrams)(valence)}{(g\ atomic\ weight)}$$

As an example, the meq (Na + K) – (Cl + S) value of a diet with 0.1% Na, 0.65% K, 0.2% Cl and 0.16% S (minimum recommendation for dry cows; NRC, 1989) will be calculated. There are 100 mg Na (0.10% = .10 g/100 g or 100 mg/100 g), 650 mg K (0.65% K), 200 mg Cl (0.2% Cl), and 160 mg S (0.16 % S) per 100 g diet DM. Therefore, this diet contains:

$$meq\ Na = \frac{(100\ mg)(1\ valence)}{(23\ g\ atomic\ weight)} = 4.3\ meq\ Na$$

$$meq\ K = \frac{(650\ mg)(1\ valence)}{(39\ g\ atomic\ weight)} = 16.7\ meq\ K$$

$$meq\ Cl = \frac{(200\ mg)(1\ valence)}{(35.5\ g\ atomic\ weight)} = 5.6\ meq\ Cl.$$

$$meq\ S = \frac{(160\ mg)(2\ valence)}{(32\ g\ atomic\ weight)} = 10.0\ meq\ S.$$

The next step is to sum the meq from the cations and subtract the meq from the anions:

meq (Na + K) - (Cl + S) = 4.3 + 16.7 – 5.6 – 10.0 = **+ 5.4 meq/100 g diet DM**.

Another simpler way to calculate DCAD is to use:

DCAD = [(%Na in DM/0.023)+(%K in DM/0.039)]-[(%Cl in DM/0.0355)+(%S in DM/0.016)].

For example, using the same numbers as above, the calculated DCAD equals (0.10% Na/0.023) + (0.65% K/0.039) - (0.2% Cl/0.0355) - (0.16% S/0.016) = **+5.4 meq/100g diet DM.**

Note that values calculated on a per 100 g basis are 10 times less than on a per kg basis (100g = kg/10). Note also that the DCAD equation with only Na, K, and Cl in it yields a value approximately 10 DCAD units higher than with the equation with Na, K, Cl, and S in it (assuming S is equal to 0.16%).

THREE SOURCES OF ERROR IN CALCULATING DCAD

1) Units

Some papers report the units of DCAD per 100g of DM and some report DCAD per kg of DM. This can cause a 10 fold calculation error, which can cause a serious formulation error if not corrected before balancing the diet. Again, note that values calculated on a per 100 g basis are 10 times less than on a per kg basis (100 g = kg/10).

2) Sulfur in the DCAD Equation

For reasons mentioned above, the sulphate ions were not initially included in the DCAD equation. However, because of the extensive use of sulphate salts in dry cow rations the DCAD equation $[(Na + K) - (Cl + S)]$ has become more common in ration formulation programs. Because S changes the DCAD calculation drastically, this has led to errors in calculating DCAD and comparing information from the literature.

3) The Spartan Dairy Ration Program Calculation

The popular SPARTAN DAIRY RATION Program took a novel approach to calculating DCAD. Because of the problems mentioned above relative to divalent ions, it considered only the inorganic form of S in the calculation. Therefore, depending on the amount of organic sources of S, the calculation of DCAD could be off by 10 to 20 meq/100 g of DM. One way to use the program to calculate the DCAD in the same way that has been done in research studies (using Equation 3) is to categorize all ingredients as minerals before checking the DCAD calculation. However qualifying the amount of organic vs. inorganic S may be a more appropriate method to account for the effect of DCAD on acid-base status because the impact of S on acid-base status is much less than earlier projected (Goff and Horst, 1997).

THE CLOSE-UP COW

The Close-Up Period

The close-up dry cow period, defined as the time from three weeks prepartum to parturition, is an extremely critical time for the dairy cow; possibly defining her entire lactational performance (Wang, 1990).

Many years ago, researchers discovered that a diet that was acidic caused the concentration of blood calcium to increase. This led to the practice of feeding a diet with more anions relative to cations to help reduce milk fever problems. The increased blood calcium in these cows not only prevented them from going down with milk fever, it also reduced problems like retained placentas and displaced abomasums. These problems were tied to a calcium deficiency that prevented the muscles from contracting. Therefore, nutritionists began feeding prepartum cows diets with less cations than anions to help increase blood calcium around the time when it was very deficient at calving. These diets are described as anionic diets or diets with a low or negative cation-anion difference.

