Reviews on the mineral provision in ruminants (I): CALCIUM METABOLISM AND REQUIREMENTS IN RUMINANTS

A.M. van den Top

CVB documentation report nr. 33
November 2005
(unchanged reprint 2009)

voor waardevolle
voederwaarden

Reviews on the mineral provision in ruminants (I): CALCIUM METABOLISM AND REQUIREMENTS IN RUMINANTS

A.M. van den Top
Adviesbureau VOER-RAAD
Groenekan

CVB documentation report nr. 33
November 2005
(unchanged reprint 2009)

Productschap Diervoeder
CVB
Postbus 29739
2502 LS Den Haag
Telefoon 070 – 3708 503
Telefax 070 – 3708 290
E-mail cvb@pdv.nl
Internet www.cvb.pdv.nl

PREFACE

In the Netherlands the ´Handleiding Mineralenonderzoek bij rundvee in de praktijk´[1] is a well-known 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'[2], 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'[3] 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.'[4] 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.
For the preparation of the present report on the Calcium provision in ruminants the COMV expresses its gratitude to the author, dr. A.M. van den Top.

Utrecht/Lelystad, November 2005.

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

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

The author, Dr. A.M. van den Top, expresses his thanks to the COMV, especially prof. dr. A. Th. van 't Klooster, and dr. M.C. Blok, for critically reading the manuscript and their advice.

1 Guidebook on mineral research for cattle in practice.
2 Committee for research on mineral nutrition
3 The Ministry for Agriculture, Nature and Food quality, the Product Board Animal Feed and the Dutch Dairy Board, respectively.
4 Guidebook mineral provision cattle, sheep and goats.

MEMBERS OF THE 'COMMISSIE ONDERZOEK MINERALE VOEDING' (COMMITTEE FOR RESEARCH ON MINERAL NUTRITION)

Prof. Dr. Ir. A. C. Beynen	Afdeling Voeding, Faculteit Diergeneeskunde, Universiteit Utrecht (Department Nutrition, Faculty of Veterinary Medicine, Utrecht University) Utrecht
Dr. M. C. Blok	Veevoederbureau, Productschap Diervoeder (Bureau for Livestock Feeding, Product Board Animal Feed) Lelystad / Den Haag
Ir. D. J. den Boer	Nutriënt Management Instituut (NMI) (Nutrient Management Institute) Wageningen
Ir. G. van Duinkerken	Divisie Veehouderij, Animal Sciences Group van WUR (Division Animal Husbandry, Animal Sciences Group of Wageningen University and Research Centre) Lelystad
Dr. Ir. A. W. Jongbloed	Divisie Veehouderij, Animal Sciences Group van WUR (Division Animal Husbandry, Animal Sciences Group of Wageningen University and Research Centre) Lelystad
Prof. Dr. A. Th. Van 't Klooster	Adviseur van de COMV (Advisor of the COMV)
Dr. Ir. W. M. van Straalen	Schothorst Feed Research Lelystad
Dr. Ir. H. Valk	Divisie Veehouderij, Animal Sciences Group van WUR (Division Animal Husbandry, Animal Sciences Group of Wageningen University and Research Centre) Lelystad
Dr. J. Veling	Gezondheidsdienst voor Dieren b.v. (Animal Health Service Ltd) Deventer

CONTENT

LIST OF ABBREVIATIONS

Abbreviation	Unit	Description
BW	kg	Body weight
CT		Calcitonin
DM		Dry matter
DMI	kg	Dry matter intake
PTH		Parathyroid hormone

1 FUNCTIONS OF CALCIUM IN THE BODY

Calcium is an essential component of the skeleton and, therefore, of vital importance for proper bone growth. Within the bone tissue, Ca is present in hydroxyapatite crystals (($Ca_{10}(PO_4)_6(OH)_2$). Extraskeletal Ca occurs as either free ions or bound to serum proteins and complexed to organic and inorganic acids. The free Ca ions (50-60% of plasma Ca) are essential for nerve conduction, cell signalling, blood clotting and muscle contractions [121].

2 DISTRIBUTION OF CALCIUM IN THE BODY

The majority of Ca in the body is present in the skeleton (98-99% of body Ca). Extraskeletal Ca represents 1-2% of total body Ca [85;121]. During late gestation and early lactation as much as 20% of Ca present in the bones can be mobilized [121]. Although the amount of Ca present in the bones represents a considerable reserve, Ca absorption as well as the ability of cows to mobilize Ca from the bones decrease with age [106;112]. Therefore, acute increases in Ca needs due to the start of lactation can result in the development of milk fever.

3 CALCIUM ABSORPTION AND KINETICS

3.1 General

Calcium uptake from the intestine of ruminants occurs mainly in the small intestine, although small amounts may be absorbed from the forestomachs [24;36;121;133]. In the abomasum, both net secretion and absorption of Ca can occur [133]. Absorption of Ca from the anterior small intestine is both an active (mediated by vitamin D_3) and a passive process [30]. The physiologically active form of vitamin D_3 (1,25-dihydoxycholecalciferol) is either directly obtained from the feed (concentrates, supplements) or produced in the body from related compounds. In the skin 7-dehydrocholesterol can be metabolized to cholecalciferol under ultraviolet irradiation. Vitamin D_2 can be obtained from sun-cured roughages. Both compounds are metabolized in the liver to 25-OH-cholecalciferol and subsequently in the kidney to the active vitamin D_3. A comprehensive review of vitamin D metabolism and functions is presented in references [30;57].

The Ca absorption from the forestomachs is enhanced in the presence of Na [39] and phosphate [11;35] and decreased in the presence of high Mg concentrations [39;119]. The ruminal Ca^{2+} content is decreased in the presence of long-chain fatty acids [87]. Absorption from both the intestine [121] and the reticulo-rumen [36] is stimulated by parathyroid hormone (PTH) and 1,25-dihydroxycholecalciferol. Parathyroid hormone secretion is sensitive to small variations in ionic Ca concentration in the extracellular fluid and, in turn, stimulates vitamin D_3 activation in the kidney. Vitamin D_3 acts more slowly in activating Ca uptake by both the intestinal mucosa (with the help of calbindin) and the bones [108;121], but not from the forestomachs [110]. As PTH secretion is lowered in hypomagnesemic sheep in response to temporary hypocalcemia, poor Mg availability (e.g. due to a high K content of the feed) entails the risk of milk fever [94;106;126]. The irresponsiveness of bone and kidney to PTH stimulation during (subclinical) hypomagnesemia is possibly mediated by a metabolic alkalosis [48].

In case of excessive Ca supply, these homeostatic mechanisms are reversed by calcitonin (CT) secretion, which decreases Ca absorption from the intestine and increases its deposition in the bones [121]. In thryroidectomized sheep, CT decreases Ca secretion into the saliva [73].

3.2 Differences in calcium metabolism due to different calcium sources

3.2.1 Interactions of calcium and oxalate

Summary of Relative Ca bioavailabilities as measured, using either true absorption or retention, have been extensively reviewed by Soares [112]. Selected results are given in Table 1. Retention values are often low. However, the absolute amount of Ca absorbed is greatly influenced by the ratio between intake and requirement (I/R ratio, see chapter 4).

Table 1 Selected results of Ca bioavailability trials in cattle [112]

Source	RV (%)	Standard	RC	Added level (%)[a]
Ca chloride RG	132	Ca carbonate	T	0.33
Ca chloride FG	120	Ca carbonate	T	0.33
Dicalcium phosphate (RG)	125-126	Ca carbonate	T	0.33
Dicalcium phosphate FG	116-124	Ca carbnate	T	0.33
Limestone	88-93	Ca carbonate	T	0.33
Monocalcium phosphate RG	120-140	Ca carbonate	T	0.33
Orchard grass hay	98-100	Ca carbonate	T	NG

FG = feed grade; NG = not given; RC = response criterion; RG = reagent grade; RV = relative value to standard; T = true absorption; [a] level of Ca added to the basal ration

3.2.2 Conclusions

In comparison with mineral sources the availability of Ca from plant material, such as lucerne and white clover, can be low, but results vary considerably [85;112].The fact that Ca is bound to or surrounded by slowly degradable plant cell structures and the occurrence of poorly available oxalate-bound Ca in plants may contribute to a low Ca availability (see paragraph 3.3.1). Moreover, possibly both the plant species and maturity stage might contribute to the observed differences. Finally, in experiments of Van 't Klooster [65] ± 90% of duodenal Ca in a sheep and a cow was ultrafiltrable (gras and grass hay-based rations). Therefore, Ca availability from Dutch grass species is not necessarily as low as values reported abroad and, moreover, may be dependent on the intake/requirement ratio (I/R ratio, see chapter 4). Within the mineral sources of Ca, Ca chloride, monocalcium phosphate and dicalciumphosphate are readily available (Table 1). However, Ca chloride may be caustic to the animal's gastrointestinal tract. As an oil emulsion, it may be relatively safe [55;132]. In most cases the application of Ca carbonate will be a convenient way to add Ca to the ration. The choice for mono- or dicalciumphosphate instead of Ca carbonate may be influenced by the need to add phosphate to the ration or not.

3.3 Interactions influencing calcium absorption

3.3.1 bioavailability trials in ruminants

3.3.1.1 Cattle and sheep

As Ca is absorbed in its ionic form, compounds binding Ca^{2+}, and thereby reducing the ionic Ca concentration, may impair Ca absorption. In ruminant nutrition, this is mainly the case for oxalate. In lucerne hay, as much as 20-33% of total Ca was demonstrated to be oxalate-bound Ca. Vascular bundles in the lucerne leaves containing lots of Ca oxalate crystals were largely unaffected by ruminal digestion [130]. This may be detrimental to Ca absorption. However, in other cases 48-71% of Ca-oxalate was hydrolyzed by bullocks [81]. Plants containing relatively large amounts of oxalate, such as fescue (*Festuca spp.*) [129] and dock (*Rumex spp.*) [33;88] can cause disease and death due to interference with Ca metabolism. Moreover, oxalate-containing plants may be palatable to ruminants. Oxalate consumed by ruminants may (1) be degraded by rumen bacteria, (2) precipitate with Ca or Mg and/or (3) be absorbed from the rumen and bind Ca in the blood to produce hypocalcemia and/or (4) be excreted. Insoluble oxalate salts may then accumulate in tissues, especially the rumen wall and the kidneys. The condition can be lethal due to (1) hypocalcaemia, (2) uremia due to kidney damage and/or (3) interference of oxalate with energy metabolism (succinate dehydrogenase and lactate dehydrogenase). The problem may be aggravated when hungry animals are allowed to graze a heavy stand of these plants while having restricted access to drinking water [61;129;135]. Animals suffering from acute oxalate poisoning can die suddenly. Before death, excessive salivation, depression, tremors, rapid and labored breathing and ataxia may be observed [88].

