THE LATEST IN TRANSITION COW NUTRITION AND MANAGEMENT: AN EMPHASIS ON DCAD FOR THE PRE AND POSTPARTUM COW

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Introduction

The objective of this paper and presentation will be to deliver the newest information on current strategies that manipulate dietary cation-anion difference to prevent milk fever related problems and improve postpartum lactational performance. For a broader examination of these and other related topics see recent reviews by Beede (1995), and Horst et al. (1997).

The Transition Period

The Transition Period Defined

The transition period is defined here as the time between three weeks prepartum and three weeks post partum. This period is an extremely critical time for the dairy cow; possibly defining her entire lactational performance (Wang, 1990).

Prepartum Feeding to Prevent Milk Fever

Milk fever has been reported to 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; 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.

Many years ago, researchers discovered that feeding an acidic diet to the prepartum cows 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 like potassium and more anions like chloride to help increase blood calcium before calving. These diets are often described as anionic diets and have a low or negative cation-anion difference.

Feeding Anionic Salts

Feeding anionic salts or manipulating the dietary cation-anion difference (DCAD) 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.

Acid-Base Status and 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:

$$\text{meq } [(Na + K + Ca + Mg) - (Cl + S + P)] / 100\text{g of dietary DM}$$

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:

$$\text{meq (Na + K - Cl)/100 g dietary DM}$$

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:

$$\text{meq [(Na + K) - (Cl + S)]100 g dietary DM)}$$

Calculating DCAD

In the actual calculation of DCAD using Equation 3 mineral concentrations are first converted to meq as follows:

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

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:

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

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

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

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

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 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).

Recent Research on DCAD for Prepartum Cows

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) recommended the following equation:

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

Na, K and Cl are 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 (i.e., change in urine pH) of hydrochloric acid. Sulfuric acid would be considered the most bioavailable chemical form of the sulfate (SO4-2) 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

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.

DCAD Feeding Strategy

Detailed feeding strategies for using anionic salts including the recommended salts to use, length of feeding interval, and specific precautions can be found in several excellent reviews (Beede 1995; Horst et al., 1997). The most common 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. The latest 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 diets were evaluated: 1) control, 2) Biochlor (Biovance Technologies, Omaha, NE), 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).

Response to Varying DCAD

We conducted 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.

How Much Dietary Ca Should be Fed?

In the trials in which negative DCAD aided in prevention of milk fever, dietary concentrations of Ca have generally been higher than requirements (approximately 1.2 - 1.5% Ca). The basis for this strategy is that negative DCAD increases urinary excretion of Ca; therefore, if dietary Ca were low with a negative DCAD, hypocalcemia could occur, regardless of, and separately from, milk fever. Conversely, high dietary Ca with low DCAD may be necessary for anionic salts to be successful. However, the optimal dietary Ca content has not been established.

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. Two additional reports on this topic were presented at the 1999 ADSA meetings. In the first report, Rodriguez et al. (1999) high (1.98% DM) versus low (0.48% DM) dietary Ca with negative DCAD (-11 meq/100 g) were tested in periparturient cows. Urine pH was low and not influenced by Ca. All indicators of subclinical hypocalcemia indicated the lower dietary Ca concentration was better than the higher Ca concentration for prevention. The second study (Beede et al., 1999) showed no effects of prepartum dietary Ca (from 0.47 to 1.94% Ca in the total DM) on the incidence of periparturient diseases with or without a negative DCAD. Urine pH was lower and plasma ionized Ca tended to be higher when DCAD was negative. Note that there were no disease problems in the control group, therefore, there were no problems to correct. Also note that these diets were at the low and high end of the Ca range fed in the field.

Until more definitive studies become available on lower dietary Ca concentrations, we will continue to recommend 120 to 150 g of Ca/day for cows fed anionic salts. When more positive DCAD concentrations are used, feed a reduced amount of dietary Ca (closer to the lower end of this recommendation). And when more negative concentrations are fed, feed a dietary Ca at the upper end of this recommendation. The source of Ca may influence the effect of Ca. For example, Ca from alfalfa forage is less bioavailable than calcium carbonate and calcium carbonate is less bioavailable than calcium chloride.

Using Urine pH to Monitor DCAD

Upon feeding anionic salts, urine pH changes quickly (within 2 - 4 days). Therefore, monitoring urine pH 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.

