What is DCAB (Dietary Cation-Anion Balance) and What is the Potential for Use in Dry and Lactating Rations?

David I. Byers, DVM
Galax, Virginia

As our knowledge of ruminant nutrition increases, consequently so does our ability to fine tune feed rations. In recent years a new idea in ration formulation and dairy cattle nutrition has emerged. The technique, known as Dietary Cation Anion Balance (DCAB), has enabled many dairymen to more precisely balance dairy rations.

DCAB is also called the following: Dietary Cation Anion Difference (DCAD), Dietary Electrolyte Balance (DEB), Anion Cation Balance (ACB), Strong Ion Balance (SIB), and Fixed Ion Balance (FIB). These terms are generally used interchangeably, and they will be so used in this paper.

This paper is presented to increase awareness of DCAD and its application in dairy cattle formulation. The objectives are threefold: (1) to review the basic science of DEB, (2) to examine the application of DCAB in nonlactating cows, and (3) to explore tha application of DCAD in lactating cows and growing animals. The ultimate goal is that the science of DCAB is clarified and its truth applied in the real dairy world.

The Basic Science of Dietary Electrolyte Balance (DEB)

A review of some basic chemistry will be helpful. Atoms that have lost or gained electrons are called ions. There are two types on ions: (1) cations, which are positively charged ions, *e.g.*, N_2a^+ and K^+, and (2) anions, which are negatively charged ions, *e.g.*, Cl" and S^{2-}.

We shall, only deal with four ions: Na, K, Cl and S. These ions are called strong ions[11] because they exert the strongest ionic effect on acid-base balance.

Acid-base metabolism is a complex subject, but one needs to remember that all animals need to be electrically neutral. That is, the sum of the positive charges in a solution must equal the sum of the negative charges. This is the principle of electrical neutrality, and it is the underlying principle of DCAB.[1,2,11]

For example, if a cow is fed a diet high in the anions Cl" and S^{2-}, there will be a slight decrease in blood pH. This increase in acidity will yield a basic response. To buffer the anions, cations will be mobilized. Ca will be mobilized from bone and Ca absorption will be increased in the gut. Because of these events, blood Ca is increased. The above reactions are often called the anionic effect, and this is extremely important in dry cow formulations, which we shall later examine.

We can use DEB to quantitate the relationship of these strong ions in a diet and predict whether it will elicit an acidic or basic response when fed to an animal. Two formulas are commonly used to decide the effect on acid-base balance. These formulas simply involve taking the difference of cations and anions. Therefore the name, Dietary Cation Anion Difference (DCAD), is an actual description and thus, the most accurate term to use for this idea. Note that the two formulas differ only by whether the anion portion includes the S ion. The equations are as follows:

$$mEq(Na + K) - Cl/100 \text{ g Dry Matter (DM)}$$
$$mEq(Na + K) -(Cl + S)/100 \text{ g DM}$$

From the above equations, one can see that the basic unit of measure is the equivalent (Eq) or milliequivalent (mEq). An Eq is simply the atomic weight adjusted for ionic charge (Table 1). A mEq is one thousandth of an Eq. This is necessary because we are concerned with electrical charge, not mass.[1,2,11] Therefore, it is essential to convert percent dietary concentration to mEq.

Table 1. Milliequivalents of key elements

EL	AT (g)	VL	EW (g)	mEq (g)
Na	23	1	23	.023
K	39	1	39	.039
Cl	35.5	1	35.5	.0355
S	32	2	16	.016

EL=element, AT=atomic wt, VL=valence, EW=equivalent wt, mEq=milliequivalent

Presented at the Feed and Nutritional Management Cow College, VA Tech, Blacksburg, VA on January 7-8, 1993

The mEq/100 g DM for the strong ions may be simply figured out as follows:

% Na ÷ .023
% K ÷ .039
% Cl ÷ .0355
% S ÷ .016

Tables 2 and 3 are examples of calculating DCAB. Results may be either a positive or negative value. If DCAB is positive, then there are more cations than anions in the diet and it will exert an alkalogenic effect on acid-base balance. On the other hand, if DCAB is negative, then there are more anions than cations in the diet, and it will produce an acidogenic effect on acid-base balance. Research has shown that lactating cows and growing animals do best on cationic diets;[13,14,15] whereas, nonlactating cows do best on anionic rations. [1,2,5,7,10,11] Table 4 summarizes these differences.