3.3.1.2 Goats

As yet, no problems due to oxalate ingestion by goats have been reported.

3.3.1.3 Conclusion

In general, the most important aspect of the oxalate content of plants and rations will be the fact that Ca absorption from oxalate-rich rations and plants is relatively low. Risk factors (allowing hungry and/or thirsty animals to graze heavy stands of oxalate-rich plants) should be avoided. Until more information is available, this is assumed to be also the case for goats.

3.3.2 Interactions of calcium and phytate

3.3.2.1 Cattle, sheep and goats

Although phytate may impair Ca bioavailability in non-ruminating animals [112], phytase-mediated ruminal breakdown of phytate is usually sufficient to prevent this interaction in ruminating animals. No data are available on the effect of phytate on Ca metabolism in milk-fed calves.

3.3.3 Interactions of calcium and aluminium

3.3.3.1 Cattle and sheep

As summarized by Schenkel and Klüber [107] in cattle and sheep the addition of 300-1450 ppm Al (from either $AlCl_3.6H_2O$, Al-citrate or $Al_2(SO_4)_3$ [7;123;124]) had no effect on absorption and tissue or plasma concentrations of Ca. Only in one case the addition of 1000 ppm Al to the ration[5] of cows resulted in increased apparent absorption, urinary excretion and retention of Ca [101]. The addition of 2000 ppm Al to the ration[6] of wether lambs decreased apparent Ca absorption [123]. Tissue Ca concentrations were not influenced by Al treatment. The addition of 2000 ppm Al/kg DM (from Al-citrate) to the ration of wethers tended to reduce Ca concentrations in kidney, pancreas and parthyroid gland as compared to their citrate-treated countermates [7]. Using the same experimental design in beef cows (2000 ppm additional Al[7]) urinary Ca concentrations were increased, whereas serum Ca concentrations tended to be higher in the Al-treated group [8].

3.3.3.2 Goats

No experimental evidence on the influence of Al on Ca metabolism in goats is available.

3.3.3.3 Conclusion

Under normal circumstances Al concentrations in grass range from 100 to 400 ppm Al (DM). Only at the end of the grazing season (October) the Al concentrations can exceed 1600 ppm (DM) [101]. Although in the majority of the experiments mentioned above the Al concentrations substantially exceed those normally found in forages, only minor influences on Ca metabolism have been reported. Therefore, the practical importance of Al on Ca metabolism in ruminants seems to be minor.

3.3.4 Interactions of calcium and magnesium

3.3.4.1 Cattle

In steers fed a ration[8] containing 3 g Mg/kg DM or supplemented with Mg to contain either 14, 25 or 47 g Mg/kg DM for 130 days both apparent Ca absorption and serum, liver and kidney Ca concentrations decreased significantly with increasing dietary Mg concentrations [25]. Bone Ca concentrations were not different between the groups. The steers on the two highest Mg levels had severe diarrhea and were lethargic.

---

[5] Hay/concentrates ration; Al concentration not given; additional Al from $Al_2(SO_4)_3.18H_2O$.

[6] Maize(starch)/cottonseed hulls/soybeans/lucerne/molasses ration containing 168 ppm Al; additional Al from $AlCl_3.6H_2O$.

[7] Cottonseed hulls/maize/maize gluten meal ration containing 200 ppm Al; additional Al from Al-citrate.

[8] Maize/orchardgras hay/soybean meal/loasses ration; extra Mg from MgO (feed grade).

3.3.4.2 *Sheep and goats*

No experimental evidence is available on the effect of high dietary Mg concentrations on Ca metabolism in small ruminants.

3.3.4.3 *Conclusion*

The Mg levels reported to cause clinical symptoms due to Mg toxicity (25 and 47 g/kg DM) extremely exceed normal Mg levels in ruminant rations (up to 5 g Mg/kg DM [22]). This is even the case for the 14 g/kg DM level. At this level, biochemical alterations of Ca metabolism were already visible. However, as no levels in between have been used, applicability under practical circumstances remains questionable. Only in cases of gross overdosing of Mg [104] impairment of Ca metabolism can be expected.

3.3.5 Interactions of calcium and lactose

3.3.5.1 *Cattle and goats*

No experimental data concerning the influence of lactose on Ca metabolism in cattle and goats are available.

3.3.5.2 *Sheep*

In an experiment with 4 sheep fitted with ruminal and intestinal cannulas and fed lucerne hay with or without lactose[9], ruminal pH and acetate concentration, as well as Ca absorption from the small intestine, were lower when lactose was fed. However, in the lactose-fed group Ca absorption from the forestomachs was increased, resulting in an increase in apparent Ca absorption from the lactose-enriched diet [97]. Ruminal propionate concentration was increased.

3.3.5.3 *Conclusion*

An increase in the dietary supply of ruminally fermentable carbohydrates may be positively correlated with Ca absorption from the gastrointestinal tract of sheep. However, due to lack of data this effect cannot be quantified.

3.3.6 Interactions of calcium and phosphorus

3.3.6.1 *Cattle*

In a steer fed a total mixed ration[10] supplying theoretically adequate Ca, P and Mg (4.0, 3.9 and 1.8 g/kg DM, respectively) but with a Ca:P ratio of 1:1, complete obstruction of the urethra was observed [128]. The clinical sings were frequent tenesmus, evidence of abdominal pain, regurgitation and labored breathing. Two experiments were carried out with different Ca:P ratios before calving to study the effects on the incidence of milk fever [12;44]. The Ca:P ratios ranged from 1.1:1 to 2.3:1. However, due to uncertainties concerning Mg supply or possible interactions with dietary energy intakes during the dry period these studies did not show clear results as to the influence of the Ca:P ratio on the incidence of milk fever. Finally, in a dairy herd fed a ration[11] with a Ca:P ratio of 1.1:1 with many problems of dystocia, retained placenta, poor uterine involution and post-partum metritis with

---

[9] 700 g lucerne hay with or without 40 g lactose/day.
[10] Cracked maize/maize gluten/gluten balancer/hay/diatomaceous earth ration.
[11] No ration composition given.

concurring low serum Ca concentrations, treatment with steamed bone meal for 3 months dramatically improved the clinical situation and increased serum Ca levels [20].

3.3.6.2 Sheep

In an experiment with ram lambs fed rations[12] containing 3.6-4.1 g Ca/kg DM and either 1.2, 2.4 or 4.8 g P/kg DM, apparent Ca digestibility was 17.2, 22.2 and 1.7, respectively [70]. Calcium retention was 5.6, 13.0 and –12.3% of intake, whereas dietary Ca:P ratio was ± 3.2:1, 1.7:1 and 0.8:1, respectively. Similar observations were made in an other experiment with 2 wethers fed a ration[13] containing 4.0-4.9 g Ca/kg but differing in P content [2]. The P contents were 0.7, 2.4, 3.9 or 4.0 g/kg or 2.4 and 3.8 g P/kg. The corresponding Ca:P ratios were 6.6:1, 2.1:1, 1.3:1 and 1:1 or 2.1 and 1.3, respectively. The 6.6:1 Ca:P ratio in the first sheep severely depressed unidirectional Ca absorption rate[14], whereas the second sheep also showed a significantly lower Ca absorption rate during P depletion[15].

3.3.6.3 Goats

Goats fed a ration consisting of *Leucaena leucocephala* containing a Ca:P ratio of 6:1 to 14:1 developed osteomalacia of the mandibles [134]. In another experiment, goats were fed a ration[16] containing 11.9 g Ca/kg DM, 0.6 g P/kg DM and 12.0 g Mg/kg DM with or without 1% NH_4Cl [111]. Severe crystalluria (struvite crystals) was observed in the group not supplemented with NH_4Cl. Retention of Ca and P was significantly increased in the NH_4Cl-treated group.

3.3.6.4 Conclusion

Both too high and too low Ca:P ratios may be detrimental to Ca metabolism. Especially a Ca:P ratio < 1:1 results in very poor Ca digestibility and retention. This may result in rickets or urolithiasis, mainly depending on the dietary Mg concentration [31;128]. Although it is often recommended to keep the dietary Ca:P ratio at 1.5:1 to 2:1 [128], there is only poor evidence to adopt this recommendation when both dietary Ca, P, Mg and vitamin D concentrations are adequate[20].

3.3.7 Interactions of calcium and fat

3.3.7.1 Cattle

When the ether extract of the ration[17] of lactating cattle was increased from 3 to 6% (DM) by adding ground raw soybeans to the concentrate, apparent Ca absorption increased (4 and 16%, respectively). However, when the ether extract of the ration was increased from 6 to 11% (DM) by adding blended hydrolyzed fat the apparent Ca absorption showed a slight decrease (24 vs 20%) [86]. Milk yield and fat production was not different between the groups.
In cows fed rations[18] with or without 1 kg of rapeseed oil infused into the rumen per day for 28 days, ionizable Ca concentration in ruminal fluid was lower in the oil-fed animals at

---

12 Maize cobs/maize starch/cerelose ration; extra P from monosodium phosphate.
13 Maize/molasses/maize flour/wheat straw/urea ration; extra P from Na dihydogen phosphate dihydrate.
14 From 0.2/h to 0.03/h.
15 From 121.4 µmol/h to 9.4 µmol/h.
16 Hay/concentrates ration.
17 Lucerne/concentrates/maize silage ration.
18 Maize silage/soybean meal/concentrate mix ration.

certain hours of the day [40]. However, the amount of Ca-soaps formed in the rumen was low. Dry matter intake including oil infusion was 16.4 and 17.5 kg/day for the non-supplemented and oil-fed groups, respectively.

In lactating cattle[19] fed either 2.5 or 5% additional animal-vegetable fat, overall apparent Ca absorption was not influenced by fat addition [96]. Diets were calculated to meet requirements and DMI was comparable between the groups (average 17.4 kg/day). As fatty acid intake was calculated to be 431, 819 and 1145 g/day for the non-supplemented, 2.5% and 5.0% ration, respectively, crude fat percentages in the DM of these rations must have been approximately 2.5%, 5% and 6.5% (DM), respectively.

In another experiment, plasma Ca concentrations were not influenced by increasing the dietary fat intake of lactating cows from 0.6 to 1.1 kg DM/day [116].

In steers fed rations[20] with or without added yellow grease (5% on DM basis) apparent Ca absorption was not influenced [136].

As discussed above, fats and oil as such may be added to the ration of dairy cattle. On the other hand, fatty acids can also be added to the ration as Ca soaps of long-chain fatty acids. Supplements consisting of saturated long-chain fatty acids (palmitate, stearate) usually contain 9-10% Ca [66a]. When Ca soaps of fatty acids are added to the ration at a level of 4% (DM) [66a], this equals an addition of as much as ± 4 g Ca/kg DM of ration. As most Ca soaps of fatty acids are more or less completely dissociated below pH 5 [115a], this means that the majority of Ca from these supplements will be available for absorption in the abomasum.