Milk fever may affect 5-7% of all high producing adult dairy cows in the United States (Jordan and Fourdraine, 1993). In addition, the prevalence of subclinical hypocalcemia may be as high as 66% for multiparous dairy cows following calving (Beede et al., 1992). Research indicates that cows with clinical milk fever produce 14% less milk in the subsequent lactation and their productive life is reduced approximately 3.4 years when compared to non-milk fever cows (Block, 1984; Curtis et al., 1984). Furthermore, cows that recover from milk fever have an increased risk of ketosis, mastitis (especially coliform mastitis), dystocia, left displaced abomasum, retained placenta, and milk fever in the subsequent lactation (Curtis et al., 1984; Wang, 1990; 1993; Oetzel, 1988). Guard (1996) estimated that the cost associated with a single case of milk fever is approximately $334, when considering lost production and income, veterinary costs, and treatment costs.

Feeding Anionic Salts

Feeding anionic salts or manipulating the dietary cation-anion difference of the diet has become a common approach on dairies that can accommodate multiple dry cow groups. Feeding close-up dry cows less Na and K relative to Cl and S (i.e., a negative DCAD diet) increases blood Ca at calving, presumably by increasing bone mobilization and (or) absorption of Ca in response to changes in acid-base status. Studies have shown that when dry cows were fed diets with negative DCAD, milk fever cases were reduced drastically, and in some cases completely eliminated.

It is important to emphasize that for the trials in which negative DCAD aided in prevention of milk fever, dietary concentrations of Ca were high

(approximately 1.5% Ca). Negative DCAD increases urinary excretion of Ca; therefore, if dietary Ca were low with a negative DCAD, hypocalcemia may occur, regardless of and separately from milk fever. Conversely, high dietary Ca with low DCAD may be necessary for this method to be successful. However, the optimal dietary Ca content has not been established.

RECENT RESEARCH

Research on the DCAD Expression

Because of differences in bioavailability of each mineral element in the DCAD expression, the functional equation most applicable in practical situations differs. Based on the bioavailability figures for Ca, Mg and P from NRC (1989), Goff et al. (1997a,b) suggested that the equation:

meq(Na + K + 0.38Ca + 0.30Mg) - (Cl + 0.60S + 0.5P)/ 100g of dietary DM   **Equation 4**

was more appropriate. Na, K and Cl were considered 100% bioavailable and the bioavailability of 60% for S was based on work of Tucker et al. (1991).

Goff and Horst (1997) then compared the acidifying effects of dietary hydrochloric acid or sulfuric acid on urine pH of nonlactating Jersey cows. Sulfuric acid exhibited about one-third of the acidifying power (e.g., change in urine pH) of hydrochloric acid. Sulfuric acid would be considered the most bioavailable chemical form of the sulfate (SO_4^{-2}) anion compared with other mineral sources of sulfate, such as magnesium sulfate, calcium sulfate, and ammonium sulfate.

Goff et al. (1997a) compared the relative acidifying strengths of six anion sources with a similar animal model. Urine samples were taken 4 h after feeding on d 3, 4, and 5 of each experimental period in which a different anion source was fed. Urine pH's of multiparous non-lactating Jersey cows fed hydrochloric acid, calcium chloride, ammonium chloride, calcium sulfate, magnesium sulfate, and elemental S were 6.2, 7.1, 7.0, 7.6, 7.9, and 8.2, respectively. The order of strength from strongest to weakest acidifiers was hydrochloric acid, ammonium chloride, calcium chloride, calcium sulfate, magnesium sulfate, and elemental sulfur.

Overall, the Cl-containing salts were more acidogenic than the SO_4^{-2}-containing salts. Elemental S had no effect on acid-base status as one should expect; although occasionally elemental S is found as a source of anion in mineral supplements for close-up diets. These new data cause us to question what the most appropriate DCAD equation should be and what anion sources are most appropriate for supplementation. Based on results of these two experiments, Goff et al. (1997b) suggested that a more biologically or functionally correct DCAD equation might be:

meq [(Na + K + 0.15Ca + 0.15Mg) - (Cl + 0.20S + 0.3P)]/ 100g of dietary DM   **Equation 5**

Recently, Rodriguez et al. (1997) found no difference in urine or blood plasma pH when non-lactating, non-pregnant Holstein cows were fed diets with either 0.5 or 2.0% Ca (supplemental Ca from $CaCO_3$) across diets with DCAD set at about -10 meq[(Na + K) - (Cl + S)]/ 100g of dietary DM. In both trials the high Ca diets reduced DMI when anionic salts were fed. Therefore, excessively high dietary Ca levels are not recommended. We continue to recommend 120 to 150 g of Ca/day for cows fed anionic salts. When more positive DCAD concentrations are used, feed a dietary Ca concentration at the lower end of this recommendation. And when more negative concentrations are fed, feed a dietary Ca at the upper end of this recommendation. Remember that the source of Ca influences its overall effect. For example, Ca from alfalfa forage is less bioavailable than calcium carbonate and calcium carbonate is less bioavailable than calcium chloride.

