# Reviews on the mineral provision in ruminants (VII): CATION-ANION DIFFERENCE IN DAIRY COWS

J.Th. Schonewille A.C. Beynen

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# Reviews on the mineral provision in ruminants (VII): CATION-ANION DIFFERENCE IN DAIRY COWS

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> CVB documentation report nr. 39 September 2005

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#### PREFACE

In the Netherlands the 'Handleiding Mineralenonderzoek bij rundvee in de praktijk'<sup>1</sup> is a wellknown publication that has been used already for decades as a guide to trace and treat mineral disorders in cattle. The fifth edition of this guidebook was published in 1996. The content of this publication was largely identical to that of the fourth edition (1990). Therefore the (independent) committee that is responsible for the contents of the guidebook (the 'Commissie Onderzoek Minerale Voeding'<sup>2</sup>, COMV) decided in 2000 that a thorough revision was desired.

The committee was of the opinion that, if possible, the available scientific literature should be summarized and evaluated once again. Furthermore, attention should be paid to the mineral provision of categories of cattle other than dairy cattle, as well as to that of sheep and goats. Finally, the basic principles for the calculation of the mineral requirements should be described in a transparent way.

The intended revision was made possible as the Dutch 'Ministerie van Landbouw, Natuur en Voedselkwaliteit' (LNV), the 'Productschap Diervoeder' and the 'Productschap Zuivel'<sup>3</sup> were willing to subsidize this extensive and ambitious project.

The COMV decided to execute the project as follows.

- External experts, invited by the COMV, should summarize and evaluate the relevant literature in a so-called 'basal document' (with two exceptions to be written in English).
- Subsequently, these documents should be critically evaluated by the COMV.
- These basal documents should then be used to write and arrange the several chapters of the revised 'Handleiding'.

The revised 'Handleiding' is available (in the Dutch language) since October 2005, under the title 'Handleiding mineralenvoorziening rundvee, schapen en geiten.'<sup>4</sup> This book is published by the 'Centraal Veevoederbureau' (CVB; Central Bureau for Livestock Feeding) in Lelystad, as was also the case for the previous edition.

The COMV was of the opinion that the valuable basal documents, that became available during the course of this project, should be published too. By doing so everyone has the possibility to trace the basis for the text of the revised 'Handleiding'. The CVB was gladly willing to issue these documents as CVB Documentation reports. In connection with this the authors and the members of the COMV have disclaimed all rights and have assigned them to the Productschap Diervoeder, of which the CVB is one of the services.

For an overview of the CVB Documentation Reports that will appear in this context, you are referred to an Annex in the back of this report.

Utrecht/Lelystad, September 2005.

Professor dr. ir. A.C. Beynen	
Chair of the COMV	

Dr. M.C. Blok Secretary of the COMV and Head of the CVB

For the preparation of the present report on the Dietary Cation Anion Difference (DCAD) provision in ruminants the COMV expresses its gratitude to the authors, dr. ing. J. Th. Schonewille and prof. dr. ir. A.C. Beynen. The authors express their thanks prof. dr. A. Th. van 't Klooster and dr. M.C. Blok for critically reading of the manuscript and their advice.

<sup>&</sup>lt;sup>1</sup> Guidebook on mineral research for cattle in practice.

<sup>&</sup>lt;sup>2</sup> Committee for research on mineral nutrition

<sup>&</sup>lt;sup>3</sup> The Ministry for Agriculture, Nature and Food quality, the Product Board Animal Feed and the Dutch Dairy Board, respectively.

<sup>&</sup>lt;sup>4</sup> Guidebook mineral provision cattle, sheep and goats.