Effects of DCAD on Postpartum Lactational Performance

Studies Using the Three Element (Na + K - Cl) DCAD Equation

Kentucky researchers (Tucker et al., 1988) were the first to conduct a study specifically designed to evaluate the effect of DCAD as (Na + K - Cl) on acid-base status and lactational performance of dairy cattle. They compared diets formulated with -10, 0, +10 or +20 DCAD. A diet with a +20 DCAD improved dry matter intake

(DMI) 11% and MY 9% compared with a diet with -10 DCAD. Blood HCO_3- increased linearly with increasing DCAD, which indicated an improvement in acid-base status with high DCAD compared with low DCAD. They concluded that responses to increasing DCAD were independent of specific Na, K or Cl effects. Because lactation diets typically contain greater DCAD than +20, these results were initially more theoretical than practical. For example, the NRC (1989) minimum Na, C1, and S requirements indicate that DCAD should be greater than about +25 DCAD. The next question that had to be answered was whether or not responses would continue to increase with diets above +20 DCAD.

West et al. (1991) in Georgia answered part of this question when they evaluated diets with up to +40 meq/100 g of diet DM. Their study used two 4 x 4 Latin squares blocked by environmental temperature (cool vs. hot). Separate squares included four Holstein and four Jersey cows. Diets contained +2.5, +15, +27.5 or +40 DCAD. No effect of environment was reported, but increasing DCAD from +2.5 to +27.5 increased DMI, MY and blood bicarbonate (HCO_3-). These findings suggested that performance was depressed with lower DCAD. At +27.5 DCAD, negative effects were overcome. Above +27.5 DCAD no additional improvement was attained.

In another study by this group (West et al., 1992), diets with even higher DCAD (+10, +21.7, +33.4 and +45.1) were fed to a total of 16 lactating dairy cows during hot weather. Source of cation (Na or K) used to manipulate DCAD also was compared. Increasing DCAD increased DMI linearly, independent of Na or K source. Yield of 3.5% FCM was not affected by DCAD or cation source. Milk fat concentration was greater with Na- compared with K-manipulated diets (3.92 vs. 3.62%). Blood pH increased linearly; whereas blood HCO_3- increased curvilinearly. There was no effect due to cation source on acid-base status. Their results indicated that increasing DCAD improved DMI and acid-base status in a manner consistent with other studies. In general, DCAD was independent of a specific Na or K effect.

The influence of Na, K and Cl at constant DCAD was evaluated by Tucker and Hogue (1990). Diets were formulated to provide +32 DCAD in either: a basal diet (adequate in dietary Na, K, and Cl), a basal diet containing an additional 1.17% NaCl, or a basal diet containing an additional 1.56% KCl. Fifteen mid lactation cows were assigned to replicated 3 x 3 Latin squares. The KCl-fed cows consumed more DM and had lower milk fat percentage than NaCl-fed cows, but there were no differences in MY. It was concluded that dietary DCAD was a more important determinant of dietary impact on systemic acid-base status than actual dietary concentrations of Na, K, and Cl.

To model the effect of multiple concentrations of DCAD across a variety of diets and management conditions, Sanchez et al. (1994b) assembled a large database from 10 years of studies with mid lactation cows in Florida. Combining data from many studies into one analysis verified the curvilinear response to DCAD. Dry matter intake, MY and FCM yield were all maximized at +38 DCAD (Na + K - Cl)/100 g. These models were validated by comparing them to independent data of Tucker et al. (1988), West et al. (1991) and West et al. (1992). The DCAD models developed from the data base predicted results very well. For DMI, the DCAD model and independent data set predictions differed only by an average of 2.87% (range .19 to 12.27%). For MY, they differed only by an average of 2% (range .13 to 7.94%). Absolute deviations between the data base DCAD models and independent data set predictions (corrected for experiment effects) ranged from .24 to 1.22 kg/d for DMI and .07 to .60 kg/d for MY. A summary of studies that used the Na + K - Cl expression is presented in Table 1.