Results of these recent experiments have stimulated considerable discussion of DCAD equations and supplementation of anions. There is no consensus on which equation to use. If a more precise estimate is required the weighted equations are probably most effective. However, the simplest and most practical approach may be to use the three-element equation. Until additional data are available most researchers continue to recommend the four-element expression (Equation 3).

DCAD Feeding Strategy

Detailed feeding strategies for using anionic salts including:

- Recommended salts to use,
- Length of feeding interval, and
- Specific precautions

can be found in several excellent reviews (Beede 1995; Horst et al., 1997a,b). The most common
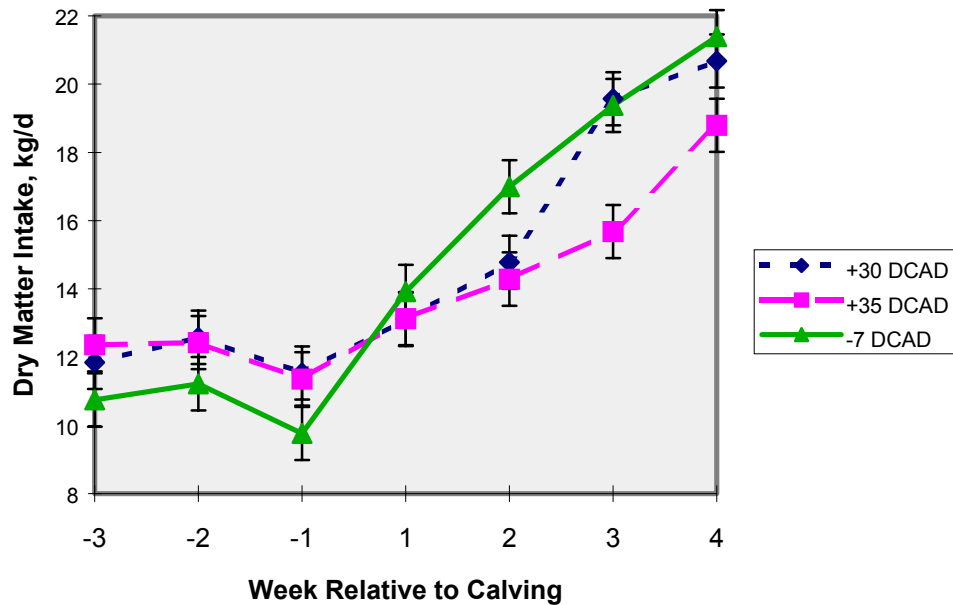
Figure 1: Intake response to varying diets [a grass-based (+30 DCAD), an alfalfa-based (+35 DCAD), or an alfalfa plus anionic salts diet (-7 DCAD)] fed prepartum to Holstein cows. After parturition all cows were fed a similar alfalfa-based lactation ration (from Joyce et al., 1997).

recommendation is to add sulfate salts until Mg and S is maximized at 0.4 to 0.45% and then chloride salts until DCAD is lowered to -10 to -15 meq/100g dietary DM. Calcium intake should be increased to approximately 120 to 150g per cow/day. New information on this concept is outlined below.

Optimal DCAD and Dose of Anionic Salts

Controlled experiments have not yet determined the optimal DCAD. The recommended target DCAD of -10 to -15 meq/ 100g dietary DM may be lower than needed to achieve the desired changes in acid-base status and subsequent increases in blood Ca. However, this range of DCAD provides a margin of safety to account for varying K concentrations in feeds and K consumed from pasture or free-choice hay. Recent research from the University of Idaho addressed this question further and established a numerical relationship between DCAD and blood calcium. (Giesy et al., 1997). The study also showed a tight relationship between DCAD and urine pH. Urine pH can be monitored on farm to make sure diets are formulated correctly.

What if the Basal Dietary DCAD Is Too High?