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## LIST OF ABBREVIATIONS

Abbreviation	Unit	Description	
Са		Calcium	
CI		Chlorine	
DCAD	mEq	Dietary Cation-Anion Difference	
DM	kg	Dry matter	
g		Gram	
К		Potassium	
kg		Kilogram	
L		Litre	
Mg		Magnesium	
mEq		Milli-equivalents	
mmol		Millimoles	
Na		Sodium	

## 1 THEORETICAL CONCEPT

The pH of the extracellular fluid is maintained within narrow limits, with pH values in arterial blood ranging from 7.35 to 7.45, with a mean of 7.4. Normally, pH of body fluid is constantly under attack because of the addition of acids and bases to body fluids originating from either ingestion or production in metabolism. There are three basic mechanisms to maintain pH of body fluids; chemical buffering, respiratory adjustment of blood carbon dioxide concentration, and the excretion of hydrogen- or bicarbonate ions by the kidneys (32). The epithelial uptake of acids and bases may interfere with systemic acid-base balance, which is illustrated in the practice of ruminant feeding. In the Netherlands, grass silages generally have a high K content (58) and the associated anions of K-salts in grasses are predominantly in the form of organic acids such as malate, citrate, and aconitate (10,28,41). These organic anions are completely metabolized to carbon dioxide and water, but they enter metabolic cycle only as undissociated organic acids. Consequently, hydrogen ions are withdrawn from carbonic acid, which results in the accumulation of bicarbonate ions. These are electrically balanced by K and other cations. The increase in systemic  $HCO_3^{-1}$ concentration leads towards an alkalosis, but is actually prevented by the renal excretion of HCO<sub>3</sub><sup>-</sup> (and excess K<sup>+</sup>), which results in the production of strong alkaline urine. In contrast, a predominant absorption of milliequivalents of non-metabolisable anions is associated with an increase in systemic hydrogen concentration, which may induce acidosis (32). The occurrence of acidosis is prevented by an initial increase of renal reabsorption of HCO<sub>3</sub> and may be followed by a subsequent secretion of urinary of H<sup>+</sup> (38) resulting in the production of acidic urine. In man (and dogs), both ammonium and phosphate are used as a vehicle to excrete hydrogen. However, the renal excretion of excess H<sup>+</sup> in ruminants is in the form of  $NH_4^+$  (62). Thus, an electrically unbalanced absorption of non-metabolisable ions; i.e. so called 'fixed or strong ions' affects systemic acid-base balance which can be explained by the physiological need to maintain electrical neutrality in body fluids (66). Clearly, the influence of an electrolyte on systemic acid-base balance depends on the amount absorbed and its electrical charge. Therefore, concentrations of electrolytes are conveniently expressed in terms of milliequivalents (mEq) rather than mmol. In Table 1 factors are given to convert dietary concentrations expressed on weight basis (g/kg DM) into mEg/kg DM.

Element	Atomic weight	Valence	<b>Conversion factor</b>
Sodium (Na)	23.0	+1	43.5
Potassium (K)	39.1	+1	25.6
Chloride (Cl)	35.5	-1	28.2
Sulphate <sup>1</sup>			
SO4 <sup>2-</sup>	96.1	-2	20.8
S	32.1	-2	62.4

Table 1: Atomic weight, valence and factor to convert from	g/k	g DM to	mEq/kg	DM.
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<sup>1</sup> Although physiologically only sulphates  $(SO_4^2)$  are of interest, in this table conversion factors for both S and  $SO_4^2$  are given, because in feed analyses usually S is reported.

In theory, all the cations and anions in the ration potentially influence sytemic acid-base balance, but the major electrolytes involved are the cations Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and anions Cl<sup>-</sup>, H<sub>2</sub>PO<sub>4</sub><sup>-</sup>/HPO<sub>4</sub><sup>2-</sup>, and SO<sub>4</sub><sup>2-</sup>. With respect to H<sub>2</sub>PO<sub>4</sub><sup>-</sup>/HPO<sub>4</sub><sup>2-</sup>, a charge of 1.75 is assumed (38). However, it was already mentioned that only absorbed cations and anion affects systemic acid-base balance, and it was suggested by Goff and Horst (21) that the effect of dietary ions on systemic acid-base balance is most accurate described by:

 $(Na^{+} + K^{+} + 0.15 Ca^{2+} + 0.15 Mg^{2+}) - (Cl^{-} + 0.5 H_2PO_4^{-}/HPO_4^{2-} + 0.6 SO_4^{2-})$ [1].

