Use of Acidifying Diets for Prevention of Milk Fever in Dairy Cattle

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Introduction to Dietary Cation-Anion Difference (DCAD)

Acidifying diets (either by addition of anionic salts or mineral acids) are commonly used in the United States to prevent milk fever in dairy cattle. The ability of different diets to cause acidification of the cow can be explained by dietary cation-anion difference (anion-cation balance, dietary electrolyte balance, strong ion difference). The DCAD of diets can be manipulated with relative ease, simply by adding relatively more anions or cations.

Understanding how DCAD affects calcium metabolism first requires a short review of chemistry. Dietary electrolytes can be classified as either anions or cations. Anions have a negative charge; cations have a positive charge. The charge carried by these electrolytes affects acid-base balance and ultimately calcium metabolism. Important dietary cations are sodium, potassium, calcium, and magnesium; important dietary anions are chloride, sulfur, and phosphorus. Sodium, potassium, sulfur, and chloride (the monovalent ions) are thought to exert the strongest ionic effects on acid-base balance and are referred to as the "strong ions" (19).

Manipulation of dietary cation-anion difference in ruminants does not result in noticeable changes in blood pH, because both kidney and bone compensate to maintain normal blood pH. For example, strongly anionic diets are acidogenic, but blood pH remains constant because urinary pH is reduced from about 8.0 to about 7.5. Similarly, cationic diets are alkalogenic but have little effect on blood pH because the urine becomes more alkaline.

Dietary cation-anion difference can be used to determine the relationship between strong cations and anions and thus predict whether a diet will evoke an acidic or alkaline response when fed to a dairy cow. Several equations for calculating DCAD of a diet have been proposed:

$$\text{DCAD (meq)} = (Na + K + Ca + Mg) - (Cl + SO_4 + H_2PO_4 + HPO_4)$$

$$\text{DCAD (meq)} = (Na + K + Ca + Mg) - (Cl + S + P)$$

$$\text{DCAD (meq)} = (Na + K + .15\ Ca + .15\ Mg) - (Cl + .20\ S + .30\ P)$$

$$\text{DCAD (meq)} = (Na + K) - (Cl + S)$$

$$\text{DCAD (meq)} = (Na + K) - (Cl)$$

New research data on the relative acidogenic properties of different anion sources (7, 9) suggests that the third equation, which applies different coefficients for the divalent ions, should be the most accurate. The fourth equation listed above [(Na + K) – (Cl + S)] has become the *de facto* standard DCAD equation among researchers and nutritionists. Potential problems with this equation are that it over-values the anionic contribution of sulfur and that it ignores the cationic contributions of calcium and magnesium.

Calculation of the DCAD of a diet, regardless of the equation employed, requires using the equivalent weights of the electrolytes. This is necessary because acid-base balance is affected by electrical charge rather than mass. The equivalent weight is equal to the molecular weight divided by the valence (electrical charge strength). The term milliequivalent (meq) is used to express equivalent weights; one milliequivalent equals 1/1000th of an equivalent. Table 1 provides reference values for calculating equivalent weights of important electrolytes and converting from percents to milliequivalents. Once milliequivalents are calculated, DCAD can then be computed by subtracting the anions from the cations using one of the equations listed above.

TABLE 1. Molecular weights, equivalent weights, and conversions from percent to milliequivalents of anions and cations used in calculating DCAD.

Element	Molecular Weight	Valence	Equivalent Weight	To convert from % to meq, multiply by:	
	(g)	---	(g)	(meq/kg)	(meq/lb)
Sodium (Na)	23.0	1	23.0	434.98	197.72
Potassium (K)	39.1	1	39.1	255.74	116.25
Chloride (Cl)	35.5	1	35.5	282.06	128.21
Sulfur (S)	32.1	2	16.0	623.75	283.52
Calcium (Ca)	40.1	2	20.0	499.00	226.82
Magnesium (Mg)	24.3	2	12.2	822.64	373.93
Phosphorus (P)	31.0	1.8[1]	17.2	581.14	264.15

[1] The valence of P is 1.8 based on the normal distribution of mono-hydrogen and di-hydrogen forms of phosphorus in the body.

