Reviews on the mineral provision in ruminants (II): PHOSPHOROUS METABOLISM AND REQUIREMENTS IN RUMINANTS

H. Valk

CVB documentatierapport nr. 34
November 2005

Centraal Veevoederbureau

Reviews on the mineral provision in ruminants (II): PHOSPHOROUS METABOLISM AND REQUIREMENTS IN RUMINANTS

H. Valk
Animal Sciences Group
Lelystad

CVB documentatierapport nr. 34
December 2005

Centraal Veevoederbureau
Postbus 2176
8203 AD Lelystad
Telefoon 0320 – 29 32 11
Telefax 0320 – 29 35 38
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. Of this guidebook the fifth edition was published in 1996. The content of this publication was largely identical to that of the fourth edition. 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 of the guidebook was desired.
The committee was of the opinion that, if possible, the available scientific literature should be updated and evaluated once again. Furthermore, attention should be paid to the mineral provision of other categories of cattle than dairy cattle, and to that of sheep and goats as well. Finally, the basic principles for the calculation of the mineral requirements should be described in a transparent way.

The intended revision was made possible when 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 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 Phosphorus provision in ruminants the COMV expresses its gratitude to the author, dr. ir. H. Valk.

Utrecht/Lelystad, november 2005.

Professor dr. ir. A.C. Beynen	Dr. M.C. Blok
Chair of the COMV	Secretary of the COMV and Head of the CVB

The author expresses his thanks to dr. ir. A. W. Jongbloed and dr. M.C. Blok for critically reading of 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 (Animal Health Service Ltd) Deventer

CONTENT

LIST OF ABBREVIATIONS

Abbreviation	Unit	Description
BW	kg	Body weight
d		Days of gestation
DM		Dry matter
DMI	kg	Dry matter intake
MW	kg	Expected mature body weight
q		Metabolisability
WG	g/day	Weight gain

1. PHYSIOLOGICAL FUNCTIONS OF PHOSPHORUS

Phosphorus (P) is a main structural element of the body because of its role in the formation of bone tissue, as a constituent of cell membranes and its role in almost all metabolic pathways. Most of the body P is located in bones and teeth; the other part is distributed in the fluids and soft tissues where it is involved in a range of essential functions with regard to the utilization of fat, carbohydrate, protein and other nutrients in the body. Furthermore, P is a component of nucleic acids, which are carriers of genetic information. Inorganic phosphates also play a role in buffering body fluids, including those of the rumen. For a proper functioning of rumen micro-organisms, P is needed especially for those that digest plant cellulose. And further, P seems to be involved in the control of appetite (Ternouth, 1990). In conclusion, it can be postulated that P plays an important role in all types of metabolic processes in the body and in the rumen where P is needed for microbial activity.

2. DISTRIBUTION OF PHOSPHORUS BETWEEN TISSUES

An adult dairy cow with a live weight of 600 kg contains about 4,5 kg P from which 80% is located in bone and teeth. About 30% to 40% of that amount can be mobilized during P-depleted periods. At sufficient P supply, inorganic P concentrations in blood plasma and rumen fluid are 1.8 and 30 mmol/L, respectively (Pfeffer et al., 2005). It was calculated that if these concentrations reduced by up to 90% within ten days, about 60 g P could be mobilized from this rapid exchangeable P pool.

3. PHOSPHORUS ABSORPTION AND KINETICS

3.1 Site of P absorption and secretion.

Phosphorus in the form of orthophosphates is absorbed predominantly in the proximal part of the small intestine. Under a normal P feeding regime, very little P is excreted in the urine and so the P balance is regulated within the gut by control of either absorption or secretion or both (McDowell, 2003). The flow of P from the rumen to the small intestine exceeds P intake by an order of magnitude that is attributed to the salivary P flow. Because feed P and saliva P are completely mixed in the rumen, it is hard to differentiate in absorption efficiencies between these two P sources and, therefore, identical absorption coefficients are assumed (Pfeffer et al., 2005). Salivary P secretion depends on salivary flow and the salivary P concentration. Saliva production is a function of dietary dry matter (DM) content and intake (DMI) and the composition of the diet, while saliva P concentration is related to blood plasma P concentration (Valk and Beynen, 2002). Blood plasma P concentration depends on the amount of P that is absorbed from the small intestine and the excretion of P in milk (Ternouth and Coates, 1997). In an overview, Pfeffer et al. (2005) reported P concentrations in mixed saliva varying from 4.3 mmol/L (dairy cows) to 32 mmol/L (sheep). In contrast to monogastrics, vitamin D plays a lesser role in regulating P metabolism in ruminants. As a result of the secretion of P to the gastrointestinal tract mainly through the salivary glands, the excretion route of excess P is via faeces. For more detailed information the reader is referred to recently published reviews by Valk et al. (2002) and Pfeffer et al. (2005).