However, under practical feeding conditions absorption coefficients of Ca, Mg and P are not known and may be different from that used in the formula. Therefore, most nutritionists use the equation  $(Na^+ + K^+) - (Cl^- + SO_4^{-2})$  [2]. In the latter equation, dietary sulphate and chloride are assumed to be equally effective in reducing the dietary cation - anion difference

(DCAD). Indeed, Oetzel et al. (45) indicated that iso-equivalental supplementation of Ca/Mgsulphates and - chlorides had a similar effect on blood-acid-base status and urine. However, recent studies clearly indicate that the acidifying property of Cl<sup>-</sup> versus  $SO_4^{2-}$  is about 60% higher (25). It must be kept in mind that the acidifying properties of sulphates are essentially restricted to supplemental sulphates because intrinsic S only marginally affects acid-base status of ruminants. It was shown by Wang and Beede (79) that a rise in dietary crude protein content from 11 to 19%, thereby raising the dietary S content from 1.1 to 3.2 g S/kg dry matter, significantly affected blood base excess but blood- and urinary pH were not significantly affected. Because intrinsic S has only a mild effect on systemic acid-base balance, it can be suggested to use only dietary Na, K and Cl to calculate the cation - anion difference. However, in contrast to formula [2], hardly any literature references with respect to target levels are available, at least in dairy cows. In relation to the prevention of milk fever the target value of DCAD (formula 2) is currently set at about – 50 ( 21) to –100 mEq/kg DM (53).

Finally, it must be stated that the application of the above-described concept under practical conditions is secondary to an adequate supply of the minerals in question. Thus, deficiency or toxicity must be abolished before manipulating the content of dietary fixed cations and anions (4).

### 2 DIETARY CATION-ANION DIFFERENCE AND MILK FEVER

#### 2.1 Incidence of milk fever

In an observational study in the Netherlands for three consecutive years (1994-1996), in which cows of 16 dairy herds participated (n = 1.872), the incidence of milk fever was 11% (77). This incidence rate is similar to that observed by Oetzel et al. (44) i.e 11.8% (n = 102), but incidence rates of 18.4% (n = 1,165) have been reported also (43). However, in an epidemiological study using data of Finnish Ayshire cows, an incidence rate of 4% (n = 61,124) was reported (27) which is similar to the incidence rate of 4.7% (n = 1,983) reported by Curtis et al. (7). In another study (26), using high producing dairy cows from 14 herds (10,265 kg milk/cow, n = 7,523) only 70 cases of milk fever were registered (0.9%) and such a low incidence rate (1.4%) was also reported by Markusfield (40) from 8,521 high producing dairy cows with an annual milk production ranging from 7000 to 9500 kg. Thus, the mean incidence of milk fever range from 0.9 to 18.4% as based on the studies mentioned above, but incidence rates of milk fever on individual farms may range from zero to more than 50% ( 77). It may be suggested that genetic factors are involved in the development of milk fever. Indeed, Oetzel (43) observed higher incidences of milk fever in Yersey and Swedish Red and White cows compared to Holstein cows, but the difference in incidence rate of milk fever did not reach statistical significance. It is generally known that the risk of milk fever increases with parity, especially cows with parity 3 and higher have an increased risk to develop milk fever (7, 26, 27, 43, 77). Furthermore, it was observed that the level of milk production increases the cow's odds for milk fever but this was only significant when milk yields of previous lactation was higher than 7060 kg milk compared to productions lower than 4740 kg milk (27). The cows used in the study of Velthuis et al. (77) were of a Friesian-Holstein x Holstein-Friesian cross and members of high producing dairy herds i.e. a mean of 7950 kg milk/cow in 305 days (range 6925-9002). The mean age of the cows at parturition was 3.97 years (range 3.81-4.44) and 32.5 % of these cows (range 26.7%-38.7%) were heifers. It seems that neither differences in level of milk production nor age, fully explain the observed differences in the incidence of milk fever between the dairy herds. Thus, it may be suggested that nutrition and/or feeding management have a major influence on the occurrence of milk fever between individual farms.