Manipulating DCAD to Prevent Milk Fever

The traditional method of preventing milk fever has been to restrict calcium intake during the dry period. In theory, this helps condition the cow to calcium deficiency and makes her better able to respond to the acute, intense calcium demands which occur when lactation commences. Calcium intake during the dry period is usually restricted by replacing some or all of the alfalfa hay in a dry cow diet with a grass hay and using additional corn silage and concentrates. This feeding practice does help reduce the incidence of milk fever, but it has several drawbacks. Feeding concentrates and/or corn silage to dry cows may be expensive and may predispose cows to over-conditioning and subsequent fatty liver syndrome, ketosis, and/or abomasal displacements because of their high energy density. Diets consisting of grass hay and corn silage alone have been advocated; however, such diets usually contain sub-optimal levels of protein. Avoidance of alfalfa in the prepartum diet because it is too high in calcium is unfortunate because alfalfa is usually the least expensive and most readily available source of forage protein. Avoidance of alfalfa in the dry period also forces a detrimental forage switch at the time of calving, since lactating rations are usually based on alfalfa forage.

DCAD is more important in controlling milk fever than calcium intake (8, 14, 16). Dietary calcium does somewhat influence the incidence of milk fever; however, it does so in a non-linear fashion. Both high and low dietary calcium were associated with slightly lower incidence rates of milk fever (16). High concentrations of dietary potassium (a strong cation and dietary alkalinizer) caused milk fever in a recent study (8), but differing levels of dietary calcium had no effect on milk fever incidence (see Table 2).

TABLE 2. Effect of dietary potassium and calcium on milk fever and urinary pH in Jersey cows. Adapted from Reference 8.

Diet	DCAD[a] (meq/kg)	Milk fever cows/Total cows	Milk fever treatments/Diet	Urinary pH (Mean ± SEM)
Low Ca[b] - Low K[c]	-150	0/9	0	5.8 ± .22
Low Ca – Medium K[c]	+150	4/11	9	8.0 ± .08
Low Ca - High K[c]	+450	7/9	15	8.1 ± .11
High Ca[b] - Low K	-150	2/10	2	5.7 ± .09
High Ca – Medium K	+150	6/9	9	7.9 ± .11
High Ca - High K	+460	3/12	4	8.2 ± .06

[a] DCAD = Dietary Anion-Cation Difference, expressed as (Na + K) - (Cl + S), milliequivalents per kilogram of diet dry matter.

[b] Low Ca diets were .49% Ca and high Ca diets were 1.5% Ca.

[c] Low K diets were 1.1% K, medium K diets were 1.8% K, and high K diets were 2.5% K. Potassium was added as potassium bicarbonate.

Dairy cattle diets with a high DCAD (alkaline diets) tend to cause milk fever, while a low or negative DCAD (acidic diets) tends to prevent milk fever (2). Acidic diets promote bone mobilization (osteocytic resorption) since bone (along with the kidney) acts as a buffer against excessive systemic acidity. Acidic diets have minimal effect on intestinal absorption of calcium (5). Additionally, low DCAD diets have been shown to increase the amount of 1,25 dihydroxyvitamin D produced per unit increase in parathyroid hormone (3, 6, 18). This increases osteoclastic bone resorption, which is probably the most important calciotropic effect of acidic diets (5).

Most typical diets fed to dry cows will have an DCAD [using the formula (Na + K) - (Cl + S)] of about +100 to +250 meq/kg dry matter. Addition of a cationic salt (such as sodium bicarbonate) to the dry cow diet increases DCAD and increases the incidence of milk fever. Adding anionic salt(s) (minerals high in Cl and S relative to Na and K) or mineral acids to the diet lowers DCAD and reduces the incidence of milk fever. Adding three equivalents of anions to 12 kg of diet dry matter lowers DCAD by 250 meq/kg Properties of common anionic salts are presented in Table 3.

TABLE 3. Approximate retail costs and properties of anionic salts used in prevention of milk fever. Adapted from Reference 14.

Anionic salt	Molecular Weight	Equivalent Weight	Cost:	
	(g)	(g)	($/cwt)	(¢/eq)
$MgCl_2 \cdot 6H_2O$	203.3	101.7	92.50	20.7
$MgSO_4 \cdot 7H_2O$	246.5	123.2	30.00	8.1
$CaCl_2 \cdot 2H_2O$	147.0	73.5	21.00	3.4
$CaSO_4 \cdot 2H_2O$	172.2	86.1	19.00	3.6
NH_4Cl	53.5	53.5	40.00	4.7
$(NH_4)_2SO_4$	132.1	66.1	21.50	3.1

Research on Acidifying Diets for Milk Fever Prevention

Research conducted in Belgium and Norway in the 1970's gave the first indications that lowering DCAD of the dry period diet would reduce the incidence of milk fever in dairy cattle at freshening. Interest was raised when low incidence rates of milk fever were observed when cows were fed acid-treated grass silages. In one of those studies (4), DCAD was lowered by spraying forages with dilute acid solutions or by adding anionic salts [$CaCl_2$, $MgSO_4$, and $Al_2(SO_4)_3$]. Cows fed cationic salts ($NaCO_3$, $NaHCO_3$) in this study had an 85.7% incidence of milk fever, while those fed the dilute acids had only a 16.7% incidence and those fed the anionic salts had a 0% incidence of milk fever. Unfortunately, work in this area was not continued for most of a decade.