Table 2. DCAD for 1988 NRC recommendations for dry pregnant cows.

EL	DC (%)	mEq (g)	Quantity (mEq/100g)
NA	.10	.023	4.35
K	.65	.039	16.67
Cl	.20	.0355	5.63
S	.16	.016	10.0
DCAD	(Na+ K) - (Cl+ S		+5.39

EL=element, DC=dietary content, mEq= milliequivalent

Table 3. DCAD for 1988 NRC recommendations for early lactation cows.

EL	DC (%)	mEq (g)	Quantity (mEq/100g)
Na	.18	.023	7.83
K	1.00	.039	25.64
Cl	.25	.0355	7.04
S	.20	.016	12.50
DCAD	(Na+ K) - (Cl+ S)		+13.93

EL=element, DC=Dietary content, mEq= milliequivalent

Table 4. Relationship of DCAD, ions and acid-base balance in feeding various classes of dairy animals.

PARAMETER	DCAD+	DCAD -
Ionic Dominance	Cationic	Anionic
Acid-Base Effect	Alkalogenic	Acidogenic
Feeding Class	Lactating & Growing	Nonlactating

In formulating rations it is necessary to manipulate DEB according to the class of animal being fed to achieve optimum performance. For example, cations may need to be added to diets for lactating cows. Cationic salts are used for this purpose. The most common ones are sodium bicarbonate ($NaHCO_3$) (Table 6), sodium carbonate (Na_2CO_3) (Table 6), potassium bicarbonate ($KHCO_3$), and potassium bicarbonate (K_2CO_3). It is obvious from their chemical formulas that these salts provide Na and K cations.

Anionic salts are used to decrease DCAD. They provide Cl and S anions. The most common anionic minerals are magnesium sulfate ($MgSO_4 \bullet 7H_2O$), calcium sulfate ($CaSO_4 \bullet 2H_2O$), ammonium chloride (NH_4CL), and calcium chloride ($CaCl_2 \bullet 2H_2O$) (Table 5). In review, the following points should be kept in mind: (1) The ions that exert the strongest effect on acid-base balance are Na, K, Cl, and S. (2) The underlying principle of DEB is related to the physiological need to maintain electrical neutrality in the body. (3) DCAD allows one to quantitate the relationship between the strong ions and thus predict whether a diet will evoke an acidic or alkaline response. (4) Rations that have a + DCAD are cationic, alkalogenic and more desirable for lactating cows and growing animals. (5) Rations that have a - DCAB are anionic, acidogenic, and more desirable for nonlactating cows. (6) DEB may be manipulated by using cationic or anionic salts.

The Application of DCAB in Diets for Nonlactating Cows

Dry cow nutrition is a neglected area of dairy cattle management. This is a serious omission in that this 60-day period sets the stage for subsequent lactation performance. Thus, inattention to dry cow diets can be very costly; conversely, properly formulated rations can be very rewarding. Beede[1,2,] catches the impact of proper dry cow nutrition when he says, "It is an investment in the next lactation."

The approach to dry cow feeding that seems to offer the best results is the feeding of anionic salts. [1,2,4,9,10,12] Recent research has shown a very positive value to feeding an acidogenic diet for 3-6 weeks prepartum. The following benefits have been defined: (1) decreased incidence of milk fever and hypocalcemia, (2) increased milk production, and (3) improved reproductive performance.

Two research trials have generated much of the interest in anionic diets for the prepartum cow. A Canadian trial[4], diets of -12.9 and +33.1 mEq(Na+K)-(Cl+S)/100 g DM, showed a dramatic reduction in the incidence of milk fever, 0 vs. 47.7%, and a remarkable increase in milk yield (MY), 7.3%. Also MY was 16% greater in the cationic group that did not have milk fever. A Florida study[2], diets of -25 and +5 mEq(Na+K)-(Cl+S)/100 g DM, showed 3.6% increase in milk production.

Table 5. Nutrient profile[1] and relative value of common anionic minerals.