## 2.2 Acidogenic rations and the prevention of milk fever: Historical background and outcome of experimental work

Traditionally, the dietary strategy recommended to prevent milk fever is to decrease the Ca intake during the dry period (23,30) which enhances the efficiency of Ca absorption (72). However, implementation of this method is difficult because the required low Ca intakes (25-30 g/day) can hardly be achieved in practice. Furthermore, in a meta-analysis to assess nutritional risk factors for milk fever in dairy cattle, Oetzel (43) did not observe a relationship between the Ca content of the ration fed in the dry period, in the range from 2 to 25 g Ca/kg dry matter, and the incidence of milk fever. The conclusion that overfeeding of Ca in the dry period was not an important risk factor for milk fever was also drawn from an epidemiological study of Curtis et al. (7). Furthermore, in controlled studies of Goff and Horst (18) and Oetzel et al. (43), in which the Ca content of the ration was varied from 5 to 15 or from 6 to 11.5 g/kg dry matter, respectively, no difference in the incidence of milk fever was shown between the two Ca intakes. Therefore, other dietary strategies to prevent milk fever was shown between the feeding of so-called acidogenic rations in the dry period seems of interest.

Table 2: Effect of the feeding of acidogenic rations during the dry period and the incidence of milk fever around parturition.

Reference	Ingredients basal ration	Treatment	Dietary salts used	Incidence of milk fe	ver
				no cases/no of cows	Percentage
Dihington et al., 1975	hay, beets, formic acid	Control	Na <sub>2</sub> CO <sub>3</sub> and NaHCO <sub>3</sub>	13/14	92.8
( 11)	silage, herring meal, grains	Acidogenic	CaCl <sub>2</sub> , Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> , MgSO <sub>4</sub> , HCl , $H_2SO_4$ and NH <sub>4</sub> HSO <sub>4</sub> .	1/13	7.7
	-				
Block, 1984	alfalfa hay, corn silage, corn	Control	$Na_2CO_3$ and $NaHCO_3$	9/19	47.3
(5)		Acidogenic	CaCl <sub>2</sub> , Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> and MgSO <sub>4</sub>	0/19	0
Oetzel et al., 1988	corn silage, oat hay, alfalfa	Control		4/24	16.7
(46)	hay, cottonseed, corn	Acidogenic	$(NH_4)_2$ SO <sub>4</sub> and NH <sub>4</sub> Cl	1/24	4.2
Gaynor et al, 1989	alfalfa hay, soy mill feed	Control	NaHCO <sub>3</sub>	3/12	25.0
(17)		Acidogenic	CaCl <sub>2</sub> , MgCl <sub>2</sub> and NH <sub>4</sub> Cl	0/5	0
				·	•
Goff et al., 1991	alfalfa hay, soy mill feed	Control	NaHCO <sub>3</sub>	6/23	26.1
(22)		Acidogenic	CaCl <sub>2</sub> , MgCl <sub>2</sub> and NH <sub>4</sub> Cl	1/24	4.2
Goff et al., 1997	corn silage, soy bean meal,	Control	KHCO <sub>3</sub>	20/41	48.7
(18)	grain, beet pulp, alfalfa hay	Acidogenic	NH <sub>4</sub> Cl, MgSO <sub>4</sub>	2/19	10.5

During experiments in the sixties in which the relation between dietary Ca, P and Ca/P ratio was studied in relation to milk fever, Norwegian researchers noticed that rations containing mainly grass silage conserved with HCl and  $H_2SO_4$  (so called A.I.V. method) instead of rations with large quantities of fodder beets, markedly reduced the incidence of milk fever (12). These observations led to the hypothesis that acidogenic rations reduce the incidence of milk fever. This hypothesis was put to the test by Dinghington (11), and he observed a more than 10-fold decrease in the incidence of milk fever after the feeding of acidogenic rations (Table 2). Because of the typical ingredient composition of the Norwegian rations, Block (5) addressed the question again and showed that 47.4% of the cows that were fed the control ration in the dry period developed milk fever, whereas milk fever was fully prevented when the acidogenic ration was fed in the dry period. The preventative effect of feeding acidogenic rations during the dry period on the incidence of milk fever has been demonstrated also in several other studies (17, 18,22,46). For details concerning the rations, see Table 2.