3.3.7.2 *Sheep*

In sheep fed rations consisting of grass hay or silage and supplemented with ± 500 g of either a low-fat or a high-fat concentrate[21] for 28 days, the apparent Ca absorption was slightly lower on the high-fat rations [114]. In similar experiments [49;113], the addition of 50 g soybean oil to the ration[22] of sheep or the infusion of 52 mL of maize oil into the rumen[23] did not influence plasma Ca concentrations. Although more Ca soaps were excreted in the faeces, the infusion of maize oil did not influence apparent Ca absorption. On the other hand, in sheep fed rations containing either 2 or 10% total lipids (DM basis)[24] apparent Ca absorption was increased in the high-fat group [32]. Contrarily, both apparent and true Ca absorption was decreased at the addition of 7.5% maize oil to the ration[25] of wether lambs [117].

3.3.7.3 *Goats*

In goats fed rations[26] containing either 0, 11, 22 or 33% crushed whole soybeans (crude fat contents of the rations being 2.7, 3.1, 4.4 and 5.2%, respectively) for 28 days, serum Ca concentrations were unaffected by treatment [64].

---

19 Lucerne hay(lage)/maize silage/concentrate ration; fat was added at the expense of maize starch and sugar.
20 Lucerne hay/grass hay/barley/molasses ration.
21 Extra fat from soybean oil; 8% oil replaced an isoenergetic amount of starch.
22 Hay/grass silage/concentrate ration; total DMI was assessed to be ± 1.5 kg/day
23 Grass/white clover ration; composition unknown.
24 Extra fat from maize oil.
25 Cottonseed hulls/lucerne meal/soybean meal/maize ration; fat content of the basal ration not given, but assessed to be ± 4% crude fat (as fed).
26 Hay/maize based rations.

3.3.7.4 *Conclusion*

In several cases, the experimental design was unsuitable to judge effects of fat or oil on Ca metabolism (e.g. plasma Ca concentrations are unsuitable as a parameter of Ca aborption). Moreover, as the reported effects of dietary fat content on Ca metabolism are different, no unequivocal conclusions can be drawn. However, in general the influence of dietary lipid additions up to 5-6% of DM on Ca metabolism seems to be minor.

3.4 Recycling

Although salivary Ca concentrations are low (0.09-0.9 mM in cows [99;103;115;125]; 0.24-0.40 mM in sheep [34;90]), due to the large salivary volume this route of Ca secretion is the main contribution to total Ca secretion into the gastrointestinal tract of ruminants [103]. No quantitative information is available on recycling of this Ca.

3.5 Excretion

Excretion of Ca in cattle, sheep [17;121] and goats [92] mainly occurs via the faeces. Urinary Ca excretion in ruminants is normally low (0.8% of dietary Ca intake (cows, [109])), but can be increased by feeding anion-rich rations (up to 11.6% of Ca intake [109]). In goats similarly low values were reported (0.2-1.2% of intake [111;134]), whereas in sheep both similar (1.7-5.5% of intake [16]) and higher values were reported (11.0% of intake [70]). More details on the influence of feeding anion-rich rations (negative dietary cation-anion balance, DCAB) are given in references [48;78;79;109;120].

4 CALCIUM REQUIREMENTS

The Ca requirements of adult animals are determined by the endogenous (inevitable) losses and the secretion into milk. In growing and pregnant animals Ca is also deposited in growing (foetal) tissues. The main contribution to endogenous faecal Ca losses is made by the amount secreted into saliva [66;103]. In early lactation, animals are in negative Ca balance. In later stages of the lactation they should be enabled to replenish the Ca stores in the bones [17] (see chapter 5).

4.1 Cattle

4.1.1 Dairy cattle

In all ruminant species, true Ca absorption is considerably influenced by Ca needs and Ca supply via the feed. An increasing amount of Ca in the feed results in downregulation of Ca absorption. In fact, values for true Ca absorption are only useful when the corresponding value for the intake/requirement (I/R) ratio is given. And this requirement, in turn, has to be assessed at a certain Ca intake and assuming a value for true Ca absorption. Therefore, the assumed value for true Ca absorption is the main source of disagreement between the different authors and authorities with respect to the Ca requirements [121].

Considering the I/R ratios applied in the majority of the experiments, most of them are too high to force the animals to maximize their Ca absorption rates. Therefore, the maximal value for true Ca absorption should be higher than usually assumed (30-50%, Table 2). This is in accordance with the observations of Van Leeuwen and De Visser [68], who fed lactating cows for 7-16 months a ration[27] containing 1.7 g Ca/kg DM. Apparent Ca absorption was up to 83.8%, and, therefore, true Ca absorption must have been even higher (not determined). The animals remained healthy, DMI and milk yield were as expected and blood Ca levels were in the normal range. No signs of Ca mobilization from bones, as measured with the help of bone biopsies and hydroxyproline concentrations in blood and urine, could be observed. The Ca content of the bones even increased during the experiment. Similar observations were made by Van de Braak et al. [13;15], who fed pregnant cows rations[28] containing 2.1-2.7 g Ca/kg DM. Bone turnover rates in cows fed these low Ca levels during the end of gestation were higher than those of cows fed 6 times higher Ca concentrations during this period. However, DMI and milk yield and blood PTH levels were comparable between the groups. No milk fever occurred in the low-Ca group.
The AFRC estimate of 68% for true Ca absorption can, therefore, be considered to be safe and is adopted for the calculations of Ca requirements. Although rejected by others as being (much) too high [45;85], the 68% estimate for true absorption can even be considered to contain a safety margin regarding the very high value mentioned for apparent absorption.

In dairy cows, several assessments have been made regarding total endogenous Ca loss, Ca accretion in growing tissues and Ca accretion in the conceptus. These assessments are given in Table 2.

---

[27] Wheat straw/potato/concentrates ration.
[28] Wheat straw/concentrates ration; total Ca intake 11-13 g/day during the last weeks of gestation; DM content of the ration assumed to be 88%.

Table 2 Assessments of factors for factorial estimation of Ca requirements (both BW and DMI in kg)

Ref.		Remark
	Cattle	
	Endogenous loss	
AFRC [4]	(in g/day) 0.0079xBW + 0.66 x kg DMI – 0.74	
NRC [84;85]	0.0154 g/kg BW	Maintenance, dry and beef cattle
	0.031 g/kg BW	Lactating cattle
DLG/GfE[45]	1 g/kg DMI	
Challa & Braithwaite [23]	7.46 mg/kg BW [b]	Growing calves
	Ca accretion in growing tissues (g/kg growth)	
A(F)RC [4;85]	9.83 x (expected adult BW)$^{0.22}$ x (current BW)$^{-0.22}$	
DLG/GfE [45]	14.3	
INRA [51]	10-15	
NRC [84]	7.1 g/100 protein gain	
	Gestation (g/day)	
A(F)RC [4;9][a]	$10^{(5.19 - (5.715 \times e(-0.00303 \times d)))}$	40-kg calf at birth
House&Bell /NRC [58;85][a]	$0.02456 \times e^{(0.05581-0.00007 \times d)d} - 0.02456 \times e^{((0.05581-0.00007(d-1))(d-1)}$	
DLG/GfE [45]	3.5 (6-4 wk a.p.) or 5.0 (3-0 wk a.p.)	
NRC [84]	13.7 g/kg foetal weight	Last 3 months of gestation
	Small ruminants	
	Endogenous loss	
A(F)RC [4;5]	(in g/day) 0.228 + 0.623 x kg DMI	Sheep,goat
DLG/GfE [10]	1 g/kg DMI	Goat
Braithwaite [16]	17.1-41.0 mg/kg BW	Depending on physiological state
	Ca accretion in growing tissues (g/kg growth)	
AFRC [4]	6.75 x (expected adult BW)$^{0.28}$ x (current BW)$^{-0.28}$	Sheep
AFRC/INRA/ Meschy[4;5;74; 75]	9.83 x (expected adult BW)$^{0.22}$ x (current BW)$^{-0.22}$	Goat
DLG/GfE [10]	11.5 (milk-fed kids) or 10.0 (ruminating goats)	Goat
INRA [51]	Some less than 10-15	Sheep
Günther/Pfeffer [52;91]	10	Sheep
	Gestation (g/day)[a]	
ARC [9]	$10^{(2.499-(7.406 \times e(-0.01535 \times d)))}$	Sheep, 4 kg lamb singleton
DLG/GfE [10]	0.8 (110-120 d) – 3.6 (>141 d)	Goat

[a] d = day of gestation; [b] at a P level 0f 3.3 g/kg DM

In this report, for calculation of Ca requirements the A(F)RC equations are used, because of the most clear and extensive evidence. However, for Ca accretion during gestation the equation of House & Bell [58] is adopted.

Although in the AFRC equation for endogenous Ca loss the rationale of the partial dependence of endogenous Ca loss on BW is not clear, the contribution of BW is only slightly more than 1% of that of DMI. Regarding the reported Ca concentrations in saliva, endogenous Ca loss per kg DMI may be even lower than those calculated by different authorities (Table 3).