Mineral	Chemical Formula	Cost[2] $/ton	Cost ¢/Eq	N (%)	Ca (%)	Mg (%)	S (%)	Cl (%)
Alum. Sulfate	$Al_2(SO_4)_3 \bullet 16H_20$	1700	39.4				7.62	
Mag. Chloride	$MgCl_2 \bullet 6H_20$	1850	20.7			11.84		34.96
Mag. Sulfate	$MgSO_4 \bullet 7H_20$	500	6.8			9.76	13.03	
Ammon. Chloride	$(NH_4)Cl$	750	4.4	26.2				66.4
Cal. Chloride	$CaCl_2 \bullet 2H_20$	450	3.6		27.2			48.3
Ammon. Sulfate	$(NH_4)_2SO_4$	350	2.6	21.2			24.2	
Cal. Sulfate	$CaSO_4 \bullet 2H_20$	200	1.9		23.2		18.6	

[1] Nutrients expressed on an as fed basis (AFB).
[2] Prices courtesy of The Pillsbury Company, Minneapolis, MN.

Table 6. Chlorine levels necessary at three different levels of K on Cl to balance DCAD for -15 mEq/100 g DM

	Low Potassium (%)	(mEq/100g)	Medium Potassium (%)	(mEq/100g)	High Potassium (%)	(mEq/100g)
Na	0.10	4.35	0.10	4.35	0.10	4.35
K	0.65	16.67	1.30	33.33	1.95	50.00
Cl	0.39	11.02	0.98	27.68	1.57	44.35
S	0.40	25.00	0.40	25.00	0.40	25.00
DCA		-15.00		-15.00		-15.00

The goal in dry cow formulation is to provide an excess of anions, mainly Cl and S, compared with cations, mainly Na and K. This surplus of anions results in a series of events, which is called the anionic effect. (1) Blood pH is reduced. (2) Ca in bone is mobilized to help neutralize this acidity. (3) Ca absorption in the gut is increased. This phenomenon results in an increase of Ca in the blood, thereby reducing the incidence of milk fever and hypocalcemia. Research and field experience suggest that by reducing subclinical hypocalcemia, cows increase DMI faster in early lactation, resulting in increased milk yield and decreased incidence of periparturient disease.

Table 3 contains the 1988 NRC[8] recommendations for dry pregnant cows. Note that the DCAD is positive, +5.39. Such a diet is mildly cationic; however, under field conditions one seldom is able to formulate rations with less than 1% K, so in actuality the DCAD is generally +14 to +27. Such diets are strongly alkalotic, and these cationic diets are counterproductive in the prepartum and postpartum periods!

A. Ration Formulation

Minerals commonly used to formulate anionic rations are shown in Table 5. These minerals, as expected, are a source of Cl and S anions. Note that sodium chloride (NaCl) and potassium chloride (KCl) are not included as anionic salts. They are neutral salts and, as such, DO NOT contribute to DCAD. Consequently, one should categorize Na, K, and Cl to delineate their source. For example, Na1, Na2, may be used to define sodium.

Standard recommendations have evolved for using anionic minerals. For example, (1) feed 4 oz magnesium sulfate and 4 oz ammonium chloride; (2) feed 4 oz magnesium sulfate, 2 oz ammonium sulfate, and 2 oz ammonium chloride; or (3) feed 4 oz ammonium chloride and 4 oz ammonium sulfate. Though these recommendations will often work there are times when they will not. Therefore a more scientific approach is best. Selection of anionic salts should be based on availability, cost, potential toxicity, dietary deficiencies, palatability, and type of feeding system. To help in ration formulation the following guidelines are suggested:

1. Balance Mg at 0.40% of DM. Use magnesium sulfate, magnesium chloride, or a combination. Magnesium sulfate, due to cost, (Table 5) and palatability is the mineral of choice.

2. Balance S at 0.40% of DM. Use ammonium sulfate, calcium sulfate, aluminum sulfate or a combination. Calcium sulfate is more cost effective on an equivalent basis. *The Mineral Tolerance of Domestic Animals* (1980)[8] suggested that the maximum tolerable level of dietary sulfur for cattle was 0.40%. However, from personal experience this level seems conservative. Interestingly one researcher has recommended balancing S at 0.45%.

3. Balance Cl for a DCAD of at least -15 mEq/100 g DM. Use ammonium chloride, calcium chloride or a combination. If the incidence of milk fever in cows freshening three or more times is to be maintained at less than 5%, then an excess of anions of at least 1.5 equivalents per cow per day must be provided. The major drawback in this regard is the level of potassium in the forages. High-K feed, such as rye, requires high levels of dietary chlorine to offset the effect of potassium. Specifically, each increase in total dietary potassium of 0.10% will require raising the level of Cl in the diet 0.09%. Table 6 shows chlorine levels necessary to balance DCAD at -15 mEq/100 g DM at three levels of K. A note of caution needs to be sounded here: Including 3 Eq or greater of anions into the diet to counteract high K will probably cause palatability problems. [1,2,7,9,10] <u>Chlorine, then, is the pivotal element since it must counterbalance K.</u>

4. Provide a daily intake of 50 g of phosphorus and 150 g of calcium. Use conventional sources of calcium and phosphorus, such as calcium carbonate, monocalcium phosphate, dicalcium phosphate, etc.