#### 2.3 Dietary cation anion difference and plasma Ca around parturition

The data from Table 2 indicate that prepartal feeding of acidogenic rations may provide a useful tool to prevent milk fever. These observations suggest that plasma Ca concentrations around parturiton are maintained better when cows are fed rations with a negative instead of a positive DCAD during the dry period. Indeed, selected literature data (Table 3) show that the decrease in plasma Ca concentrations in cows around parturition is less pronounced when prepartal rations with a negative DCAD were fed. These data (Table 3) also show that total plasma Ca concentration is not affected by the feeding of acidogenic rations up to 3 days antepartum. Based on these data, it can be speculated that prepartal feeding of rations with a negative DCAD exerts its effect on plasma Ca concentration at the onset of colostrum production. It may be suggested that prepartal feeding of rations with a negative DCAD of prepartal rations. Thus, it seems that dry cows fed rations with a negative versus a positive DCAD have more Ca available to compensate for the Ca losses at the onset of lactation.

## 2.4 How does a negative DCAD affect plasma Ca concentration around parturition?

It could be hypothesized that a negative DCAD increases the efficiency of intestinal Ca absorption and/or the rate of Ca resorption from bone and/or Ca reabsorption in the kidney. When rations with a positive DCAD are fed to ruminants, urinary Ca excretion usually is very low; i.e. well below 1 g/day (60), irrespective of the level of Ca intake. However, it has been shown repeatedly that the feeding of acidogenic rations raises the urinary excretion of Ca in ruminants (16, 17,59,67) up to 6 g/day ( 60,75). Thus, a stimulatory effect of a negative DCAD on net tubular reabsorption of Ca can be excluded. It has been suggested that Ca derived from the skeleton may be the source of the extra Ca excreted in urine after feeding a diet with a negative DCAD. This suggestion was based on increased plasma hydroxyproline concentrations observed around parturition when a ration with an excess of anions was fed ( 5,35). However, Van Mosel et al. (76) histologically examined tuber coxae biopsies from periparturient cows fed a ration with a negative DCAD and no evidence was found for an increased bone resorption. Furthermore, on the basis of EDTA-infusion data, the amount of Ca that could have been withdrawn from the bones during the infusion of EDTA after the

Reference		Number	Start of feeding period	Total plasma Ca concentrations (mm	
	(mEq/kg DM)	of cows		3-7 days antepartum	At parturition
Block et al., 1984	+331	19	45 days antepartum	2.2	1.5
(5)	-129	19		2.2	2.0
Oetzel et al., 1988	+189	24	21 days antepartum	2.5	1.8
(46)	-75	24		2.6	2.1
Goff et al., 1991	+978	23	42 days antepartum	2.3	1.7
(22)	-228	24		2.3	1.9
Tucker et al., 1992	+94	60	21 days antepartum	2.3	1.9
( 69)	-34	60		2.2	2.1
Abu Damir et al., 1994	+779	6	28 days antepartum	2.6	2.0
(1)	-35	7		2.5	2.4
Phillippo et al., 1994	+539	8	28 days antepartum	2.5	1.7
(48)	-59	7		2.5	2.2
				· ·	
Goff and Horst, 1997	+442	23	21 days antepartum	2.0	1.4
(19)	+207	20		2.0	1.4
	-76	20	7	2.1	1.7
Goff et al., 1998	+86	11	21 days antepartum	1.9	1.4
( 20)	-91	9		1.9	1.8
$^{1}DCAD = (Nlo^{+} + K^{+} +)$	$(C^{1} + C^{2})$				

 Table 3: Prepartal feeding of acidogenic rations and plasma Ca concentrations in cows around parurition.

 $DCAD = (Na^{+} + K^{+} +) - (Cl^{-} + SO_{4}^{2^{-}})$ 

feeding of anion- versus cation-rich rations was estimated to be 58 and 56% of the total amount of Ca trapped by EDTA for the rations that were rich in anions and cations, respectively (59). It was concluded that bone was a major source of Ca during the EDTA infusions, irrespective the type of ration that was fed.