Table 3 Bovine endogenous Ca loss expressed in g/kg DMI at varying DMI as calculated by the equations of NRC, AFRC and DGL/GfE (BW = 650 kg)

DMI (kg)	NRC [85]	AFRC [4]	DLG/GfE [45]
	Endogenous Ca loss (g/kg DMI)		
10	1 (dry cattle)	1.1	1
18.5	1.1 (lactating cattle)	0.9	1
27	0.7 (lactating cattle)	0.8	1

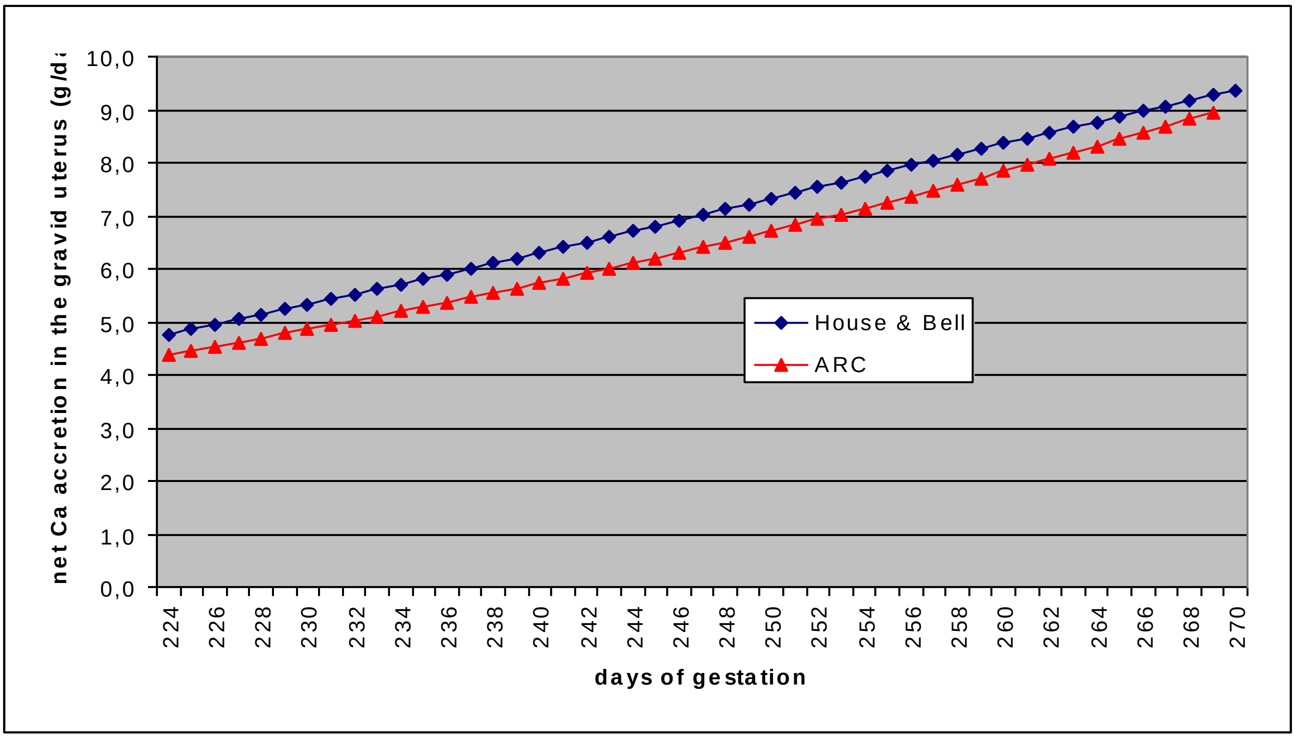
As demonstrated in Table 4, for usual DMI rates most authorities calculate the endogenous Ca loss expressed per kg DMI to be 0.7-1.1 g Ca/kg DMI. However, salivary Ca secretion is the major contribution to endogenous Ca loss. In the experiment of Rogers and Van 't Klooster [103] salivary Ca concentration was shown to be 0.5 mM (= 20 mg/L), whereas saliva flow was demonstrated to be 15.2 L/kg DMI at different types of rations[29]. Therefore, the salivary Ca secretion per kg DMI in that experiment was 15.2 x 20 = ± 300 mg Ca/kg DMI. For the total gastrointestinal secretions this value may be slightly higher (e.g. ± 0.35 g/kg DMI). This is a much lower value than assumed by most authorities. If the quality of the ingested feed and/or the salivary Ca concentration [99] is lower, this difference will be even larger. However, as these effects cannot be sufficiently quantified, the AFRC equation will be used for calculation of endogenous Ca losses.

For Ca accretion in growing tissues, the AFRC equation is the only one quantifying the dependence of Ca need to age.
The outcomes of the equations of the ARC [9] ($10^{(5.19-(5.715 \text{ x } e(-0.00303 \text{ x days of gestation})))}$ x 1.1 (factor 1.1 used for adaptation to 44 instead of 40-kg calf)) and House and Bell [58] ($0.02456 \text{ x } e^{(0.05581-0.00007 \text{ x } d)d} - 0.02456 \text{ x } e^{((0.05581-0.00007(d-1))(d-1)}$) for Ca accretion in the pregnant uterus are largely similar. However, close examination of both data sets reveals some differences. The ARC data on Ca accretion in the fetus originate from the experiment of Ellenberger (1950) [38]. In this experiment, the mineral content of 24 Holstein fetuses was investigated from 135-267 days of gestation. In 1993, House and Bell carried out the same procedure with 18 Holstein calves between 190 and 270 days of gestation. In none of these experiments the actual birth weight was determined, as all calves were slaughtered at least 10 days before the expected calving date. However, in the House and Bell experiment nearly always the BW of the fetuses was beyond those of the fetuses in the Ellenberger experiment[30]. Even if the ARC Ca accretion data (designed for a 40-kg calf) are multiplied by 1.1 to obtain values for a 44-kg calf at birth [120], during most of the gestation period the ARC Ca accretion data are consistently below those of House and Bell (Figure 1). This difference might originate from an increase in the relative contribution of the skeleton to the birth weight of Holstein calves as caused by nearly half a century of breeding. Finally, in the House and Bell experiment both the fetus and non-foetal conceptus (foetal fluids, foetal membranes, uterine wall etc.) were collected and analyzed. The original ARC data from Ellenberger only consist of fetus mineral data. To calculate data for the total pregnant uterus, the ARC has used data for the non-foetal conceptus from another experiment. Therefore, it is decided to use the equation of House and Bell for Ca accretion in Holstein calves during gestation, as this equation might be the most reliable and the most applicable to modern cattle. Similar remarks apply to the experiment of Ferrell et al. [41], who analyzed the mineral composition of 81 bovine fetuses and adnexa during gestation. This experiment employed mixed breed beef heifers[31] with a low BW (332 kg). Daily Ca accretion values in the gravid uterus were approximately half those found in Holstein cows. Therefore, these results were considered not to be applicable to Ca accretion in Holstein fetuses.

---

29 Hay/concentrates or grass rations.
30 Values were only depicted in a graph.
31 Angus, Hereford and Red Poll crossbred heifers were mated to 5 half-sibling Brown Swiss bulls.

Figure 1 Calcium accretion from 224 to 270 days of gestation as calculated using the equations of House and Bell [58] and the ARC [9]



Bovine colostrum contains approximately 2.0 g Ca/kg [98], whereas the Ca content of mature milk is assessed to be (g/kg) 1.03 [43], 1.20 (1.00-1.40) [3;63], 1.20 [4;68], 1.25 [45], 1.26 [69]. The mean of these values is 1.20 g/kg, which is used to calculate Ca requirements. This value is in accordance with the mean value of 1.20 g/kg which is found in milk from Dutch dairy cows (NIZO Food Research, Ede, The Netherlands). Values of 1.4 [71], 1.84 [62] or 1.95 [102] are considered to be abnormally high values, not applicable under Dutch circumstances. Milk Ca content is hardly influenced by changes in dietary Ca concentrations [68].

4.1.2 Beef cattle

No separate calculations need to be made for the Ca requirements of beef cattle. Estimates of the different factors resemble those made for dairy cattle [84], whereas the assumed value for true absorption overrules the other differences. Only for small breeds the Ca accretion data during gestation from Ferrell et al. [41] might be used.

4.2 Sheep

Similar to cattle, for sheep and goats also the A(F)RC equations are adopted. For Ca accretion in growing tissues of sheep the AFRC equation is
$6.75 \times (\text{expected adult BW})^{0.28} \times (\text{current BW})^{-0.28}$ [4].
For endogenous loss values in sheep and goats the same remark applies as for cattle.
The values for true Ca absorption as given in Table 2 are mostly obtained employing Ca levels well beyond requirements and, therefore, may not have forced the animals to maximize their Ca absorption rates. As soon as the Ca content of the ration approaches requirement levels, true Ca absorption increases to values > 55%. As it is not clear as to what extent Ca absorption was really maximal, it seems defendable to adopt the 68% estimate of the AFRC [4] for small ruminants either.

The ARC [9] Ca accretion values during gestation are derived from a comparative slaughter experiment employing 51 Merino ewes carrying a single fetus [67]. The ewes were slaughtered from < 30 days to 145 days of gestation. During twin pregnancy, the outcome of the equation mentioned in Table 3 should be multiplied by a factor of 1.975 (total birth weight of twin lambs 7,9 kg [5]).

Sheep colostrum is reported to contain 1.0-3.3 g Ca/kg [37], whereas mature milk contains 1.6 [4;62], 1.64 [17], 1.8 [83] or 1.9 g Ca/kg [51]. Thus, sheep milk is assessed to contain on average 1.7 g Ca/kg. This value is used for calculation of Ca requirements. Massese sheep milk is reported to contain 2.3 g Ca/kg [21], which is considered not to be applicable to Dutch sheep.

4.3 Goats

Besides one report dealing with true Ca absorption in goats [59] no separate information is available on endogenous Ca loss or Ca accretion in the pregnant uterus. Therefore, for these factors the values assumed for sheep are used. For Ca accretion in growing tissues of goatsthe AFRC equation is used (9.83 x (expected adult BW)$^{0.22}$ x (current BW)$^{-0.22}$) [5].

Mature goat milk contains (g Ca/kg) 0.9 [89], 1.2 [91], 1.21 (Saanen and related breeds) [80], 1.25 [51], 1.26 [74;75], 1.3 [5], 1.38 [82] and 1.40 [71]. On average, these values for mature milk are 1.24 mg Ca/kg. A (rounded) value of 1.2 is, therefore, used for calculation of Ca requirements. Two high values (1.80 [102] and 1.94 [62]) were considered abberating high values not applicable to Dutch dairy goats.

4.4 Conclusion

The following equation can be used to calculate the required Ca concentration of ruminant rations:

$$C = \frac{100 \text{ x } (a + (\text{kg milk x } b) + c + d)}{A_{Ca} \text{ x DMI}}$$

in which
- C = required dietary Ca concentration (g/kg DM)
- A_{Ca} = true Ca absorption (%) (assumed to be 68%)
- DMI = dry matter intake (kg/day)
- a = endogenous loss (g/day; using the AFRC equation given in Table 3)
- b = 1.2 g/kg milk for cattle, 1.7 g/kg milk for sheep and 1.2 g/kg milk for goats
- c = Ca content of growing tissues (g Ca/kg growth; using the AFRC equation given in Table 3)
- d = amount of Ca needed for pregnancy (g/day; using the House and Bell equation for cattle and the ARC equation for small ruminants given in Table 3)

5 ALLOWANCES

Using the above equation (see paragraph 4.4), some examples of minimal dietary requirements and allowances have been calculated (Table 4). These allowances do not include a safety margin, as this is supposed to be included in the absorption coefficient (see paragraph 3.4). Moreover, transient Ca deficiencies can be compensated for in later stages of the lactation cycle.

Table 4 Examples of calculated Ca requirements and allowances.