Research with the Four Element DCAD [(Na + K) - (Cl + S)] Equation

A large study with 48 cows and 15 dietary treatments was conducted by Sanchez et al. (1994a) to investigate lactational and acid-base responses to DCAD as [(Na + K) - (Cl + S)]. Treatments consisted of combinations of Na, K and Cl, so that DCAD ranged from 0 to +50 [(Na + K) - (Cl + S)]/100g DM. The basal diet was 54.5% concentrate, 5.5% cottonseed hulls and 40% corn silage (DM basis). Dry matter intake and MY was highest when DCAD [(Na + K) - (Cl + S)] was between +17 to +38 and +25 to +40, respectively (Figure 5). There was one odd treatment (a low Cl, high K, and high Na treatment combination) that may have caused a Cl deficiency. Had that treatment not been included the regression line would have shifted to the right. Blood HCO_3- (P=.09) also responded quadratically to increasing DCAD. Blood HCO_3- was maximized with +38 DCAD [(Na + K) - (Cl + S)]. In support of conclusions of Tucker et al. (1988) and West et al. (1991 and 1992) results of this study indicated that feeding diets with less than +20 DCAD depressed blood HCO_3- and should not be fed. Note that with most DCAD studies (this one included) dietary carbonate and bicarbonate concentrations are confounded with DCAD. Because these salts are used to elevate DCAD, DCAD effects cannot be separated from well known ruminal and systemic buffering effects of carbonate and bicarbonate salts.

Research with the [(Na + K) - (Cl + S)] Equation Throughout Different Phases of Lactation

Three switchback experiments (Delaquis and Block, 1995) were conducted with 12 cows each in early, mid, and late lactation. Each experiment compared two DCAD levels calculated as [(Na + K) - (Cl + S)]/100g DM. Increasing DCAD from +5.5 to + 25.8 in early lactation and from +14.0 to + 37.3 in mid lactation increased DMI and milk production. These effects were not observed in late lactation (with either +20.0 or +37.5 DCAD). Concentration of blood HCO_3- was decreased in early lactation and excretion of carbonate ions in urine was reduced by a lower DCAD at all stages of lactation. Responses in this study are consistent with the effect of DCAD on acid-base status observed in other studies; however, this study supports the concept that response to DCAD is affected by stages of lactation.

Perhaps the most complete study on the effects of DCAD on early lactation dairy cows conducted to date is an unpublished trial by Elliott Block and associates from McGill University (E. Block, personal communication, 1999). Block fed a control diet with no added Na or K (+18 DCAD) and two higher (+25 and +52) DCAD diets to early lactation (0 - 10 weeks in milk) Holstein cows. Within the higher DCAD diets he manipulated the source of DCAD (by using either sodium bicarbonate or potassium carbonate alone or a combination of both) to determine the individual or combined effects of Na and K. Block determined that the combination of Na and K yielded the best response in DMI and milk production and that the +52 DCAD diet yielded the highest milk production response (Figure 5). The combinations of Na and K also resulted in the highest blood bicarbonate concentrations (Figure 5). A summary of studies that used the (Na + K) - (C1 + S) expression is presented in Table 2.

Potassium as the Source of Increased DCAD

The above positive responses observed with combinations of Na and K point to the unique role of dietary K, which has been particularly evident during heat stress. Heat stressed cows lose K via sweat and milk is actually higher in K than Ca. Thus the heat stressed dairy cow is often K deficient. Research conducted by Joe West in Texas, and Griffel and Sanchez in Idaho where potassium carbonate was the source of dietary K, indicates that there is a linear response to dietary K during summer in Texas and Idaho (West et al., 1986, West et al., 1987a,b, Griffel et al., 1997). Figure 6 shows the fat-corrected milk responses to varying dietary K in both mid and early lactation. When adding additional dietary K, note that dietary Mg needs to be increased also due to the effect K has on reducing absorption of dietary Mg. Note also that potassium carbonate must be handled and mixed carefully in feed mills and on the farm. Follow manufacturers recommendations carefully.

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,
- The effect of dose of anionic salts
- Optimal DCAD, the role of dietary Ca, and
- Using urine pH to monitor effectiveness.

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). Anionic salts are most effective when fed in a TMR twice daily. 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. The response to feeding anion salts 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.

The most recent literature on DCAD for the postpartum cow indicates that:

- The optimal DCAD for mid lactation cows is between +27.5 and +40 meq [(Na + K) - (Cl + S)]/100g DM.
- The optimum DCAD for early lactation cows may be as high as +50 but until more field data on these higher levels becomes available, increasing DCAD to +40 is currently the most practical strategy.
- The combination of Na and K is better than Na or K as the sole source of the increased DCAD — dietary K appears to have a unique role independent of its effect on DCAD.

These recommendations for DCAD can be affected by numerous factors including production level, feeding management, level of intake depression (i.e., heat stress, etc.), acid producing potential of the diet, and concentrations of other fixed ions like Mg. More research is needed to determine the exact effect of these other factors on DCAD recommendations.