Thus, it seems that Ca resorption from bone is not influenced by a negative DCAD. However, Van Mosel et al. (76) suggested that bone accretion was decreased after the feeding of an anion rich ration. An unaltered bone resorption combined with a decreased bone accretion could theoretically explain the observed increase in urinary Ca excretion. This implicates that Ca balance both at the level of the bone and the whole body would be negative. To maintain whole-body Ca balance, an increase in urinary Ca excretion must be compensated for by an equal increase in Ca absorption. Indeed, Lomba et al. (37) calculated on the basis of regression analysis, a positive relationship between the amount of fixed anions (66) in the ration and Ca absorption in cows. Furthermore, it was shown under controlled feeding conditions (6) that addition of NH<sub>4</sub>Cl to the ration of sheep both stimulated urinary Ca excretion and intestinal Ca absorption. This observation in sheep can be extrapolated to cows since Schonewille et al. (60) showed that Ca absorption in dry, nonpregnant cows was increased with a negative DCAD. The question arises whether the increase in urinary Ca excretion would stimulate Ca absorption or vice versa. Stacy and Wilson (65) showed that intravenous administration of hydrochloric acid increased urinary Ca excretion within two hours. This prompt effect on urinary Ca excretion was caused by a decrease in tubular Ca reabsorption, which appears to be related with a decreased urinary bicarbonate excretion (47) as induced by the shift in systemic acid-base balance towards acidosis. Furthermore, Goff and Horst (20) showed that urinary pH was decreased and urinary Ca excretion was increased already 1 day after the DCAD was changed from 313 to -180 mEq/kg dry matter. The rapid urinary response to acid loading cannot be immediately compensated for by an increase in intestinal Ca absorption because adaptation of intestinal Ca absorption is a slow, gradual process that takes 2 to 6 days for full development (72). It can be concluded that the feeding of a ration with a negative DCAD induces a rapid increase in urinary Ca excretion, which in turn stimulates intestinal Ca absorption. Thus, the increase in intestinal Ca absorption hastens after the increase in urinary Ca excretion, leading to a negative Ca balance directly after the ration is changed from a positive to a negative DCAD. This implicates that plasma Ca concentration initially decreases thereby stimulating the release of parathyroid hormone (PTH), which in turn augments renal vit. D metabolism towards production of 1,25-dihydroxycholecalciferol (31) resulting in an increased intestinal Ca absorption (24). Thus, the mechanism by which prepartal rations with a negative DCAD prevent milk fever involves an increased efficiency of Ca absorption, which resembles the mechanism by which a prepartal ration with a low Ca content prevents milk fever. However, rations with a low Ca content enhance the efficiency of Ca absorption, but they do not increase the absolute amount of Ca absorbed. Thus, low Ca rations have little effect on urinary Ca excretion. In contrast, in cows fed anion-rich rations, both Ca absorption and urinary excretion are increased. Thus, the flow of Ca through the body in cows fed anion-rich rations must be substantially higher than in cows fed low Ca rations. Theoretically this extra flow of Ca through the body could be a source of Ca when hypocalcemia occurs. Indeed, it was shown by Schonewille et al. (57) that urinary Ca losses were diminished in cows fed anion-rich rations, when plasma Ca concentrations were stressed by intravenous administration of Na<sub>2</sub>EDTA. Thus, the flow of Ca was diverted from excretion with urine to support plasma Ca concentrations. In conclusion, the extra Ca excreted in urine after feeding a ration with a negative DCAD is available when hypocalcemia occurs. This extra Ca acts in concert with the observed higher Ca absorption (60) to prevent milk fever in dairy COWS.

Thus, it can be concluded that the raise in urinary Ca excretion, and subsequent release of parathyroid hormone (PTH) is considered to be the key in understanding the anti milk fever properties of acidogenic rations. Goff and Horst (21) have proposed that in cows fed high cation diets (level not further indicated) the conformational structure of PTH receptor is changed so that PTH cannot interact efficiently with its receptor. Indeed, Goff and Horst (18)

reported higher incidences of milk fever in cows when they were offered prepartal diets with increasing K concentrations. However, Roche (50) indicated that factors other than a high DCAD are probably more important in controlling milk fever because low levels of clinical cases of milk fever occurred in cows grazing pastures containing excess K (> 4%). Interestingly, hypomagnesemia may also interfere with the response of PTH on target tissue, because it might hamper the PTH induced activation of adenylate cyclase and second messenger cyclic AMP (phospholipase C) (18). Unfortunately, as far as we know, there are no controlled studies in dairy cows which proof this concept, but it has been reported by Van Leengoed et al., (74), Sansom et al. (56) and Barber et al. (3), that sub-clinical hypomagnesemia is associated with a higher incidence of milk fever. Thus, under the assumption that Mg is indeed necessary for full expression of PTH, it follows that a negative DCAD only prevents milk fever when cows are fed an adequate amount of Mg.