Category	**DMI**	**Requirement**	**Allowance**	
	kg	**g/day**	**g/day**	**g/kg DM**
Growing female cattle				
4 months, 850 g growth/day, 130 kg BW	3.9	22	22	5.6
9 months, 700 g growth/day, 250 kg BW	5.6	20	20	3.5
16 months, 625 g growth/day, 400 kg BW	7.3	21	21	2.8
Dairy cattle (650 kg BW)				
cow, dry, pregnant (8-3 wk a.p.)	11.5	27	27	2.4
cow, dry, pregnant (3-0 wk a.p.)	11	31	31	2.8
cow, lactating, 20 kg of milk	18.5	60	60	3.3
cow, lactating, 40 kg of milk	23.5	101	101	4.3
Beef cattle, intermediate type [a]				
1000 g growth/day, 100 kg BW	3	28	28	9.2
1200 g growth/day, 250 kg BW	6	32	32	5.3
1100 g growth/day, 500 kg BW	9	32	32	3.6
Veal calves [a]				
1150 g growth/day, 150 kg BW	4.5	31	31	6.8
1450 g growth/day, 275 kg BW	7	36	36	5.2
Sheep (75 kg BW)				
growing lamb, 0.3 kg growth/day, 40 kg BW [a]	1.6	5,8	5,8	3.6
sheep, pregnant, last trimester	1.9	3,8	3,8	2,0
sheep, lactating, 3 kg of milk, nursing 2 lambs	2.6	10	10	3.9
Goats (70 kg BW)				
goat, pregnant, last trimester	1.7	2,8	2,8	1.6
goat, lactating, 4 kg of milk	3.2	10	10	3.2

[a] The expected mature BW of steers and rams was assumed to be 1100 and 115 kg, respectively. Changes in assumed mature BW result in relatively small changes in Ca requirements.

Using the AFRC equation for the Ca content in growing tissues, the mature body of dairy cattle (650 kg BW) will contain 9.83 g Ca/kg BW [4]. This means the body of a 650-kg cow contains ± 6.4 kg Ca. Thus, a Ca depletion of 10-20% of body stores, as can occur in early lactation [121], equals 640-1280 g of absorbed Ca. As depletion of body stores mainly occurs during late pregnancy and during lactation [121], body stores will have to be repeleted during late lactation and during the first part of the dry period. If 640-1280 g Ca has to be repleted in 4 months, this equals 5-10 g of absorbed Ca/day during this period. For a cow producing 20 kg milk and with a DMI of 18.5 kg, this means an extra requirement of 0.3-0.5 g Ca/kg DM. Therefore, allowances for late lactation may be marginal for dairy cattle. However, it is not clear as to what extent an increase of the true Ca absorption (5-10% would suffice) will occur in response to this extra Ca need.

6 CRITERIA TO JUDGE CALCIUM STATUS

6.1 Possible indicators of Ca status

Diagnosis of acute Ca-response disorders, such as milk fever (hypocalcaemia, parturient paresis), is principally made on the basis of the clinical picture (see chapter 7). Subsequent determination of the serum Ca concentration (sample taken before the start of treatment) will confirm the diagnosis. Values below 1.5 mM in periparturient dairy cows, ewes and goats are indicative for milk fever [14;28;77]. During the course of milk fever, plasma Ca may even fall to values around 1.0 mM [121]; for healthy ruminants normal values range from 2.0-2.5 mM [28;121], 2.9-3.2 mM (sheep) or 2.2-2.9 (goat; B.G.F. Kessels, Utrecht University, personal communication). Values > 3 mM are considered toxic for cattle [95;121]. In animals that died from milk fever vitreous humor from the eyeball can be used to confirm the diagnosis, as the Ca concentration in this fluid reasonably correlates with the plasma Ca concentration. Values below 0.9 mM indicate for milk fever [95;121].

In cases of chronic Ca deficiency serum Ca levels can be below the normal range [121], but this is not always the case [29]. Determination of Ca concentrations in hair is not suitable for the prognosis of Ca-responsive disorders [100]. If the Ca content of the ration is too low, extra Ca should be supplied via the feed. However, because of the capability of ruminants to adapt their Ca absorption to a wide range of dietary Ca concentrations (see chapter 4) and because of the importance of vitamin D, P and Mg supply for proper Ca absorption (see chapter 2), determination of solely a normal Ca content of the ration is not always sufficient to judge Ca supply. Finally, assessment of bone quality cannot be used as a sole parameter of chronic Ca deficiency, because of the many other factors influencing bone mineralization [121].

6.2 Conclusion

Under practical circumstances, mainly in acute cases of Ca deficiency, determination of serum or plasma Ca will be a suitable parameter of Ca status. Judgement of long-term Ca supply requires determination of Ca, P, Mg (as well as vitamin D) supply.

7 DEFICIENCY

Calcium deficiency in ruminants can be either acute or chronic. Acute Ca deficiency usually occurs in dams around parturition, although it can sometimes also occur during lactation. Acute Ca deficiency occurs mainly in older cows, as they usually produce more milk and are less able to increase their Ca absorption and mobilization than younger ones. The clinical picture of the resulting hypocalcaemia is known as milk fever, parturient paresis, melkziekte (Dutch) or festliegen (German).
A cow suffering from milk fever is weak, recumbent and/or unable to rise. She is found lying on her sternum with the head turned to the flank. The eyes are dull and the pupils dilated. The extremities are cool. The cow usually does not eat. The pulse rate is normal or elevated and the temperature is normal. The digestive tract is atonic and the anus relaxed. When the cow is still calving, birth of the calf is delayed. The condition can end up in coma and death. Untimely therapy can result in a downer cow.
In ewes, the clinical picture is somewhat different. The condition can occur between 6 weeks before to 10 weeks after lambing. Highly conditioned ewes are more prone than lean ones. The onset is usually sudden, and up to 30% of the flock may be involved in the outbreak. Although the etiology is not fully understood, abrupt changes in feed (intake), weather or other circumstances (transportation) are usually involved. Affected ewes are slight hyperexcitability, muscle tremors and a stilted gait. Later on, dullness, lying down with the hindlegs stretched backward, tympany and regurgitation, staring eyes and shallow respiration dominate. Finally, coma and death may ensue.
In animals in advanced gestation, a condition called transport tetany may occur. Some form of Ca deficiency is thought to be involved. Symptoms during or after transport may be restlessness, hyperexcitability, paralysis and a staggering gait. Later on, the picture more or less resembles that of milk fever in cows. Pulse rate may increase to 100-120 and respiration is rapid and labored. Congestion of the mucous membranes and extreme thirst may develop. Unless treatment is inserted, animals may die within a few days [1;121].

Today, chronic Ca deficiency in ruminants is rare. Poor appetite and growth and, in the longer term, bone mineralization disorders can be observed. In young animals, malformations of teeth, jaws and legs, enlarged and painful joints and a stiff gait can be observed. This condition is called rickets and can develop within 4 weeks from birth. This can i.a. occur when the ration contains a Ca:P ratio < 1:1 [31;105]. In mature animals, painful joints, a stiff gait and fractures of the bones can be the symptoms of the condition called osteomalacia [121].

7.1 Direct measures in deficiency cases

7.1.1 Direct continuous supplementation

To supply a sufficient amount of Ca via the gastrointestinal tract, 400 g Ca phosphate or 250 g $CaCO_3$ should be given orally as soon as the swallowing reflex has returned. The cow should be given palatable roughage and some Ca-containing feeds (concentrates, sugar beet pulp) [122].

7.1.2 Direct discontinuous supplementation

Recovery is usually very rapid and remarkable after intravenous application of 7-10 g Ca (cow)[32] under careful auscultation of the pulse rate. Non-responding animals should be re-treated after 8-12 hours. Care must be taken to avoid tissue irritation. For sheep and goats, the dose is ¼ of the dose mentioned for the cow. Affected sheep should be handled with care to prevent deaths due to heart failure [1;121].

7.1.3 Slow release oral supplementation

Assuming a good-quality ration, containing adequate amounts of Ca, P, Mg and vitamin D is supplied, no special preparates for slow oral supplementation are necessary.

[32] E.g. a soltution in a 450 mL-flask containing 7.2 g Ca from Ca borogluconate and 2 g Mg from $MgCl_2$.

8 TOXICITY

Because of the extensive capacity of ruminants to decrease Ca uptake from the gastrointestinal tract, Ca itself can be considered hardly toxic. Only when the Ca uptake regulation is overruled by massive doses of vitamin D_3 a life-threatening tissue calcification due to hypercalcaemia can occur. Consumption of the plant *Solanum malacoxylon* (containing vitamin D analogues) can cause tissue calcification. However, as this plant does not occur in the Netherlands, it is not of practical importance [56;121;131]. Hypercalcaemia can also be secondary to a P deficiency [121]. Finally, long-term excessive Ca concentrations in the feed can be detrimental to the uptake of other elements, such as P, Cu and Zn and clinical symptoms can originate from deficiencies of these elements [53;60;76]. If the Ca:P ratio is kept constant on 2:1[33], the effects of high Ca intakes (23.4 g/kg of ration) on bovine Cu metabolism are less severe [60].

8.1 Direct measures in toxicity cases

Normalization of the mineral contents of the feed is the main measure to be taken in case of Ca excess. This can include removal of Ca and/or vitamin D supplements and increasing the P content of the ration, e.g. by feeding more grains [121].

33 By adding tricalcium phosphate instead of calcium carbonate to the maize silage/hay/grains ration.

9 PREVENTION OF DEFICIENCY

9.1 Short-term prevention strategies

To prevent Ca deficiency, adequate Ca, P, Mg and vitamin D supply via the ration should be ensured [121]. Special attention should be paid to the supply of these nutrients in the ration of young, growing animals and dry cows (transition to the lactation ration). Although feeding rations low in Ca to dry cows in order to increase Ca absorption rates is theoretically right, in practice it is not possible to design dry cow rations both supplying all nutrients needed, being cost-effective and sufficiently low in Ca [15]. Possibly, feeding anion-rich rations during the last weeks of the dry period can give a small contribution to increasing Ca absorption just after parturition [120;127]. To maximize feed intake around parturition, care should be taken not to overfeed the cows during the last stage of the preceding lactation and the subsequent dry period. During the last weeks before parturition, cows should be adapted to the roughage fed to the lactating cows [120].
In sheep, risk factors for the occurrence of Ca deficiency or transport tetany should be avoided. Loading of pregnant animals for shipment should be accomplished with a minimum of excitement (see chapter 7).

9.2 Long-term prevention strategies

Liming of soils has only a limited effect on Ca content of forages and, therefore, cannot be relied on to ensure an adequate Ca supply to ruminants [28]. On the other hand, liming can be very useful to correct soil pH and to stimulate grass growth [27]. If the Ca content of the forage is to be increased, application of a grass-white clover mixture can be considered. White clover contains more Ca than adjacent grasses (e.g. 24 vs. 6 g CaO/kg DM for white clover and grasses, respectively) [19]. White clover is less suitable for peat soils, as the soil pH on these soils is often too low to enable the white clover to develop [27].