3.2 Faecal excretion of phosphorus

Total faecal P excretion depends largely on the level of P intake (Ternouth, 1989) and contains unabsorbed dietary and unabsorbed endogenous P. Further, faecal P excretion is a resultant of the balance between P intake and the need of P for growth, milk production, pregnancy and maintenance. If P intake is in excess in relation to the need, then faecal P increases especially by a higher secretion of P via the salivary glands. As a consequence, the pool of P in the gastrointestinal tract increases and as a result the relative absorption decreases, so that faecal P output markedly increases. As P intake increases, P excess over need can be also excreted in the urine. At depleted P supply, faecal P excretion reaches a level of inevitable loss, which is related to DMI. This inevitable faecal P loss is measured as total faecal P containing both exogenous (undigested feed P) and endogenous P. Endogenous P originates from the animal's body and reaches the lumen of the digestive tract mainly by salivary secretion. The net P requirement for maintenance corresponds with the minimal endogenous faecal P loss (negligible urine P). Major differences between recommendation systems are in the estimation of the net maintenance requirement. In some systems the minimal endogenous P loss is based on a theoretical extrapolation to zero P intake, whereas others estimate this P loss at a P supply just enough to meet the requirement.

4 PHOSPHORUS REQUIREMENTS.

Estimating the amount of P that animals need under different physiological conditions is commonly achieved by using the factorial method. This method is based on the net requirement for maintenance, milk yield, growth and pregnancy and an assumed P absorption coefficient from the feed.

4.1 Dairy cows

4.1.1 Maintenance.

For all ruminant categories, the estimates of the net maintenance requirement of P are based on DMI, saliva flow and saliva P concentration. When dairy cows were offered P-depleted rations, saliva P concentration can be reduced to levels below 5 mmol/L (Valk et al., 2003). However, in that study sometimes levels of 7 mmol P/L were measured at marginal blood plasma levels. Therefore, it is assumed that for a sufficient P supply a salivary P concentration of 8 mmol/L is necessary for both lactating and non-lactating cows. Based on the work of Valk and Beynen (2002) a saliva production per kg DMI of 13 L for dairy cows and 15 L for non-lactating cows is assumed. So, the amount of P secreted via salivary glands per kg DMI is 3.22 g and 3.72 g for lactating and non-lactating dairy cows, respectively. These amounts are reabsorbed by 75% so that a fraction of 0.25 is excreted in the faeces, resulting in an endogenous faecal P loss of 0.81 and 1.04 g P per kg DMI for lactating and non-lactating dairy cows, respectively. The UK uses a net maintenance requirement of 1 or 0.7 g P per kg DMI when the metabolisability (q) of the diet is lower or higher than 0.7 (AFRC, 1991). However, in research with dairy cows offered a P-deficient diet, a slight increase in total faecal P excretion has been observed when milk production increased (Valk et al., 2002). Therefore, it is questionable whether metabolisability influences the net maintenance P requirement. In 1993, Germany introduced a new P recommendation system (GfE, 1993) mainly based on the work of Spiekers et al. (1993), who offered P-deficient diets to dairy cows and measured faecal P output. The excretion of faecal P per kg DMI was about 1.2 g daily for the two treatment groups. Because of the definition of inevitable faecal loss defined as a measured faecal output, this fraction needs no correction for availability to give the dietary requirement (Pfeffer et al., 2005). Within the GfE system, this value of 1.2 g/kg DMI is multiplied by 0.8, which was the absorption coefficient under the experimental conditions. To estimate gross P requirement for maintenance, 1.0 g P per DMI was divided by 0.7, which included an unnecessary safety margin (Pfeffer et al., 2005). Based on the research in Germany, NRC (2001) adopted 1.0 g P/kg DMI as the net maintenance requirement, in addition to an inevitable excreted fraction in the urine (0.002 g/kg body weight). In summary, it can be concluded that the new Dutch P recommendation system estimates the lowest net maintenance requirement for P.