#### 2.5 Implementation in practice

As was mentioned earlier, prepartal feeding of low Ca rations is often recommended in practice, but is difficult to implement because of the required low dietary Ca content. Since the mechanism underlying the preventive effect of rations with a negative DCAD resembles that of feeding low Ca during the dry period, adding anions to the prepartal ration low in Ca further enhances efficiency of intestinal Ca absorption. However, for concerns regarding Ca requirement, the absolute amount of Ca absorbed, not the percentage of ingested Ca, is of importance. Thus, to contribute optimally to the prevention of milk fever, Ca intakes should be raised around parturition to increase the absolute amount of Ca absorbed.

The considerations mentioned above suggest that prepartal rations with a negative DCAD should be accompanied by a low dietary Ca content in order to optimise the efficiency of Ca absorption. In contrast, Wang and Beede (78) suggested that Ca absorption only increases after feeding rations with a negative DCAD when Ca intake is high. Contrary, it was shown by Schonewille et al. (61) that a two-fold increase in Ca intake, i.e. 47.5 to 83.7 g/day, did not affect the absolute amount of Ca absorbed after feeding anion-rich ration to dry, non-pregnant cows. Thus, the level of Ca intake also did not affect urinary Ca excretion. It follows that percentage of Ca absorption was lower when compared to the normal Ca intake. It can be concluded that the highest efficiency of Ca absorption is achieved when a prepartal ration with a negative DCAD is accompanied with a normal Ca intake under practical conditions.

A second point of practical importance is the time required for feeding a ration with a negative DCAD to contribute successfully to the prevention of milk fever. It was already mentioned that a ration with a negative DCAD has a prompt effect on urinary Ca excretion and consequently, almost instantaneous triggers intestinal Ca absorption. It was shown by Van't Klooster (72) that the process of Ca absorption takes at least 6 days before it is fully adapted. It would follow that the minimum time required for a ration with a negative DCAD to be fed would be about one week prior to calving.

In ruminant practice, the dietary content of cations is high relative to that of anions resulting in a positive DCAD. The variation in DCAD is primarily explained by the dietary K content (Table 4). High K concentrations in grass are found in areas with intensive livestock production (15). In the Netherlands, at least 80% of all grass silages have a K content in the range of 30-45 g/kg dry matter (58). Thus, the DCAD in grass silage is normally very positive, which results in the production of urine by the cows with strong alkaline characteristics when grass silage is the sole source of nutrition. Consequently, it may be difficult to formulate prepartal diets sufficiently low in DCAD because the incorporation of high amounts of acidogenic salts may interfere with the palatability of the ration (51).

# Table 4: Potassium content of grass and maize silage, and its associated dietary cation - anion difference.

Type of silage	K content	DCAD <sup>1</sup>			
	(g/kg dry matter	(mEq/kg DM)			
Grass	25	+400			
	40	+750			
	50	+1000			
Maize	14	+250			
<sup>1</sup> DCAD - diotany cation - anion balance: data were calculated on the basis of tabular data					

DCAD = dietary cation - anion balance; data were calculated on the basis of tabular data collected in-house. In practice, DCAD values may deviate from those presented because of a difference in actual mineral concentrations.

## 3 DCAD AND UDDER OEDEMA

Randall et al. (49) supplemented diets with sodium chloride or potassium chloride or both. The severity of udder oedema was the lowest on the non-supplemented control diet. The response to these salt supplementations seemed to differ between farms. Nestor et al. (42) supplemented diets with sodium chloride or potassium bicarbonate starting 42 days prepartum. The oedema score was higher on the diets with NaCl or KHCO<sub>3</sub> supplements, than the diets without supplementation or with both salts supplemented.

Kiess et al. (33) lowered the DCAD in the diet and observed a lower urinary pH (6.3 vs >7.4), but didn't establish a treatment effect on the severity of udder oedema.