Table 5 Inventory of Ca allowances for cattle, sheep and goats as used in some foreign countries (g/kg DM)

		Allowance				
Country	**Ref.**	**Cattle**	**Ref.**	**Sheep**	**Ref.**	**Goat**
GB	[4]	Dairy cattle Gestation: 1.8-3.6 Lactation: 2.2-5.3 **Beef cattle**: 1.0-11.4	[4]	Growth: 1.4-7.0 Gestation: 1.3-4.3 Lactation: 2.3-4.9	[5]	Growth: 7.2 (20-kg male) 4.5 (30-kg female) Gestation: 3.1 Early lactation: 5.2
USA[b]	[84; 85]	**Dairy cattle**[a] Gestation: 4.4-4.8 Lactation 5.3-6.7 **Beef cattle** Growth: 1.7-7.1 Gestation: 1.9-4.8 Lactation: 1.5-7.0	[83]	Growth: 3.5-8.2 Gestation: 2.5-4.0 Lactation: 3.0-3.9 Rearing: 3.0-5.3	[82]	Gestation 3.5[c] Lactation 3.8[d]
Germany	[45]	Dairy cattle Growth: 150 - 550 kg BW: 6.6-3.7 (500 g growth/d) 8.6-4.2 (800 g growth/d) Gestation: 3.2 Lactation: 3.2-6.9 (5-50 kg of milk/d)		?	[10]	Growth: 2.3-6.3 Gestation: < 4 mo: 2.6 > 4 mo: 4.4 Lactation: 2.7-4.4 (1-6 kg of milk)

		Allowance				
Country	**Ref.**	**Cattle**	**Ref.**	**Sheep**	**Ref.**	**Goat**
France	[51]	**Dairy cattle** Gestation: 3.6-4.2 Lactation: 6.5-7.2 (20 kg of milk) 7.0-7.3 (40 kg of milk) **Beef cattle** Growth: 100-200 kg BW 5.5-6.0 (700 g growth/d) 9.0-10.0 (1400 g growth/d) 200-400 kg BW 5.5-6.5 (700 g growth/d) 8.0-9.5 (1400 g growth/d) 400-600 kg BW 5.0-5.5 (700 g growth/d) 7.5-8.0 (1400 g growth/d)	[51]	Growth: 5.0-6.0 (< 200 g growth/d) 7.0-9.0 (> 200 g growth/d) Gestation, early lactation: 7.0-8.0	[51]	Lactation: 6.0-7.0 (< 3 kg/d) 7.5-8.5 (> 3 kg/d)

[a] Allowances for cattle are expressed in ppm feed as fed; as DM contents of the feeds are not given, allowances cannot be calculated in ppm (DM)
[b] minimum requirements
[c] assuming 1.7 kg DMI
[d] assuming 3.2 kg DMI and 4 kg milk yield/d

LITERATURE

1 Parturient paresis in cows / Parturient paresis in ewes / Transport tetany in ruminants. In: Fraser CMeal (ed.), The Merck Veterinary Manual, 6 ed. Rahway, USA: Merck & Co., Inc.; 1986: 435-445.

2 Abdel-Hafeez HM, Mañas-Almendros M, Ross R, Care AD, Marshall DH. Effects of dietary phosphorus and calcium on the intestinal absorption of Ca in sheep. British Journal of Nutrition 1982; 47: 69-77.

3 Adrian J. Les éléments minéraux. In: Adrian J (ed.), Valeur alimentaire du lait. Paris: La maison rustique; 1973.

4 AFRC. AFRC Technical Committee on Responses to Nutrients, Report 6. A reappraisal of the calcium and phosphorus requirements of sheep and cattle. Nutrition Abstracts and Reviews. Series B, Livestock Feeds and Feeding. 1991; 61: 573-612.

5 AFRC. AFRC Technical committee on responses to nutrients. Report No. 10. The nutrition of goats. Nutrition Abstracts and Reviews, B 1997; 67: 765-830.

6 Agrawal BL, Talapatra SK. Biological availability of calcium in feedstuffs. V. Availability of calcium from mineral salts. Indian Journal of Animal Science 1971; 41: 11-14.

7 Allen VG, Fontenot JP, Rahnema SH. Influence of aluminum-citrate and citric acid on tissue mineral composition. Journal of Animal Science 1991; 69: 792-800.

8 Allen VG, Horn FP, Fontenot JP. Influence of ingestion of aluminium, citric acid and soil on mineral metabolism of lactating beef cows. Journal of Animal Science 1986; 62: 1396-1403.

9 ARC. Nutrient requirements of ruminant livestock. London: 1980.

10 Ausschuss für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie. Recommendations for the supply of energy and nutrients to goats. Frankfurt am Main: DLG Verlag; 2003.

11 Beardsworth LJ, Beardsworth PM, Care AD. The effect of ruminal phosphate concentration on the absorption of calcium, phosphorus and magnesium from the reticulo-rumen of the sheep. British Journal of Nutrition 1989; 61: 715-723.

12 Beitz DC, Burkhart DJ, Jacobson NL. Effects of calcium to phosphorus ratio in the diet of dairy cows on incidence of parturient paresis. Journal of Dairy Science 1974; 57: 49-55.

13 Braak-AE vd, Klooster Av, Hal-van-Gestel-JC-van, Malestein A. Influence of stage of lactation and calcium level of the ration on mobilisation rate of calcium and excretion of hydroxyproline in urine in dairy cows. Studies with Na_2 EDTA infusions in monozygotic twins. Zentralblatt für Veterinärmedizin [A] 1984; 31: 725-739.

14 Braak AEvd. Prepartal feeding of dairy cows and the rate of calcium mobilization at parturition. Calcium intake, feed intake, and magnesium supply. 1986. Thesis.

15 Braak AEvd, Klooster ATv', Malestein A, Faber JAJ. Effects of low and high calcium intake prepartum on calcium mobilization rate around parturition in dairy cows. Veterinary Quarterly 1986; 8: 12-23.

16 Braithwaite GD. Calcium and phosphorus requirements of the ewe during pregnancy and lactation. British Journal of Nutrition 1983; 50: 711-722.

17 Braithwaite GD, Glascock RF, Riazuddin S. Calcium metabolism in lactating ewes. British Journal of Nutrition 1969; 23: 827.

18 Braithwaite GD, Glascock RF, Riazuddin S. Calcium metabolism in pregnant ewes. British Journal of Nutrition 1970; 24: 661-670.

19 Bruggink EGJ. Enkele gegevens betreffende de macro- en microelementen in grassen, klavers en kruiden op dezelfde standplaats. Landbouwkundig Tijdschrift 1960; 72: 635-643.

20 Carson RL, Caudle AB, Riddle HE. The relationship between narrow calcium-phosphorus ratio and reproductive problems in a dairy herd: a case report. Theriogenology 1978; 9: 505-507.

21 Casoli C, Duranti E, Morbidini L, Panella F, Vizioli V. Quantitative and compositional variations of Massese sheep milk by parity and stage of lactation. Small Ruminant Research 1989; 2: 47-62.

22 Centraal Veevoeder Bureau. Tabellenboek Veevoeding. 2004.

23 Challa J, Braithwaite GD. Phosphorus and calcium metabolism in growing calves with special emphasis on. Journal of Agricultural Science, UK 1988.

24 Chandler PT, Cragle RG. Gastrointestinal sites of absorption and endogenous secretion of calcium and phosphorus in dairy calves. Proceedigns of the Society for Experimental Biology and Medicine 1962; 111: 431-434.

25 Chester-Jones H, Fontenot JP, Veit HP. Physiological and pathological effects of feeding high levels of magnesium to steers. Journal of Animal Science 1990; 68: 4400-4413.

26 Chrisp JS, Sykes AR, Grace ND. Kinetic aspects of calcium metabolism in lactating sheep offerred herbage with different Ca concentrations and the effect of protein supplementation. British Journal of Nutrition 1989; 61: 45-58.

27 Commissie Bemesting Grasland en Voedergewassen. Adviesbasis bemesting grasland en voedergewassen. Lelystad: 2002.

28 Commissie Onderzoek Minerale Voeding. Handleiding mineralenonderzoek bij rundvee in de praktijk. 1996.

29 Coppock CE, Everett RW, Belyea RL. Effect of low calcium or low phosphorus diets on free choice consumption of dicalcium phosphate by lactating dairy cows. Journal of Dairy Science 1976; 59: 571-580.

30 Deluca HF. Vitamin D: the vitamin and the hormone. Federation Proceedings 1974; 33: 2211-2219.

31 Dercksen DP, Berger JM. Rachitisachtige botveranderingen bij met kunstmelk-voeder voor kalveren. Rachitic bone lesions in kids reared on a milk substitute for calves. Tijdschrift voor Diergeneeskunde 1992; 117: 629-631.

32 Devendra C, Lewis D. The interaction between dietary lipids and fibre in the sheep. 2. Animal Production 1974.

33 Dickie CW, Hamann MH, Carroll WD, Chow F. Oxalate (*Rumex venosus*) poisoning in cattle. Journal of the American Veterinary Medical Association 1978; 173: 73-74.

34 Dua K, Care AD. Secretion of magnesium and calcium in the total saliva of sheep and its relevance ot hypomagnesaemia. Veterinary Journal 1998; 156: 217-221.

35 Dua K, Care AD. The role of phosphate on the rates of mineral absorption from the forestomach of sheep. Veterinary Journal 1999; 157: 51-55.

36 Dua K, Leonhard S, Martens H, Abbas SK, Care AD. Effects of parathyroid hormone and parathyroid hormone-related protein on the rates of absorption of magnesium, calcium, sodium, potassium and phosphate ions from the reticulo-rumen of sheep. Experimental Physiology 1994; 79: 401-408.

37 Economides S. Calcium metabolism in dairy sheep. Journal of Agricultural Science 1998; 102: 601-608.

38 Ellenberger HB, Newlander JA, Jones CH. Composition of the bodies of dairy cattle. University of Vermont Agricultural Experiment Station Bulletin 1950; 558.

39 Emanovic D, Timet D, Herak M, Mitin V, Kraljevic P, Stojevic Z, Milinkovic. Interactions of magnesium and sodium ions in the absorption of calcium ions from the bovine stomach. Veterinarski Arhiv 1997; 67: 1-10.

40 Ferlay A, Doreau M. Influence of method of administration of rapeseed oil in dairy cows. 2. Journal of Dairy Science 1995; 78: 2239-2246.

41 Ferrell CL, Laster DB, Prior RL. Mineral accretion during prenatal growth of cattle. Journal of Animal Science 1982; 54: 618-624.