Horst et al. (1997) suggested the maximum amount of anions that can be added before intake declines is about 30 meq. This means if the basal

DCAD is about +20 then the DCAD can be lowered to -10 with 30 meq of anions. However, when the basal DCAD is greater than +30 or +40 what should be the strategy? The first priority would be to remove as much high K feedstuffs as possible (some hay samples contain more than 4.0% K). Once that is done, if the basal DCAD is still + 30 or + 40 then there are two options. First, add more than 30 meq of anions and lower the DCAD to -10. This potentially could lower intake by the prepartum cow and lead to other metabolic problems (Bertics et al., 1992).

However, research conducted by Joyce et al. (1997) at the University of Idaho demonstrated that reducing intake by feeding anionic salts prepartum is not always detrimental. In that study (Figure 1) prepartum Holstein cows were fed either a grass-based (+30 DCAD), an alfalfa-based (+35 DCAD), or an alfalfa plus anionic salts diet (-7). The cows fed the -7 DCAD diet had lower intakes prepartum but greater intakes postpartum, compared with cows fed the other treatments. The -7 DCAD diet did increase blood Ca, which apparently overcame any negative effect of reducing intake. The relationship between DCAD, intake and postpartum performance was similar to that found in a recent experiment with periparturient cows (Moore et al., 1997).

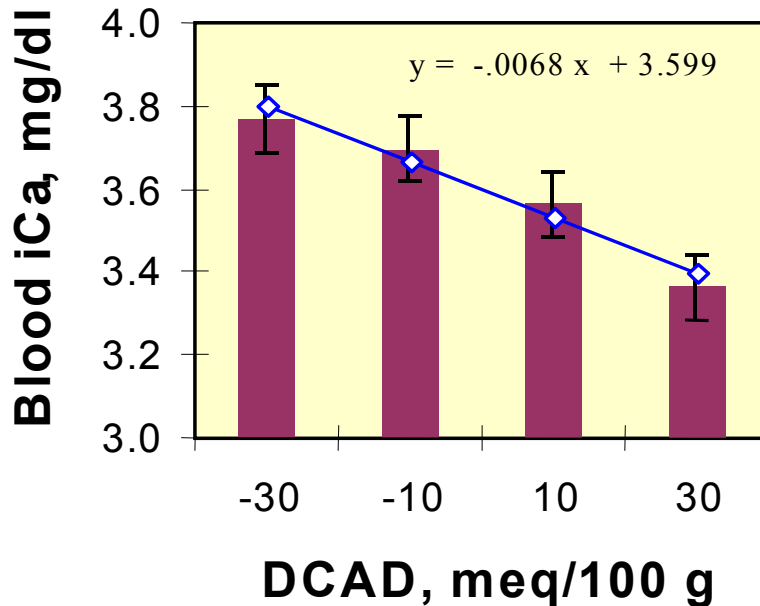Vagnoni and Oetzel (1997) studied the effects of DCAD on DMI and acid-base status. Four

$$y = -.0068 \, x + 3.599$$

Figure 2: Blood ionized Ca response to four levels of DCAD following infusion with EDTA to mimic hypocalcemia (from Giesy et al., 1997).

diets were evaluated: 1) control, 2) Biochlor (Biovance Technologies, Omaha NB), 3) magnesium sulfate and ammonium chloride, and 4) magnesium sulfate, calcium sulfate and calcium chloride. Urine pH was reduced by feeding anionic salts and Biochlor. Biochlor was the most effective treatment in reducing urine pH, followed by treatments 2 then 3.

The second option to try, if the basal DCAD is too high, would be to reduce the DCAD as much as possible, for example to +10 or 0. A potential problem with this option is that the DCAD concentration may not be low enough to control hypocalcemia. When this is done it is recommended to only increase dietary Ca partially (Beede, 1995).