The failure of vitamin D metabolite research to provide an approved, commercially viable method of preventing milk fever helped rekindle interest in research into the use of anionic salts for milk fever prevention. Widespread adoption of total mixed rations provided a method of delivering anionic salts without depressing feed intakes. In addition, new theories of acid-base balance from human medicine (19) helped explain how anionic diets cause systemic acidification.

Canadian research published in 1984 (2) used the same anionic salts [$CaCl_2$, $MgSO_4$, and $Al_2(SO_4)_3$] as the Norwegian researchers to lower DCAD of the dry cow diet to -129 meq/kg dry matter (see Table 4). Cationic salts were added to another diet to raise DCAD to +331 meq/kg dry matter. The effect of DCAD on the incidence of milk fever in this study was also very dramatic;

47.7% of the cows fed the cationic salts had milk fever, while none of the same cows fed the anionic salts developed milk fever during the two-year switchback trial.

A research trial completed by the author while at Colorado State University (14) strongly supported the findings of the Canadian workers (see Table 4). Dietary cation-anion difference was manipulated by adding anionic salts [NH_4Cl and $(NH_4)_2SO_4$] to some of the diets but not to others. Whether or not the anionic salts were added was a much more important determinant of milk fever than was calcium intake. Supplemental anionic salts were able to protect against milk fever even when the calcium content of the dry cow diet was moderate (about 100 g calcium per day). Cows supplemented with anionic salts had a lower incidence of milk fever (4% versus 17%) and had higher blood calcium concentrations on the day of calving than did unsupplemented cows.

TABLE 4. Summary of anionic salts feeding trials.

	Feed Additive					Total	Milk	Milk
DCAD	Name	Dose		Ca	P	Cows	Fever	Fever
(meq/kg DM)	---	(g/d)	(eq/d)	(g/d)	(g/d)	(No.)	(No.)	(%)
Block, 1984 (Reference 2)								
-129	$CaCl_2$	31	.4	92.5	32.2	19	0	0.0
	$MgSO_4$	94	.8					
	$Al_2(SO_4)_3$	115	1.1					
+331	$NaCO_3$	---	---	85.5	33.9	19	9	47.7
	$NaHCO_3$	---	---					
Oetzel, et al., 1988 (Reference 14)								
-75	NH_4Cl	100	1.9	75	27	24	1	4.2
	$(NH_4)_2SO_4$	100	1.5					
+189	none	---	---	83	30	24	4	16.7
Beede, et al., 1991 (Reference 1)								
-250	NH_4Cl	108	2.0	181	---	260	~10	4.0
	$(NH_4)_2SO_4$	53	.8					
	$MgSO_4$	34	.3					
+50	None	---	---	92	---	250	~23	9.0

[1] DCAD = dietary cation-anion difference, calculated as [(Na+K) - (Cl+S)].
[2] Amounts of these cationic salts added to the diet were not stated.
[3] Ca intake was either 52 or 97 g/d; Ca intake had no effect on milk fever.
[4] Ca intake was either 54 or 112 g/d; Ca intake had no effect on milk fever.

A very large field study involving 510 cows (1) utilized a mixture of three anionic salts [NH_4Cl, $(NH_4)_2SO_4$, and $MgSO_4$] at a total dose of 3.1 eq/day (see Table 4). The use of the salts lowered DCAD to -250 meq/kg dry matter and reduced the incidence rate of milk fever from 9% (control diet with no salts added) to 4% (anionic diet). The anionic diet not only included anionic salts, but was also very high in calcium (181 g/day). It is likely that both the anionic salts and the high calcium intakes were responsible for lowering the incidence rate of milk fever with this diet.