42 Fredeen AH. Effect of maturity of alfalfa (Medicago sativa) at harvest on calcium absorption in goats. Canadian Journal of Animal Science 1989; 69: 365-371.

43 Gaines TP, West JW, McAllister JF. Determination of calcium and phosphorus in milk. Journal of the Science of Food and Agriculture 1990; 51: 207-213.

44 Gardner RW, Park RL. Effects of prepartum energy intake and calcium to phosphorus ratios on lactation response and parturient paresis. Journal of Dairy Science 1973; 56: 385-389.

45 GfE. Spurenelemente. In: Staudaucher W (ed.), Empfehlungen zur Energie- und Nährstoffversorgung der Milchkühe und Aufzuchtrinder. Frankfurt am Main: DLG Verlag; 2001: 89-104.

46 Giduck SA, Fontenot JP. Utilization of magnesium and other macrominerals in sheep supplemented with different readily-fermentable carbohydrates. Journal of Animal Science 1987; 65: 1667.

47 Goetsch AL, Owens FN. Effects of calcium sources and level on site of digestion and calcium levels in the digestive tract of cattle fed high-concentrate diets. Journal of Animal Science 1985; 61: 995-1003.

48 Goff JP, H, Horst RL. Role of acid-base physiology on the pathogenesis of parturient hypocalcaemia (milk feve) - the DCAD theory in principal and practice. Acta Veterinaria Scandinavica 2003; Suppl. 97: 51-56.

49 Grace ND, Body DR. Dietary lipid and the absorption of Mg and Ca: effect of corn oil infused via the rumen on the absorption of Mg and Ca in sheep fed white clover. New Zealand Journal of Agricultural Research 1979; 22: 405-410.

50 Grace ND, Ulyatt MJ, MacRae JC. Quantitative digestion of fresh herbage by sheep. III. The movement of Mg, Ca, P, K, and Na in the digestive tract. Journal of Agricultural Science 1974; 82: 321.

51 Gueguen L, Lamand M, Meschy F. Nutrition minérale. In: Jarrige R (ed.), Alimentation des bovins, ovins & caprins. Paris: INRA; 1988: 98-111.

52 Günther K, Tölle-Nolting J, Yücelen Y. Untersuchungen zum Mineralstoffumsatz und -ansatz bei kleinen Wiederkäuern in der Wachstumsphase 1. Mitteilung Eunfluß de Ca- und P-Konzentration im Futter auf Wachstum, Skelettentwicklung und Ossifikation. Mineral metabolism and deposition in small ruminants during growth. 1 Communication. Zeitschrift fur Tierphysiologie, Tierernahrung und Futtermittelkunde 1975; 35: 76-92.

53 Haaranen S. Some observations on the zinc requirement of cattle for the prevention of itch and hair licking at different calcium levels in the feed. Nordisk Veterinaermedicin 1963; 15: 536-542.

54 Hansard SL, Crowder HM, Lyke WA. The biological availability of calcium in feeds for cattle. Journal of Animal Science 1957; 16: 437-443.

55 Hanyu H, Uzuka Y, Otani M, Tanabe S, Sarashina T. Effect of oral administration of a calcium chloride-oil emulsion on serum. Journal of Veterinary Medicine 2000; 53: 361-365.

56 Heukels H, Ooststroom SJv. Flora van Nederland, 19 ed. Groningen: Wolters-Noordhoff; 1977.

57 Horst RL, Reinhardt TA. Vitamin D metabolism in ruminants and its relevance to the periparturient dairy cow. Journal of Dairy Science 1983; 66: 661-678.

58 House WA, Bell AW. Mineral accretion in the fetus and adnexa during late gestation in Holstein cows. Journal of Dairy Science 1993; 76: 2999-3010.

59 Hove K. Intestinal radiocalcium absorption in the goat: measurement by a double-isotope technique. British Journal of Nutrition 1984; 51: 145-156.

60 Huber JT, Price NO. Influence of high dietary calcium and phosphorus and Ca:P ratio on liver copper and iron stores in lactating cows. Journal of Dairy Science 1971; 54: 429-432.

61 James LF. Oxalate poisoning in livestock. In Effects of poisonous plants on livestock. New York: Academic Press; 1978: 139-145.

62 Jandal JM. Comparative aspects of goat and sheep milk. Small Ruminant Research 1996; 22: 177-185.

63 Jenness R, Patton S. Principles of dairy chemistry. Londen: Chapman & Hall Ltd; 1959.

64 Kadzere CT, Charama T. Effects of dietary inclusion of crushed whole soybeans on blood serum. Small Ruminant Research 1993.

65 Klooster ATv'. De toestand van calcium, magnesium en enkele andere mineralen in darminhoud en mest van herkauwers in verband met hun resorptie. 1967. Thesis.

66 Klooster AThv'. Adaptation of calcium absorption from the small intestine of dairy cows to changes in the dietary calcium intake and at the onset of lactation. Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde 1976; 37: 169-182.

66a Klusmeyer TH, Lynch GL, Clark JH, Nelson DR. Effects of calcium salts of fatty acids and protein source on ruminal fermentation and nutrient flow to duodenum of cows. Journal of Dairy Science 1991; 74: 2206-2219.

67 Langlands JP, Sutherland HAM. An estimate of the nutrients utilized for pregnancy by Merino sheep. British Journal of Nutrition 1968; 22: 217-227.

68 Leeuwen JMv, Visser Hd. Dynamiek van den Ca-stofwisseling van melkgevende koeien bij een verlaagd Ca-aanbod uit het voer. Dynamics of calcium metabolism in lactating cows when the calcium content of the ration is reduced. Tijdschrift voor Diergeneeskunde 1976; 101: 825-834.

69 Ling ER. A textbook of dairy chemistry, 3rd ed. Londen: Chapman & Hall Ltd; 1956.

70 Lopes HOS, Perry TW. Effect of dietary phosphorus and roughage levels on calcium, magnesium and potassium utilization by sheep. Journal of Animal Science 2000; 63: 1983-1989.

71 Lopez A, Collins WF, Williams HL. Essential elements, cadmium and lead in raw and pasteurized cow and goat milk. Journal of Dairy Science 1985; 68: 1878-1886.

72 Martz FA, Belo AT, Weiss MF, Belyea RL, Goff JP. True absorption of calcium and phosphorus from alfalfa and corn silage when fed to lactating cows. Journal of Dairy Science 1990; 73: 1288-1295.

73 Matsui T, Kanagawa Y, Yano H, Kawashima R. Effect of calcitonin on salivary phosphorus and calcium excretion in sheep. Journal of Endocrinology 1984; 102: 365-368.

74 Meschy F. Recent progress in the assessment of mineral requirements of goats. Livestock Production Science 2000; 64: 9-14.

75 Meschy F. Elements mineraux majeurs: donnees recentes chez les caprins Mineral nutrition (macro-elements): recent progress in goats. INRA Productions Animales 2002; 15: 267-271.

76 Mills CF, Dalgarno AC. The influence of dietary calcium concentration on epidermal lesions of zinc deficiency in lambs. Proceedings of the Nutrition Society 1993; 26: 19.

77 Mosel Mv. Research on the mineral supply of dairy cows during the dry period in rel ation to prevention of milk fever. 1991. Thesis, Utrecht.

78 Mosel Mv, Klooster AThv't, Mosel Fv, Kuilen JJ. Effects of reducing dietary [(Na^+ + K^+) - (Cl^- + $SO_4^=$)] on the rate of calcium mobilisation by dairy cows at parturition. Research in Veterinary Science 1993; 54: 1-9.

79 Mosel Mv, Wouterse HS, Klooster AThv't. Effects of reducing dietary ([Na^+ + K^+] - [Cl^- + $SO_4^=$]) on bone in dairy cows at parturition. Research in Veterinary Science 1994; 56: 270-276.

80 Nagai F, Okubo T, Ushiyama K, Satoh K, Kano I. Formation of 8-hydroxydeoxyguanosine in calf thymus DNA treated with tert. Toxicology Letters 1996.

81 Negi SS. Calcium assimilation in relation to metabolism of soluble and insoluble oxalates in the ruminant system: A reappraisal. Indian Journal of Animal Sciences 1971; 41: 913-921.

82 NRC. Nutrient Requirements of Goats: Angora, Dairy, and Meat Goats in Temperate and Tropical Countries. Washington: National Academy Press; 1981.

83 NRC. Nutrient Requirements of Sheep. Washington: National Academy Press; 1985.

84 NRC. Nutrient Requirements of Beef Cattle. Washington, USA: National Academy Press; 1996.

85 NRC. Nutrient Requirements of Dairy Cattle. Washington: National Academy Press; 2001.

86 Palmquist DL, Conrad HR. High fat rations for dairy cows. Effects on feed intake, milk and fat production, and plasma metabolites. Journal of Dairy Science 1978; 61: 890-901.

87 Palmquist DL, Jenkins TC, Joyner-AE J. Effect of dietary fat and calcium sources on insoluble soap formation in the rumen. Journal of Dairy Science 1986; 69: 1020-1025.

88 Panciera RJ, Martin T, Burrows GE, Taylor DS, Rice LE. Acute oxalate poisoning attributable to ingestion of curly dock (*Rumex crispus*) in sheep. Journal of the American Veterinary Medical Association 1990; 196: 1981-1984.

89 Park YW. Comparison of mineral and cholesterol composition of different commercial goat milk products manufactured in USA. Small Ruminant Research 2000; 37: 115-124.

90 Perge P, Hardebeck H, Sommer H, Pfeffer E. Untersuchungen zur Beeinflussung der Calcium- und Phosphorgehalte in Blutserum und Speichel von Hammeln durch dier Versorgung. Zeitschrift für Tierphysiologie, Tierernährung und Futtermittelkunde 1982; 48: 113-121.

91 Pfeffer E. Energie- und Nährstoffbedarf von Ziegen. Energy and nutrient requirements of goats. Übersichten zur Tierernährung 2001; 29: 81-112.

92 Pfeffer E, Pauen A, Haverkamp R. Changes in retention of P and Ca and courses of blood plasma concentrations of inorganic phosphate and calcium in dairy goats following a change in P supply from reduced to adequate in combination with adequate or high Ca intake. Journal of Animal Physiology and Animal Nutrition 1993; 69: 22-28.

93 Powell K, Reid RL, Balasko JA. Performance of lambs on perennial ryegrass, smooth bromegrass, orchardgrass and tall fescue pasture. II. Mineral utilization, *in vitro* digestibility and chemical composition of herbage. Journal of Animal Science 1978; 46: 1503.

94 Preisler MT, Weber PS, Tempelman RJ, Erskine RJ, Hunt H, Burton JL. Glucocorticoid receptor down-regulation in neutrophils of periparturient. Am J Vet Res 2000.