Experiment to Determine Response to Varying DCAD

We recently completed an experiment (Giesy et al., 1997) that provides new data on the above two options. The objective of the study was to determine the blood Ca responses to varying DCAD

concentrations. Four non-pregnant, non-lactating Holstein cows were used in a complete 4 X 4 Latin Square Design. Each cow was fed one of four DCAD concentrations, +30, +10, -10, or -30 meq/100g DM. Rations were fed as total mixed rations with alfalfa hay, grass hay and alfalfa silage as the forages. Cows were fed these diets for 14 days then given EDTA i.v. to mimic subclinical hypocalcemia. Blood samples were taken immediately prior to the onset of infusion of EDTA and once every 30 minutes thereafter for 8 hours. Blood was analyzed for both total and ionized Ca. Urine pH also was measured.   From the results of this study, we observed that serum total Ca was highly variable and, although somewhat responsive to DCAD, did not seem to correlate well with DCAD. Blood ionized Ca, the freely available fraction of Ca, was much less variable and was very responsive to DCAD. Figure 2 shows the blood ionized Ca response to varying DCAD. We also saw an increase in blood Ca at each of the decreasing levels of DCAD. This indicates that increases in blood Ca can be achieved even when DCAD is not lowered to -10.
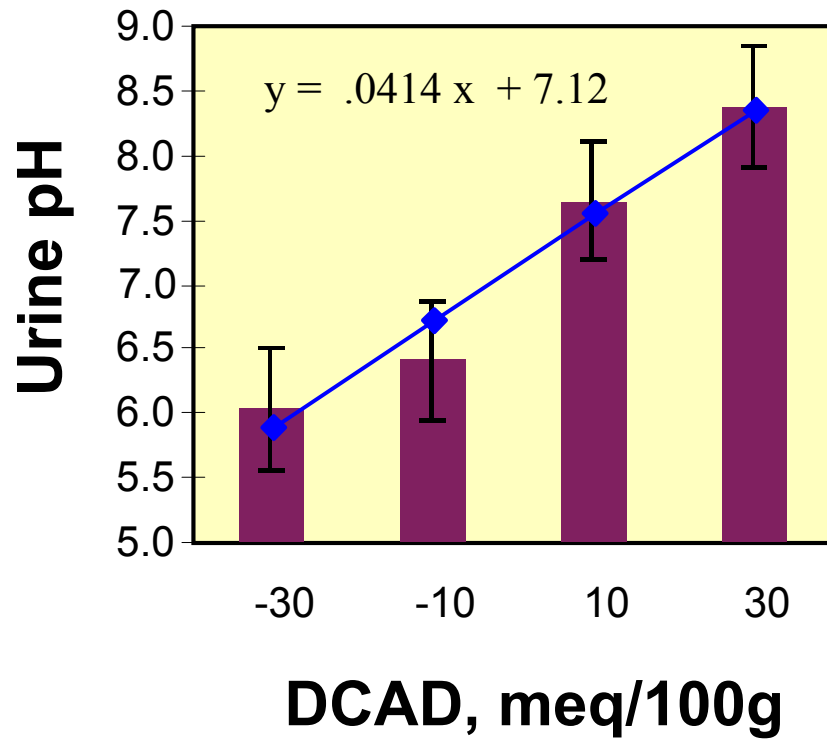
Figure 3: Urine pH response to four levels of DCAD (from Giesy et al., 1997).
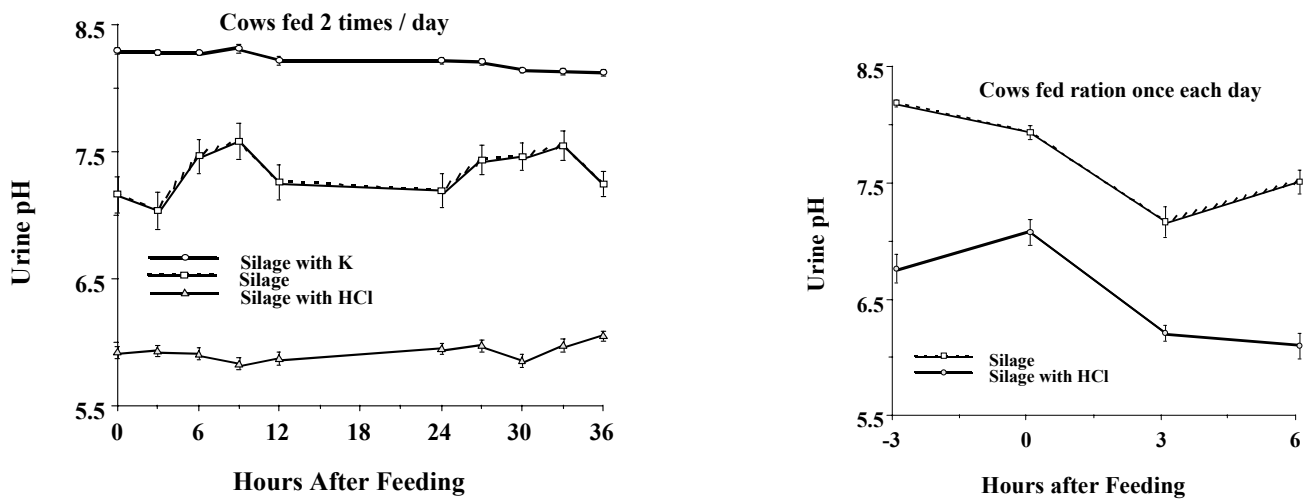