Data from many of these trials also indicate that feeding anionic salts may have benefits beyond the prevention of clinical cases of milk fever (see Table 5). Very large reductions in subclinical hypocalcemia were documented in two of these trials (1, 14). By reducing subclinical hypocalcemia, it may be possible for cows to increase dry matter intake faster in early lactation, resulting in increased milk production and decreased disease incidence. Significant increases in milk production of +7.3% (2) and +3.6% (1) were also documented. Retained fetal membranes were significantly reduced by feeding anionic salts in one study (14) but unaffected in another (1). Substantial improvements in reproductive performance were noted in one study (1). Many other studies, beyond those described above, have also shown beneficial effects of anionic salts in milk fever prevention (11, 12).

TABLE 5. Effect of anionic salt supplementation during the prepartum period on various measures of dairy cow health, reproduction, and milk production.

		Disease Rates			Reproduction		Milk Production:
Trial	DCAD	PP	PH	RFM	CR	Days Open	305-d ME
	(eq/kg)	(%)	(%)	(%)	(%)	(days)	(kg/305 days)
Oetzel et al., 1988	-75	4.2	29.2	0.0	---	---	---
(Reference 14)	+189	16.7	66.7	25.0	---	---	---
Beede et al., 1991	-250	4	19	NS[7]	71	124	9376
(Reference 1)	+50	9	50	NS	54	138	9049
Block, 1984	-129	0.0	---	---	---	---	7142
(Reference 2)	+331	47.7	---	---	---	---	6656

[1] DCAD = dietary cation-anion difference, calculated as [(Na+K) -(Cl+S)].
[2] PP = parturient paresis (clinical milk fever).
[3] PH = parturient hypocalcemia (ionized calcium < 4 mg/dl on the day of calving, with or without signs of milk fever).
[4] RFM = retained fetal membranes (membranes retained longer than 24 h postpartum).
[5] CR = conception rate at 200 d postpartum.
[6] Days open for pregnant cows.
[7] NS = no significant difference between dietary treatments.

Practical Questions About Feeding Acidifying Diets

Are acidifying diets safe? It is known that force-feeding large amounts of anionic salts or mineral acids can be detrimental. However, lack of palatability limits the likelihood of toxicity if the salts are overdosed. When anionic salts are used, a combination of salts is best. This decreases the potential of toxicity from the cation (Mg, NH_4, Al, etc.) that must necessarily accompany each salt. It is possible to exceed NRC maximum tolerable amounts of sulfur (.40%), magnesium (.50%) and NPN (.50%) by feeding large amounts of any single anionic salt.

Are acidifying diets palatable? Anionic salts are not very palatable and are best fed in a total mixed ration (TMR) rather than in a grain or mineral mix alone. Palatability problems are smaller when the salts are added to a TMR (1, 2, 13, 14). If a TMR is not possible, it is best to hand-mix the anionic salts with a wet forage (corn silage or hay silage). If only dry forages or pasture are used, then the salts can be added to a grain mix, but with some difficulty. It appears that the salts must be mixed with more than at least 2.27 kg of a grain mix (17), and even then palatability of the grain mix will be impaired. Pelleting a mixture of anionic salts does not appear to increase their palatability (17), but it may provide advantages in product formulation and in preventing separation of the anionic salts within a concentrate mixture. Pre-mixing loose salts with a carrier that has a strong flavor of its own (eg., dried distillers grains or molasses) may be helpful and is commonly practiced. Ammonium salts pre-mixed into a concentrate mixture during warm weather may result in release of ammonia gas and feed refusal. In addition, most of the salts are very hygroscopic and attract moisture, which may lead to caking of the product. Thus, anionic feed additives are routinely stored in bags lined with plastic.

Among the commonly used anionic salts, $MgSO_4$ is the most palatable and $CaCl_2$ is the least palatable (16). Sulfates appear to have an advantage in palatability over chlorides; however, the poor acidifying potential of sulfates greatly limits their use (7, 9, 15). Care must also be taken to avoid exceeding maximum tolerable levels of sulfur in the total diet.

Use of mineral acids instead of anionic salts may reduce the degree of dry matter intake depression (Goff, unpublished data, 1997), possibly because mineral acids taste acidic instead of salty. Field experience with an acidified fermentation by-product (Bio-Chlor™) supports this observation.

What combination of acidifying feed ingredients is most effective? Direct comparisons of the abilities of the individual anionic salts to prevent milk fever have not been done, because such trials would require extremely large sample sizes. Chlorides and hydrochloric acid are much better acidifiers (as measured by urinary pH) than are sulfates or sulfuric acid (7, 9, 15; Table 7). Thus, chlorides and hydrochloric acid are probably more effective in preventing milk fever. Interactions among anionic salt combinations have not been evaluated; however, there is no theoretical basis to suspect significant interactions.