References

Beede, D.K., C.A. Risco, G.A. Donovan, C. Wang, L.F. Archbald, and W.K. Sanchez. 1992. Nutritional management of the late pregnant dry cow with particular reference to dietary cation-anion difference and calcium supplementation. Proc. 24th Ann. Convention Am. Assoc. Bovine Practitioners, p. 51.

Beede, D.K. 1995. Macromineral element nutrition for the transition cow: Practical implications and strategies. Proc. Tri-State Nutrition Conf., Ft. Wayne, IN, p. 175.

Beede, D.K., T.E. Pilbeam, and S.M. Puffenbarger. 1999. Varying dietary calcium concentration with negative cation-anion difference for late pregnant cows: Effects on peripartum acid-base and calcium status, feed intake, health and lactational performance. J. Dairy Sci. 82(Suppl. 1):69.

Bertics, Sandra J. , Ric R. Grummer, Carlos Cadorniga-Valino, and Emily E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early lactation. J. Dairy Sci. 75:1914-1922.

Block, E. 1984. Manipulating dietary anions and cations for prepartum cows to reduce incidence of milk fever. J. Dairy Sci 67:2939.

Curtis, C.R., H.N. Erb, C.J. Sniffen, and R.D. Smith. 1984. Epidemiology of parturient paresis: predisposing factors with emphasis on dry cow feeding and management. J. Dairy Sci. 67:817.

Delaquis A.M. and E. Block. 1995. Dietary cation-anion difference, acid-base status, mineral metabolism, renal function, and milk production of lactating cows. J. Dairy Sci. 78:2259

Giesy, J.G., W.K. Sanchez, M.A. McGuire, J.J. Higgins, L.A. Griffel, and M.A. Guy. 1997. Quantifying the relationship of dietary cation-anion difference to blood calcium in cows during hypocalcemia. J. Dairy Sci. 80(Suppl. 1):142.

Goff, J.P.,and R.L. Horst. 1998. Effect of time after feeding on urine pH determinations to assess response to dietary cation-anion adjustment. J. Dairy Sci. 81(Suppl. 1):44.

Goff, J.P. and R. L. Horst. 1997. Comparison of sulfuric acid with hydrochloric acid as a source of acidifying anions. J. Anim. Sci. 75(Suppl. 1):98.

Goff, J.P. R. L. Horst, T.A. Reinhardt, and D.R. Buxton. 1997b. Preventing milk fever in dairy cattle. Proc. Tri-State Dairy Nutrition Conf., Ft. Wayne, IN, p. 41.

Goff, J.P., R. Ruiz, and R.L. Horst. 1997a. Relative acidogenic activity of commonly used anionic salts - re-thinking the dietary cation-anion difference equations. J. Dairy Sci. 80(Suppl. 1):169.

Griffel, L.A., W.K. Sanchez, R.C. Bull, R.F. Rynk, M.A. Guy, and B.A. Swanson. 1997. Effects of dietary protein and sodium or potassium buffers during summer on lactational performance, acid-base status and nitrogen metabolism of dairy cows. J. Dairy Sci. 80(Suppl. 1):241.

Guard, C. 1996. Fresh cow problems are costly: culling hurts the most. Page 100 in Proc. 1994 Ann. Conf. Vet. Cornell Univ., Ithaca, NY.

Horst, R.L., J.P. Goff, T.A. Reinhardt, and D.R. Buxton. 1997. Strategies for preventing milk fever in dairy cattle. J. Dairy Sci. 80:1269.

Jordan E.R., and Fourdraine R. 1993. Characterization of the management practices of the top DHI milk producing herds in the country. J. Dairy Sci. 76:3247

Joyce, P.W., W.K. Sanchez, and J.P. Goff. 1997. Effect of anionic salts in prepartum diets based on alfalfa. J. Dairy Sci. 80:2866.

Mongin, P. 1980. Electrolytes in nutrition: review of basic principles and practical application in poultry and swine. In Third Ann. Int. Mineral Conf. Orlando, FL. p.1.

Moore, S.J., M.J. VandeHaar, B.K. Sharma, T.E. Pilbeam, D.K. Beede, H.F. Bucholtz, J.S. Liesman, R.L. Horst, and J.P. Goff. 1997. Varying dietary cation anion difference (DCAD) for dairy cattle before calving. J. Dairy Sci. 80(Suppl. 1):170.

National, Research Council. 1989. Nutrient requirements of dairy cattle. 6th rev. ed. Nat'l. Acad. Sci., Washington DC.