5. Reduce the use of ammoniated salts if intake protein (IP), degradable intake protein (DIP), or nonprotein nitrogen (NPN) becomes high. It is best to keep the protein content of the prepartum ration less than 14%, the DIP less than 10%, or the NPN less than 0.50%. Some situations to watch are as follows: when urea or other NPN source is present, when ammoniated forages or legume forages are being fed, and when animal proteins are being fed to acclimate prepartum cows. In there cases the use of ammoniated salts should be reduced or even eliminated.

B. Ration Application

Anionic rations are easy to formulate, but they can be quite difficult to manage. Remember, we are dealing with an idea to fine tune dairy rations. Not surprisingly, it does require top nutritional management. There are some key feeding principles that must be followed if negatively-charged, dry cow rations are to produce superior performance and health. The following are critical.

▶ Minimize the preferential selection of feedstuffs. Three rations may exist on a farm: the ration that is formulated, the ration that is fed, and the ration that is consumed. The goal in ration delivery is for the cow to consume the ration that is formulated.

Problems are common when cows are not fed a total mixed ration (TMR) and when they can express forage preferences. In short, negative rations are best fed as a TMR.

▶ Optimize dry matter intake (DMI) at 22 lb or greater. Field experience has taught that if DMI falls below this key level in springer rations, then beware, because serious metabolic and disease problems will follow. Generally, there will be an increased incidence of retained placenta, displaced abomasum, and fatty liver.

These ingredients are not palatable, which can lead to problems with consumption. Incorporate anionic salts into a TMR, which has some moist, highly palatable feeds, *i.e.*, wet brewers grains. If this is not possible, then they should be combined with such appetizing ingredients as distillers grains and molasses in a grain mix. Pelletizing the grain seems to improve consumption. The pellet should be formulated to be fed at 7 to 8 pounds per cow per day.

Mycotoxins can also cause problems with feed intake. Vomitoxin, also known as DON, is especially troublesome. Screen suspect feeds for mycotoxins and avoid feeding moldy feeds.

▶ Acclimatize anionic salts 3 to 5 weeks prepartum. How long should anionic salts be fed? They are expensive, about $0.30 per cow per day, so length of time is an important consideration. Also, these minerals need to have time to exert a positive effect on the cow.

Research trials have ranged from 21 to 45 days.[11] Based on these studies, anionic salts seem to need 10 to 14 days to produce the anionic effect. The inaccuracy of freshening dates make this impractical in the field; therefore, it is best to aim for 3 to 5 weeks. Also, herd size can be a factor, *i.e.*, small herds may need a longer period so that they will allow a group size that will proper mixing and delivery of the ration.

In summary, the following points are important: (1) Dry cow diet greatly affects postcalving performance, and, as such, it should be viewed as the most important phase of dairy cattle nutrition. (2) The best way to provide proper nutrition for the dry cow is to formulate rations that provide the required nutrients, are nontoxic and have a DCAD of at least -15 mEq/100 g DM. (3) For successful feeding of anionic rations, top nutritional management that gives attention to detail is an absolute necessity. (4) Dairymen should strive to grow forages specifically for dry cows that will simplify DCAB, *i.e.*, low K, low protein but with high degradability, and moderate Ca.

The Application of DCAB in Diets for Lactating Cows

Poultry and swine nutritionists have used DCAB in diet formulations for many years. In chickens, the optimum growth rate has been established at +25 mEq(Na+K)-Cl/100 g as fed (AF), in swine growth rate plateaus at +17.5 mEq(Na+K)-Cl/100 g AF (referenced by West).[15]

Recent studies have shown that lactating cows should be fed cationic, alkalogenic diets. Tucker and coworkers,[14] showed 8.6% increase in milk yield (MY) at +20 mEq(Na+K)-Cl/100 g DM. West *et al.*,[15] showed an increase in DMI during periods of heat stress at +31 mEq(Na+K)-Cl/100 g DM. Florida workers[13] using a model evaluated 10 studies conducted during the 1980's and found that DMI, MY and FCM increased curvilinearly, peaking at +38 mEq(Na+K)-Cl/100 g DM. The Florida researchers also found the optimum levels for magnesium and sodium to be .40% and .58%, respectively. Continued research to find out optimum balance and source of electolytes is needed and is presently being conducted at leading universities.