What dose of anions must be fed to get the necessary effect? No studies have been done to titrate the exact dose required to "satisfactorily" decrease the incidence rate of milk fever. Most of the studies to date have used doses of about 2 to 3 eq/d of anionic salts (see Table 4). Lower doses may be effective if hydrochloric acid is used as the sole source of anions (Table 7). Most nutritionists adjust the dose of salts to a desired final DCAD of about –50 to –150 meq/kg. Difficulties in laboratory analysis for chlorine and sulfur (or use of reference values for these electrolytes) may severely limit the accuracy of calculated DCAD values.

TABLE 7. Effect of anion source on urinary pH. Adapted from References 7 and 9.

Anion Source[a]:	Urinary pH
HCl	$6.2 \pm .21$
$CaCl_2$	$7.1 \pm .36$
NH_4Cl	$7.0 \pm .20$
H_2SO_4	$7.5 \pm .23$
Ca SO_4	$7.6 \pm .15$
$MgSO_4$	$7.9 \pm .08$
S (elemental)	$8.2 \pm .04$

[a] Two equivalents/day of each anion source was fed.

Monitoring urinary pH after feeding an acidifying diet may be the most direct and useful approach to establishing the optimal DCAD. Mean urinary pH values in a group of pre-fresh dry cows should be between about 5.5 and 6.5 if anions are correctly dosed and the diet is properly formulated and delivered. There may be significant post-feeding variations in urinary pH; therefore, urine samples should be collected at a consistent time relative to feeding (usually 2 to 4 hours post-feeding).

What concentrations of dietary calcium and phosphorus should be used when acidifying diets are being fed? No research project has been conducted to definitively answer this question. There is tentative evidence that the salts work best when dietary calcium is high (1, 14). Clinical experience strongly suggests that the anionic salts should *not* be used when dietary calcium is very low (less than about 60 g per day).

There is also uncertainty regarding the optimal concentration of dietary phosphorus. Dry cow diets high in phosphorus (>80 g of PO_4 per day) will increase the risk of milk fever due to inhibitory effects on vitamin D metabolism (10). Most nutritionists provide about 40 to 50 g of phosphorus per day to pre-fresh dry cow diets

How long must an acidifying diet be fed before parturition? The time period of feeding anionic salts in previous trials has ranged from 21 to 45 days before expected parturition. It may be possible to feed an acidifying diet for a shorter time period; however, this theory has not been tested. The author's experience suggests that cows must consume an acidifying diet for at least 10 days in order to receive maximal benefit. There have been suggestions of metabolic adaptation in cows fed acidifying diets for a long time period, which may blunt the effectiveness of the anions in the diet to prevent milk fever.

Will acidifying diets cause udder edema? A large field trial (1) found no differences in umbilical-udder edema scores taken 1 to 2 weeks postpartum. Anionic salts actually slightly decrease the incidence and severity of udder edema during the prepartum period in first lactation animals (13). Because udder edema is a sporadic disease of poorly understood etiology, there is a tendency to blame acidifying diets for any case of udder edema that occurs after the onset of their use.

When should acidifying diets be fed? Whenever a herd (or individual cow who can be fed separately) has a history of milk fever problems, then use of acidifying diets should be considered. In herds without clinical milk fever problems, acidifying diets may still prevent subclinical hypocalcemia and thus reduce the incidence of displaced abomasum, improve milk production, and reduce days open.

The beneficial effects of acidifying diets can only be realized when feeding management of the pre-fresh cow is excellent. High quality feed ingredients, proper diet formulation, adequate bunk space, accurate feed mixing, and accurate feed delivery are especially important when acidifying diets are fed. Otherwise, dry matter intake depression may occur and go undetected in the pre-fresh dry cows. This can lead to negative energy balance prior to calving, fatty infiltration of the liver, and significant ketosis problems after calving. It is not acceptable to obtain milk fever prevention at the expense of fatty liver syndrome. Both diseases can be prevented with excellent pre-fresh dry cow nutritional management.

Which cows should receive the acidifying diet? If dry cows are fed individually rather than as a group, it would be advantageous to feed acidifying diets only to those cows at highest risk for milk fever, such as older cows and cows with previous episodes of milk fever. If only a few cows are fed an acidifying diet, then the extra labor of hand-preparing a TMR could be justified. If the source of anions must be part of a grain mix, then measures should be taken to improve the palatability of the mixture (premixing, etc.). Dry cows should be brought up gradually, over a three day period, to the full feeding rate of the anionic salts mixture.