Oetzel, G.R., J.D. Olson, C.R. Curtis, M.J. Curtis, and M.J. Fettman. 1988. Ammonium chloride and ammonium sulfate for prevention of parturient paresis in dairy cows. J. Dairy Sci. 71:3302.

Rodriguez, L.A., T.E. Pilbeam, and D.K. Beede. 1997. Effects of dietary anion source and calcium concentration on dry matter intake and acid-base status of nonlactating nonpregnant Holstein cows. J. Dairy Sci. 80(Suppl. 1): 241.

Rodriguez, L.A., T.E. Pilbeam, D.K. Beede, and J.P. Goff. 1999. High versus low dietary calcium with negative cation-anion difference prepartum: Effects on peripartum acid-base and calcium status. J. Dairy Sci. 82(Suppl. 1):68.

Sanchez, W.K. and D.K. Beede. 1991. Interrelationships of dietary Na,K and Cl and cation-anion difference in lactation rations. In Proc. Florida Rum. Nutr. Conf. University of Florida, Gainesville. p.31.

Sanchez, W.K., D.K. Beede, and J.A. Cornell. 1994a. Interactions of sodium, potassium, and chloride on lactation, acid-base status, and mineral concentrations. J. Dairy Sci. 77:1661.

Sanchez, W.K., D.K. Beede, and M.A. DeLorenzo. 1994b. Macromineral element interrelationships and lactational performance: Empirical models from a large data set. J. Dairy Sci. 77:3096.

Tucker, W.B., G.A. Harrison, and R.W. Hemken. 1988. Influence of dietary cation anion balance on milk, blood, urine, and rumen fluid in lactating dairy cattle. J. Dairy Sci. 71:346.

Tucker, W.B. and J.F. Hogue. 1990. Influence of sodium chloride or potassium chloride on systemic acid-base status, milk yield, and mineral metabolism in lactating dairy cows. J. Dairy Sci., 73:3485.

Tucker, W.B., J.F. Hogue, D.F. Waterman, T.S. Swenson, Z. Xin, R.W. Hemken, J.A. Jackson, G.D. Adams, and L.J. Spicer. 1991. Role of sulfur and chloride in the dietary cation-anion balance equation for lactating dairy cattle. J. Dairy Sci. 69:1205.

Vagnoni, D.B. and G.R. Oetzel. 1997. Effects of dietary cation-anion difference on dry matter intake and acid-base status of dry cows. J. Dairy Sci. 80:241 (Abstr.).

Wang, C. 1990. Influence of dietary factors on calcium metabolism and incidence of parturient paresis in dairy cows. Ph.D. Dis., Univ. Florida, Gainesville.

West, J.W., C.E. Coppock, D.H. Nave, and G.T. Schelling. 1986. Effects of potassium buffers on feed intake in lactating dairy cows and on rumen fermentation in vivo and in vitro. J. Dairy Sci. 69:124.

West, J.W., C.E. Coppock, D.H. Nave, J.M. Labore, and L.W. Greene. 1987a. Effects of potassium carbonate and sodium bicarbonate on rumen function in lactating Holstein cows. J. Dairy Sci. 70:81.

West, J.W., C.E. Coppock, K.Z. Milam, D.H. Nave, and J.M. Labore. 1987b. Potassium carbonate as a potassium source and dietary buffer for lactating cows during hot weather. J. Dairy Sci. 70:309.

West, J.W., B.G. Mullinix, and T.G. Sandifer. 1991. Changing dietary electrolyte balance for dairy cows in cool and hot environments. J. Dairy Sci. 74:1662.

West, J.W., K.D. Haydon, B.G. Mullinix, and T.G. Sandifer. 1992. Dietary cation-anion balance and cation source effects on production and acid-base status of heat-stressed cows. J. Dairy Sci. 75:2776.

Table 1: Summary of the effect of DCAD on milk, intake and blood bicarbonate concentrations in studies using the (Na + K - Cl) DCAD expression.

Study	DCAD (Na + K - Cl) meq/100g DM	Parameter	Response
Tucker et al., 1988	-10, 0, +10, +20	Milk, Intake, Blood HCO_3-	Linear
West et al., 1991	+2.5, +15, +27.5, +40	Milk, Intake, Blood HCO_3-	Curvilinear
West et al., 1992	+10, +22, +33, +45	Intake, Blood HCO_3-	Linear, Curvilinear
Sanchez et al., 1994b	Empirical Models	Milk, Intake, FCM	+ 38 Max, Curvilinear

Table 2: Summary of the effect of DCAD on milk, intake and blood bicarbonate concentrations in studies using the [(Na + K) - (Cl + S)] DCAD expression.