Lema et al. (36) supplemented prepartum diets with  $CaCO_3$  or  $CaCl_2$  for three weeks. The reduction in DCAD (about 190 mEq/kg DM) resulted in a significant lower oedema scoring during 21 to 15 days before calving. However, in the second week after parturition the oedema score was significantly higher in the heifers that received  $CaCl_2$  before calving.

It can be concluded that there is no evidence for a direct relationship between DCAD and udder oedema. This is in line with Van der Kolk (73) who stated that there is no pathophysiologic concept for dietary interventions to reduce udder oedema.

## 4 DCAD AND BLOAT

Turner (71) indicated that a high ratio between potassium and sodium in herbage resulted in a higher incidence of bloat. Such a high ratio can be explained by fertilisation with potassium or by the fact that bloat producing legumes are natrophobes and contain a low sodium concentration. Majak and Hall (39) concluded that a shift in ionic concentrations (less sodium and more potassium) in the rumen could contribute to the occurrence of bloat through colloidal aggregation of chloroplast particles. However, the authors stated that this didn't imply a causal relation.

Because there is no information about the DCAD of the used diets, it is at this moment impossible to claim a (direct) relationship between DCAD and bloat.

## 5 DCAD AND MILK PRODUCTION

Sanchez et al. (52) designed an experiment to establish the relationship between DCAD and the responses of lactating cows. They concluded that a DCAD between + 300 and + 500 mEq per kg dry matter resulted in the highest milk productions and the highest dry matter intakes. In a review, Sanchez and Beede (54) derived about the same optimum for DCAD (+ 250 to +500 mEq/kg DM).

On the basis of 7 experiments under moderate temperature conditions (8,9,13,55,68,70,80) regression analysis suggested that higher levels of DCAD were associated with lower levels of dry matter intake, but within experiments this tendency was not observed. Moreover, regression analysis showed that potassium together chloride explained the variance in dry matter intake better than DCAD.

In the nine studies mentioned in this section, the dietary K concentrations ranged from 9 to 22 g K/kg DM, which is relatively low compared to the levels generally observed in the Netherlands. Therefore, it is not clear whether the outcome of these studies can be extrapolated to Dutch conditions.

## 6 DCAD AND UROLITHS

The DCAD-concept is also a well-known dietary tool so as to prevent struvite  $(MgNH_4PO_4.6H_2O)$  formation in the urinary tract of lambs fed high concentrate diets. In contrast to diets high in roughage, the salivary phosphorus (P) flow is strongly reduced when high concentrate diets are fed. In this condition, a relative large amount of the excreted P shifts from faeces to urine (63). Therefore, the feeding of high concentrate diets is accompanied by an increased risk of struvite formation. However, the formation of struvite crystals is prevented by a urinary pH < 6.5 (14,29). Because diets with a negative DCAD might induce the production of acidic urine, compounds such as ammonium chloride can be used to antagonize the formation of struvite crystals. On the basis of a meta-analysis of 21 studies in dairy cows, which involved 86 dietary treatments, Spanghero (64) developed a regression formula predicting urinary pH in response to DCAD; i.e. Urinary pH = 7.45 +  $0.0488 \times DCAD - 0.0005 DCAD^2$  (R<sup>2</sup> = 0.81, DCAD expressed in mEq/100 g of DM). Substituting a value of 6.5 for urinary pH results in a DCAD of -167 mEg/kg of DM. Similar to Spanghero (64), Bannink and Van Vuuren (2) also attempted to quantify the relationship between DCAD and urinary pH; i.e. Urinary pH =  $5.72 + 2.57 / (1 + EXP (-0.015 \times DCAD))$  $(R^2 = 0.69)$ . The latter formula yields a DCAD of -55 mEq/kg DM when urinary pH is fixed at 6.5. Unfortunately, both studies are based on observations in dairy cows and, as far as we know, similar studies are not available for lambs fed high concentrate diets. However, L'Estrange and Murphy (34) have shown in sheep fed pelleted grass meal, that a DCAD of about -200 mEq/kg of DM was associated with urinary pH values ranging between 5.5 and 6.0. It is clear that the issue is not yet settled, but we arbitrarily suggest to advice a tentative value of -170 mEq/kg of DM so as to effectively reduce the urinary pH in order to prevent the formation of struvite crystals.

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