What can be done if dry matter intake decreases while feeding an acidifying diet? If dry matter intake more than 1 kg/day in a group of pre-fresh dry cows fed an acidifying diet, then decrease the dose of anions to the point that dry matter intake is restored. Excessive loss of dry matter intake just prior to calving is very undesirable and may lead to ketosis and/or fatty liver syndrome.

Are the anionic salts cost-effective? Current costs of 2 to 3 equivalents of anions is about 20 to 30 cents per cow per day. Costs of milk fever (both clinical and subclinical) are substantially greater than this. If gains of milk production of 3 to 7% can be expected, then the economic return from feeding the salts is about 10 to 1 for increased milk production alone (1).

REFERENCES

1 Beede, D.K., C.A. Risco, G.A. Donovan, C. Wang, et al. 1991. Nutritional management of the late pregnant dry cow with particular reference to dietary cation-anion difference and calcium supplementation. Page 51 *in* Proc. 24th Annu. Conv. Amer. Assoc. Bovine Pract., Orlando, FL. Amer. Assoc. Bovine Pract., Stillwater, OK.

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

3 Damir, H.A., M. Phillippo, B.H. Thorp, J.S. Milne, L. Dick, and I.M. Nevison. 1994. Effects of dietary acidity on calcium balance and mobilisation, bone morphology, and 1,25 dihydroxyvitamin D in prepartal dairy cows. Res. Vet. Sci. 56:310.

4 Dishington, I.W. 1975. Prevention of milk fever (hypocalcemic paresis puerperalis) by dietary salt supplements. Acta Vet. Scand. 16:503.

5 Fredeen, A.H., E.J. DePeters, and R.L. Baldwin. 1988. Characterization of acid-base disturbances and effects on calcium and phosphorus balances of dietary fixed ions in pregnant or lactating does. J. Anim. Sci. 66:159.

6 Goff, J. P., R. L. Horst, F. J. Mueller, J. K. Miller, G. A. Kiess, and H. H. Dowlen. 1991. Addition of chloride to a prepartal diet high in cations increases 1,25-dihydroxyvitamin D response to hypocalcemia preventing milk fever. J. Dairy Sci. 74:3863.

7 Goff, J.P. and R.L. Horst. 1996. Comparison of sulfuric acid with hydrochloric acid as a source of acidifying anions. Proceedings, Midwest Section of the ADSA/ASAS, Abstract #274.

8 Goff, J.P. and R.L. Horst. 1997. Effects of the addition of potassium or sodium, but not calcium, to prepartum rations on milk fever in dairy cows. J. Dairy Sci 80:176.

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

10 Horst, R.L., J.P. Goff, and T.A. Reinhardt. 1994. Calcium and vitamin D metabolism in the dairy cow. J. Dairy Sci. 77:1936.

11 Jäkel L., M. Fürll, T.A.J. Bauerfeld, and B. Groppel. 1996. Prevention of milk fever (MF) with anion-rations. Proceedings, XIX World Association of Buiatrics Congress, Edinburgh, p. 264-265.

12 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.

13 Lema, M., W.B. Tucker, M. Aslam, I.S. Shin, P. LeRuyet, and G.D. Adams. 1992. Influence of calcium chloride fed prepartum on severity of edema and lactational performance of dairy heifers. J. Dairy Sci. 75:2388.

14 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.

15 Oetzel, G.R., M.J. Fettman, D.W. Hamar, and J.D. Olson. 1991. Screening of anionic salts for palatability, effects on acid-base status, and urinary calcium excretion in dairy cows. J. Dairy Sci. 74:965.

16 Oetzel, G.R. 1991. Meta-analysis of nutritional risk factors for milk fever in dairy cattle. J. Dairy Sci. 74:3900.

17 Oetzel, G.R., and J.A. Barmore. 1993. Palatability of anionic salts fed in a concentrate mix. J. Dairy Sci. 76:1617.

18 Phillippo, M., G.W. Reid, and I.M. Nevison. 1994. Parturient hypocalcaemia in dairy cows: effects of dietary acidity on plasma minerals and calciotropic hormones. Res. Vet. Sci. 56:303.

19 Stewart, P.A. 1983. Modern quantitative acid-base chemistry. Can. J. Physiol. Pharmacol. 61:1444.