Cationic salts are used to increase DCAB in diets. $NaHCO_3$ and Na_2CO_3 are commonly used sources (Table 7), which are the salts comprising Sodium Bicarbonate, S-Carb™, and Alkaten™. There is little difference among these products; therefore, selection should be based on cost per unit of sodium. $KHCO_3$ and K_2CO_3 are generally not available commercially.

Table 3 shows the DCAD for early lactation cows, recommended by the 1988 NRC. One should note that this ration should be manipulated with cation salts so that DEB is increased significantly.

Table 7. Composition of some commonly available commercial cationic salts

Item	Sodium Bicarbonate	S-Carb™	Alkaten™
$NaHCO_3$ (%)	100.0	37.0	34.8
Na_2CO_3 (%)		47.0	43.8
Sodium (%)	27.4	30.4	28.5
Hydration (%)		16.0	14.9
Inert (%)			6.1

In summary, the following points are noteworthy: (1) Lactating cows should be fed cationic rations that have a DCAB of +38 mEq(Na+K)-Cl/100 g DM or +19 mEq(Na+K)-(Cl+S)/100 g DM. (2) Sodium Bicarbonate, S-Carb™, or Alkaten™ may be used to increase DCAB in diets for lactating cows.

References

1. Beede, D.K., W. K. Sanchez and C. Wang. 1990. Dietary electrolyte balance and anionic diets for dairy cows in late gestation. Proceedings First Annual Ruminant Nutrition Symposium. p. 21. 2. Beede, D.K., C. Wang, G. A. Donovan, L.F. Archbald, and W.K. Sanchez. 1991. Dietary cation-anion difference (electrolyte balance) in late pregnancy. Proceedings Florida Dairy Production Conference Proceedings. p. 98. 3. Beede, David K. 1991. Mineral and water nutrition. Veterinary Clinics of North America Food Animal Practice. 7:373. 4. Block, E. 1984. Manipulating dietary anions and cations for prepartum dairy cows to reduce the incidence of milk fever. J. Dairy Sci. 67:2939. 5. Chase, L.E. 1992. Cation-anion balance in dairy rations-practical considerations. Proceedings Cornell Nutrition Conference. p. 160. 6. Gaynor, P.J., F.J. Mueller, J.K. Miller, N. Ramsey, J.P. Goff, and R. L. Horst. 1989. Parturient hypocalcemia in Jersey cows fed alfalfa haylage-based diets with different cation to anion ratios. J. Dairy Sci. 72:2525. 7. Goff, J.P. 1992. Cation-anion difference of diets and its influence on milk fever and subsequent lactations: The good and the bad news. Proceedings Cornell Nutrition Conference. p. 148. 8. NRC. 1988. Nutrient Requirements of Dairy Cattle edition 6. National Academy Press. Washington, DC. 9. Oetzel, G.R., J.D. Olson, C.R. Curtis, and M.J. Fettman. 1988. Ammonium chloride and ammonium sulfate for prevention of parturient paresis in dairy cows. J. Dairy Sci. 71:3302. 10. Oetzel, G.R., M.J. Fettman, D.W. Hamar, and J.D. Olson. 1991. Screening of anionic salts for palatability effects of acid-base status, and urinary calcium excretion in dairy cows. J. Dairy Sci. 74:965. 11. Oetzel, G.R. 1991. Update on the use of anionic salts for the prevention of milk fever. Proceedings Minnesota Nutrition Conference. p. 34. 12. Sanchez, W.K., D.K. Beede, and J.A. Cornell. 1990. Lactation performance and acid-base status of mid-lactation Holsteins fed graded concentrations of cation-anion differences (CAD) of sodium, potassium and chlorine. J. Dairy Sci. 73(Suppl.1): 162. 13. Sanchez, W.K., and Beede, D.K. 1991. Interrelationships of dietary Na, K, and Cl and cation-anion differences in lactation rations. Proceedings Florida Ruminant Nutrition Conference. p. 31. 14. 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 cattle. J. Dairy Sci. 71:546. 15. 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.