Figure 4: Post feeding urine pH responses from cows fed twice/day (left panel) or once/day (right panel). Diets were based on either corn silage, corn silage with supplemental potassium carbonate, or corn silage with supplemental hydrochloric acid (from Goff et al., 1998).

Using Urine pH to Monitor DCAD Programs

Upon feeding anionic salts, urine pH changes quickly (within 2 – 4 days). Monitoring urine pH, therefore, can be a useful tool to determine whether or not the ration is having the desired physiological effects. The urine pH response to DCAD from the study of Giesy et al., (1997) is shown in Figure 3.

This tight relationship between DCAD and urine pH was similar to that found in a recent experiment with periparturient cows (Moore et al., 1997). In that study they fed diets for 21 d to close-up cows with DCAD of +14, 0, and -5 meq (Na + K) - (Cl + S)/ 100g of dietary DM. Supplemental anions were provided from calcium chloride, magnesium sulfate, and magnesium chloride. Total dietary Ca varied (0.44, 0.97, and 1.5% Ca) with the three decreasing DCAD, respectively. The source of supplemental Ca was from increasing calcium chloride and calcium carbonate in the 0 and -5 meq diets. Urine pH of close-up cows immediately before calving was 7.98, 7.0, and 6.21 for +14, 0, and -5 meq, respectively.

Finally, a common question that arises when urine pH monitoring programs are instituted is "When should urine pH be collected?" Goff and Horst (1998) evaluated the effect of time after feeding on urine pH. In their first study they fed 21 nonpregnant dry Jersey cows twice per day (at 8 a.m. and 8 p.m.) either a +32 or -14 DCAD diet ((meq Na + K) – (Cl + S)/100g diet DM). The negative DCAD diet had HCl added to it. Urine pH was measured just before feeding at 8 a.m. and again 3, 6, 9, and 12 hours later. In this twice/day feeding study, urine pH's averaged 8.2 for controls and 7.3 for HCl treatment throughout the day, but there was no significant diurnal variation in urine pH (Figure 4). In their second trial, 25 dry cows were fed just once per day. As before, the HCl diet significantly reduced urine pH, but in contrast to the first study, there was a significant diurnal variation in urine pH (Figure 4). Urine pH of HCl fed cows was 7.04 at feeding time and 6.17 at 3 hours after feeding. The study demonstrated there could be diurnal shifts in urine pH when close-up cows are only fed once per day.

When establishing an on-farm urine pH measuring protocol the best strategy would be to collect urine from about 10 cows at the same time of day each week, preferably 2 to 6 hours after feeding. This can be done on-farm, using standard pH paper or a field pH meter. If the average urine pH is much greater than 6.5 (the target level), the ration is not affecting acid-base status enough to significantly alter blood Ca concentrations at calving. Measure urine pH the same time every week to ensure that the desired effect is being maintained.

CONCLUSIONS

New information on DCAD for the prepartum cow presented includes:

- Information on different DCAD equations,
- Relative effectiveness of anion sources,
- Potential errors in calculating DCAD,
- Role of dietary Ca.
- optimal DCAD, and
- The effect of dose of anionic salts.

Much more information on the use of urine pH as a monitoring tool is now available, including the quantitative relationship to DCAD and the effect of feeding on diurnal variations in urine pH.

From the available literature, the optimal DCAD for prepartum cows appears to be between 0 and -10 meq [(Na + K) – (Cl + S)]/100g DM. Reduced DCAD should be fed in conjunction with increased dietary Ca (~ 120 – 150 g/day). Also, urine pH should be monitored weekly 2 to 6 hours after feeding to ensure that cows are eating the desired ration.

The recent research of Giesy et al. (1997) supports field observations by consulting nutritionists when feeding anionic salts. The response to feeding anions is not all-or-none. Increases in blood Ca and reductions in urine pH occur with every increment of reduced DCAD. Any reduction in DCAD (via reduced dietary K or the use of supplemental anions), when close-up cows are fed high DCAD diets, can be beneficial.

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