Study	DCAD Meq [(Na + K) - (Cl + S)]/ 100g DM	Parameter	Response
Sanchez et al., 1994a	15 Tmt's	Intake, Milk, Blood HCO_3-	+ 25 Max + 31 Max + 38 Max
Delaquis and Block, 1995	+ 5.5 to +25.8	Milk, Intake, Blood HCO_3-, Early lactation	Positive
Delaquis and Block, 1995	+14 to +37.3	Milk, Intake Mid lactation	Positive
Delaquis and Block, 1995	+20 to +37.3	Milk, Intake Late lactation	NS
Block, Unpublished 1999	+ 18 to +52	Milk, Intake, Blood Bicarbonate Early Lactation	Positive; Dependent on Source of DCAD

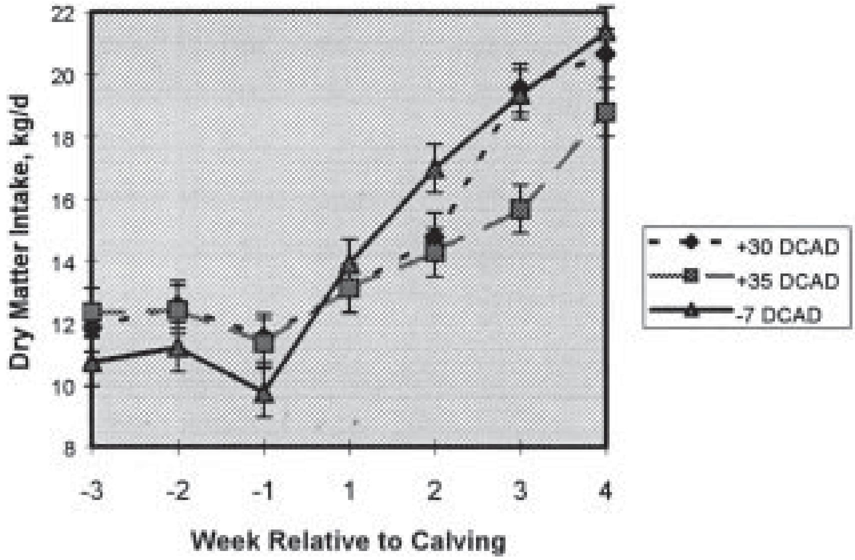


Figure 1: Intake response to varying diets [a grass-based (+30 DCAD), an alfalfa-based (+35 DCAD), or an alfalfa plus anionic salts diet (-7 [(Na + K) - (Cl + S)]/ 100g DM) fed prepartum to Holstein cows. After parturition all cows were fed a similar alfalfa-based lactation ration (from Joyce et al., 1997).

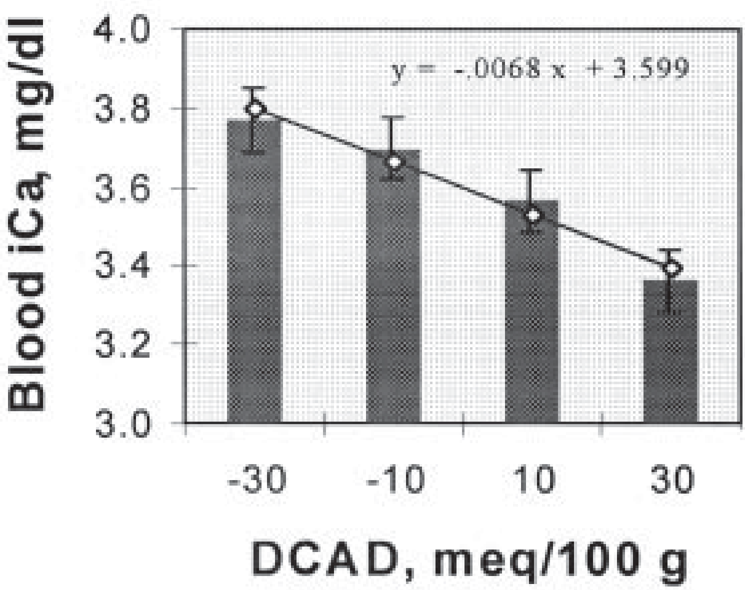


Figure 2: Blood ionized Ca response to four levels of DCAD, [(Na + K) - (Cl + S)]/ 100g DM following infusion with EDTA to mimic hypocalcemia (from Giesy et al., 1997).