95 Puls R. Mineral Levels in Animal Health. British Columbia Ministery of Agriculture; 1988.

96 Rahnema S, Wu Z, Ohajuruka OA, Weiss WP, Palmquist DL. Site of mineral absorption in lactating cows fed hig-fat diets. Journal of Animal Science 1994; 72: 229-235.

97 Rayssiguier Y, Poncet C. Effect of lactose supplement on digestion of lucerne hay by sheep. II. Absorption of magnesium and calcium in the stomach. Journal of Animal Science 1980; 51: 186-192.

98 Reinhardt TA, Horst RL, Goff JP. Calcium, phosphorus, and magnesium homeostasis in ruminants. Veterinary Clinics of North America, Food Animal Practice 1988; 4: 331-350.

99 Riad F, Lefaivre J, Barlet JP. 1,25-Dihydroxycholecalciferol regulates salivary phosphate secretion in cattle. Journal of Endocrinology 1987; 112: 427-430.

100 Ritter M, Hardebeck H, Kowertz D, Sommer H. Mineralstoffe im Rinderhaar und ihre Bedeutung für Vorsorgeuntersuchungen in Milchviehherden. Mineral elements in bovine hair and their importance for disease prognosis in dairy herds. Tierärztliche Umschau 1981; 36: 549-552.

101 Robinson DL, Hemkes OJ, Kemp A. Relationships among forage aluminium levels, soil contamination on forages, and availability of elements to dairy cows. Netherlands Journal of Agricultural Science 32: 73-80.

102 Rodriguez-Rodriguez EM, Sanz AM, Diaz RC. Chemometric studies of several minerals in milk. Journal of Agricultural and Food Chemistry 1999; 47: 1520-1524.

103 Rogers PAM, Klooster ATT. The fate of Na, K, Ca, Mg, and P in the digesta. Mededelingen Landbouwhogeschool Wageningen 1969; 69-11: 26-39.

104 Rowe NS. Magnesium poisoning in cattle. Veterinary Record 2003; 152: 636.

105 Saha AC, Deb SK. Osteodystrophia fibrosa in goat. Indian Veterinary Journal 1973; 50: 14-17.

106 Sansom BF, Manston R, Vagg MJ. Magnesium and milk fever. Veterinary Record 1983; 112: 447-449.

107 Schenkel H, Klüber J. Mogliche Auswirkungen einer erhöhten Aluminiumaufnahme auf landwirtschaftliche Nutztiere. Possible effects of increased intake of aluminium in livestock. Übersichten zur Tierernährung 1987; 15: 273-299.

108 Schneider KM, Parkinson GB, Houston JC, Leaver DD. 1,25 dihydroxyvitamin D3 increases plasma magnesium and calcium in sheep fed liquid diets low in clacium and magnesium. Australian Veterinary Journal 1985; 62: 82-85.

109 Schonewille JT, Klooster ATv', Dirkzwager A, Beynen AC. Stimulatory effect of an anion (chloride)-rich ration on apparent calcium absorption in dairy cows. Livestock Production Science 1994; 40: 233-240.

110 Schröder B, Goebel W, Huber K, Breves G. No effect of vitamin D3 treatment on active calcium absorption across ruminal epithelium of sheep. Journal of Veterinary Medicine. Series A 2001; 48: 353-363.

111 Senthilkumar RP, James CS, Gangadevi P, Kunjamma C-RL. Effect of supplemental ammonium chloride on biochemical changes and amelioration of experimental urolithiasis in goats. Indian Journal of Animal Sciences 2001; 71: 698-702.

112 Soares-JH J, Ammerman CB, Baker DH, Lewis AJ. Calcium bioavailability. Bioavailability of nutrients for animals: amino acids, minerals, and vitamins 1995; 95-118.

113 Steele W. The effects of soya-bean oil and type of forage in the diet on the plasma lipid composition of sheep. British Journal of Nutrition 1980; 44: 333-341.

114 Steele W. Intestinal absorption of fatty acids, and blood lipid composition in sheep. Journal of Dairy Science 1983; 66: 520-527.

115 Storry JE. Calcium and magnesium contents of various secretions entering the digestive tract of sheep. Nature 1961; 190: 1197-1198.

115a Sukhija PS, Palmquist DL. Dissociation of calcium soaps of long-chain fatty acids in rumen fluid. Journal of Dairy Science 1990; 73: 1784-1787.

116 Tesfa AT, Tuori M, Syrjala-Qvist L. The effects of increasing levels of rapeseed oil in the diets of lactating. World Review of Animal Production 1992; 27: 34-40.

117 Tillman AD, Brethour JR. The effect of corn oil upon the metabolism of calcium and phosphorus by sheep. Journal of Animal Science 1958; 17: 782-786.

118 Tillman AD, Brethour JR. Utilization of phytin phosphorus by sheep. Journal of Animal Science 1958; 17: 104.

119 Timet D, Stojevic Z. Influence of magnesium ions on gastric absorption of calcium in cattle. Veterinarski Arhiv 1982; 52: 247-252.

120 Top AMvd, Schonewille JT, Beynen AC. Voeding van drachtige koeien in de droogstand. Literatuurstudie ter actualisering van de voedingsadviezen door het CVB. CVB-documentatierapport 27.

121 Underwood EJ, Suttle NF. The Mineral Nutrition of Livestock, 3rd edition ed. Wallingford: CABI; 1999.

122 Vakgroep Inwendige Ziekten der Grote Huisdieren. Dictaat Stofwisselingsziekten. 1986; 1-7.

123 Valdivia R, Ammerman CB, Henry PR, Feaster JP, Wilcox CJ. Effect of dietary aluminum and phosphorus on performance, phosphorus utilization and tissue mineral composition in sheep. Journal of Animal Science 1982; 55: 402-410.

124 Valdivia R, Ammerman CB, Wilcox CJ, Henry PR. Effect of dietary aluminum on animal performance and tissue mineral levels in growing steers. Journal of Animal Science 1979; 47: 1351-1356.

125 Valk H, Sebek LBJ, Klooster A-Tv. Onderzoek naar de mogelijkheden tot verlaging van de P-behoefte van melkvee. Rapport ID-DLO 1998; 98.038.

126 Van Leengoed LAMG. Het vóórkomen van hypomagnesaemie by droogstaande runderen. Incidence of hypomagnesaemia in dry cows. Tijdschrift voor Diergeneeskunde 1979; 104: 431-433.

127 Veenendaal M, Zhang X, Lemmens AG, Beynen AC. Liver and plasma copper concentrations in rats fed diets containing various. Biological Trace Element Research 1992; 34: 213-218.

128 Villar D, Larson DJ, Janke BH, Schwartz KJ, Yaeger MJ, Carson TL. Case report - obstructive urolithiasis in a feedlot steer. Bovine Practitioner 2003; 37 (1): 74-77.

129 Waltner TD, Meadows DH. Urolithiasis in a herd of beef cattle associated with oxalate ingestion. Canadian Veterinary Journal 1980; 21: 61-62.

130 Ward G, Harbers LH, Blaha JJ. Calcium-containing crystals in alfalfa: their fate in cattle. Journal of Dairy Science 1979; 62: 715-722.

131 Wasserman RH. Active vitamin D-like substances in Solanum malacoxylon and other calcinogenic plants. Nutrition Reviews 1975; 33: 1-5.

132 Wentink GH, van den Ingh TS. Oral administration of calcium chloride-containing products: testing for deleterious side-effects. Veterinary Quarterly 1992; 14: 76-79.

133 Yang MG, Thomas JW. Absorption and secretion of some organic and inorganic constituents and the distribution of these constituents throughout the alimentary tract of young calves. Journal of Nutrition 1965; 87: 444-458.

134 Yates NG, Hoffmann D, Seripto S. Mandibular osteodystrophy fibrosa in Indonesian goats fed Leucaena. Tropical Animal Health and Production 1987; 19: 121-126.

135 Young JA, James LF. Oxalate poisoning. In The ecology and economic impact of poisonous plants on livestock production. 1988: 261-274.

136 Zinn RA, Shen Y. Interaction of dietary calcium and supplemental fat on digestive function. Journal of Animal Science 1996.

ANNEX: OVERVIEW OF THE SERIES OF CVB DOCUMENTATION REPORTS 'REVIEWS ON THE MINERAL PROVISION IN RUMINANTS'

CVB Documentation report Nr. 33: Reviews on the mineral provision in ruminants I: Calcium metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 34: Reviews on the mineral provision in ruminants II: Phosphorous metabolism and requirements in ruminants (H. Valk)
CVB Documentation report Nr. 35: Reviews on the mineral provision in ruminants III: Magnesium metabolism and requirements in ruminants (J.Th. Schonewille and A.C. Beynen)
CVB Documentation report Nr. 36: Reviews on the mineral provision in ruminants IV: Sodium metabolism and requirements in ruminants (J.Th. Schonewille and A.C. Beynen)
CVB Documentation report Nr. 37: Reviews on the mineral provision in ruminants V: Potassium metabolism and requirements in ruminants (J.Th. Schonewille and A.C. Beynen)
CVB Documentation report Nr. 38: Reviews on the mineral provision in ruminants VI: Chlorine metabolism and requirements in ruminants (J.Th. Schonewille and A.C. Beynen)
CVB Documentation report Nr. 39: Reviews on the mineral provision in ruminants VII: Cation Anion Difference in Dairy Cows (J.Th. Schonewille and A.C. Beynen)
CVB Documentation report Nr. 40: Reviews on the mineral provision in ruminants VIII: Iron metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 41: Reviews on the mineral provision in ruminants IX: Copper metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 42: Reviews on the mineral provision in ruminants X: Cobalt metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 43: Reviews on the mineral provision in ruminants XI: Iodine metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 44: Reviews on the mineral provision in ruminants XII: Zinc metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 45: Reviews on the mineral provision in ruminants XIII: Manganese metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 46: Reviews on the mineral provision in ruminants XIV: Selenium metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 47: Reviews on the mineral provision in ruminants XV: Fluorine, chromium, nickel and molybdenum metabolism and requirements in ruminants (A.M. van den Top)
CVB Documentation report Nr. 48: Reviews on the mineral provision in ruminants XVI: Contaminants: Cadmium, lead, mercury, arsenic and radio nuclides (A.M. van den Top)
CVB Documentation report Nr. 49 (in Dutch): Literatuurstudie over de mineralenvoorziening van herkauwers XVII: Nitraat en nitriet (A.M. van den Top)
CVB Documentation report Nr. 50 (in Dutch): Literatuurstudie over de mineralenvoorziening van herkauwers XVIII: Kwaliteit van drinkwater (A.M. van den Top)