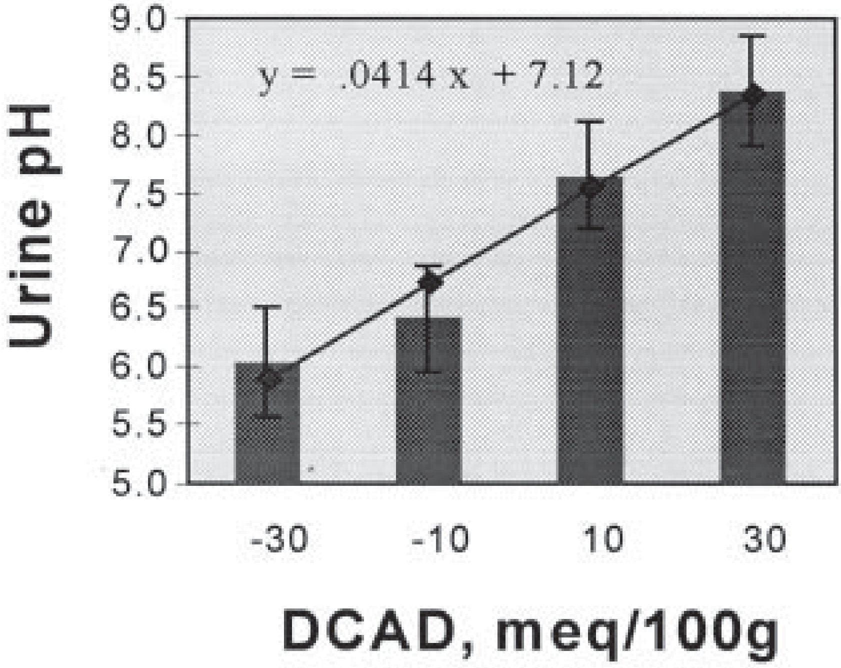


Figure 3: Urine pH response to four levels of DCAD, [(Na + K) - (Cl + S)]/100g DM (from Giesy et al., 1997).

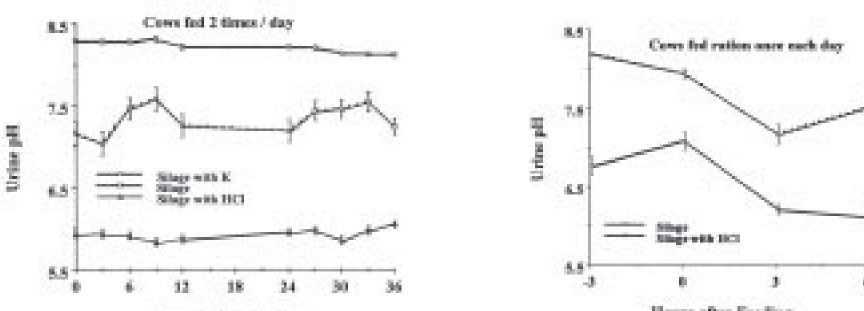
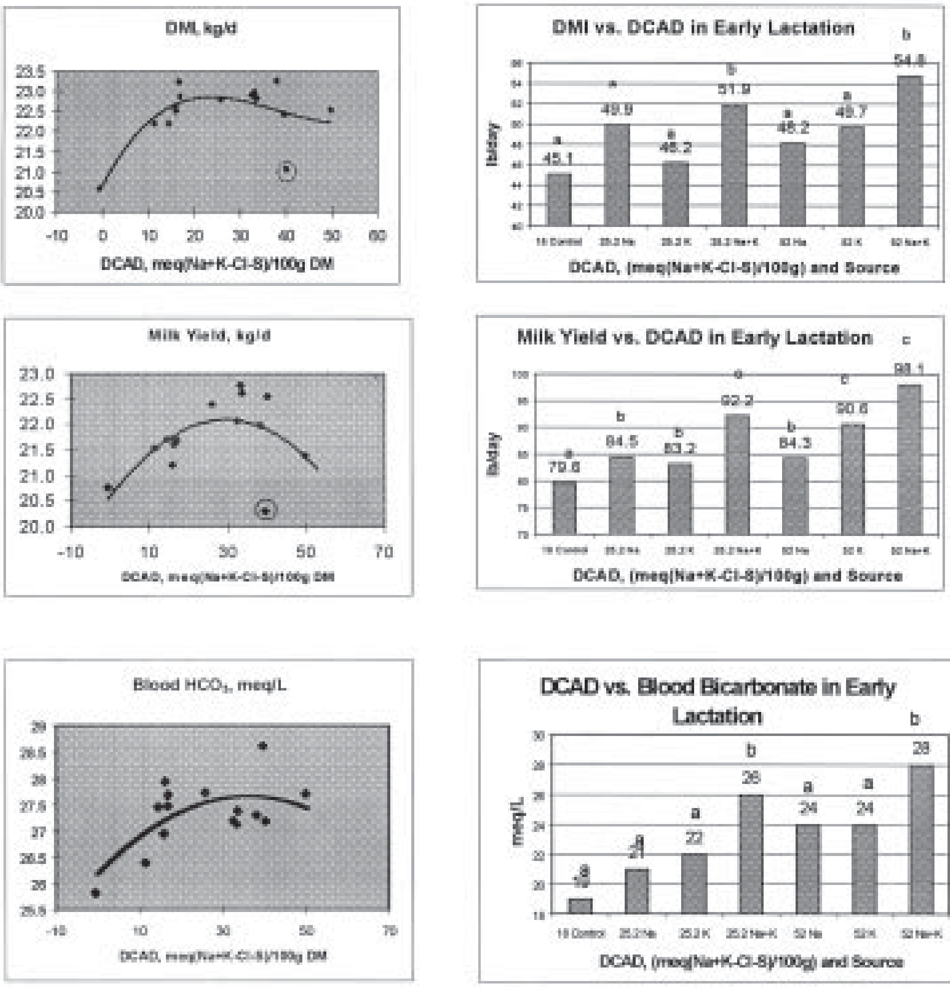


Figure 4: Post feeding urine pH responses from cows fed twice/day (left panel) or once/day (right panel). Diets were based on either corn silage, corn silage with supplemental potassium carbonate, or corn silage with supplemental hydrochloric acid (from Goff et al., 1998).



Mid lactation

Early Lactation

Figure 5: Dry matter intake, milk yield, and blood bicarbonate response to (DCAD [(Na + K) - (Cl + S)]/100g DM) in mid lactation (left panel) and early lactation (right panel) cows. Data in left panel are from Sanchez et al., 1994a (treatments circled are from a low Cl, high K, and high Na treatment combination that may have caused a Cl deficiency). Data in right panel are from Elliott Block, McGill University (1999, unpublished data). Block evaluated both DCAD concentration and source (either Na, K or a proprietary combination of both) in ten early lactation cows (weeks 1-10 in milk) per treatment. Different superscripts indicate a statistical difference (a=P< 0.05; b = P< 0.01) between treatment and control.

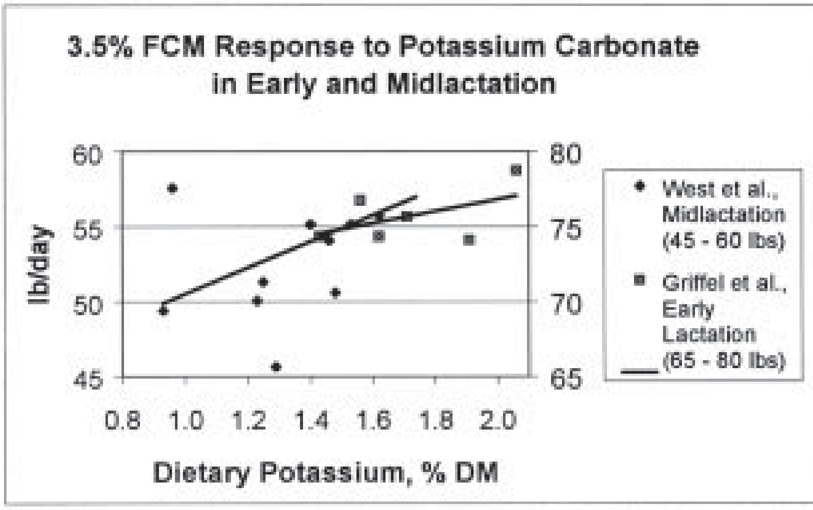


Figure 6: Fat-corrected milk response (3.5% FCM) response to feeding various potassium concentrations (as potassium carbonate) to heat stressed mid lactation dairy cows (West et al., 1986; West et al., 1987a,b) and early lactation cows during summer in Idaho (Griffel et al., 1997).