4.1.2 Pregnancy

The net requirement for pregnancy is estimated using the equation of NRC (2001):

absorbed P to meet the demands of the conceptus (g/d) =

$$0.02743 \times e^{((0.05527-0.000075 \times d) \times d)} - 0.02743 \times e^{((0.05527-0.000075 \times (d-1)) \times (d-1))}$$

where d = day of gestation.

Within the NRC recommendation system, this equation predicts the P accretion of the conceptus at any day beyond 190 days of gestation. Within our recommendation system we decided to start at day 224 (week 32 of gestation) assuming that the P requirement of the conceptus at < 224 days of gestation is negligible compared to the total P requirement.

4.1.3 Growth

The net requirement for growth is estimated using the AFRC (1991) formula:

$$P\ (g/day) = (1.2 + (4.635 \times MW^{0.22} \times BW^{-0.22})) \times WG$$

where MW = expected mature live body weight (kg),
BW = current body weight (kg),
WG = weight gain (kg/day).

This equation is also used in the NRC (2001) recommendation system estimating the sink of P in soft tissues and bone during growth. In bone, P is related to Ca assuming an accretion ratio of calcium to phosphorus of 2.1. The expected mature live weight for dairy cattle and young stock is set at 650 kg.

4.14. Milk production

Based on work done in the last fifteen years, Pfeffer et al. (2005) assumed an average P concentration in milk of 0.9 g/kg over the course of a lactation. Based on recent work in the Netherlands (CVB Documentatierapport nr. 32, 2005) and Denmark (Sehested, pers. communication), milk P is set on 1.0 g/kg milk. This increase in milk P content could be probably explained by higher milk protein and milk fat concentrations, milk substances that contain P, compared to the past and other countries. Especially in high yielding dairy cows, the quantity of P secreted into milk must be regarded as the dominating factor establishing P requirement, and there is evidence that milk P content is somewhat higher than 0.9 g/kg. More research is needed to establish current milk P contents within different countries.

4.2. Beef cattle

In The Netherlands, two different beef production systems are used. One is based on an intensive system starting with calves from 14 weeks old and finishing for slaughtering when they are 36 weeks old (pink veal calves). The other system is also an intensive system starting with beef bulls at 6 months of age and slaughtering them at 16-24 months old at live weights ranging from 600-1100 kg (beef bulls).

4.2.1 Maintenance

As already mentioned above, the estimates of the net maintenance requirement of P are based on DMI, saliva flow and saliva P concentration. With regard to *veal beef calves*, saliva P concentrations and live weight gain reduced when dietary P reduced from 4 g to 2.5 g P/kg DM during the harvesting period (Plomp et al., 1999a). Because an increase in dietary P content to 5.5 g P/kg DM did not markedly influence the performance of the calves, it seemed that 4 g P was enough to meet the requirement. Therefore, the average saliva P concentration of 9.5 (s.d. 0.6) mmol/L for the group fed 4 g P/kg DM was used in the recommendation system. In line with dairy cows, saliva production was set on 13 L per kg DMI and absorption rate on 75%. As a consequence, for this category beef calves a net maintenance requirement of 0.95 g P per kg DMI is suggested.

For beef steers, the average of 8.3 (s.d. 0.9) mmol/L in saliva of steers fed 2.5 and 3.0 g P/kg DM (Plomp et al., 1999b) was used in the recommendation system. Saliva P concentrations of both treatment groups were used because their performance was not different. Using also 13 L per kg DM and 75% absorption, the net maintenance requirement for beef steers is 0.83 g P per kg DMI.

For young female stock, the net maintenance requirement is supposed to the same as for beef steers.

4.2.2 Growth

For beef cattle, the deposition of P during growth is estimated using the equation in 4.1.3. The expected mature live weight for *veal beef calves* is set at 650 kg and for beef steers at 1100 kg for early-ripening and intermediate types, and 1150 kg for late-ripening types.

4.3 Sheep and goats

4.3.1 Maintenance

In their model, Imamidoost and Cant (2005) estimated daily saliva productions of 7.2 L during resting, 16.2 L during eating and 19,5 L during ruminating. Cirio et al. (2000) reported 5.8 L, 10.2 L and 14.8 L as total saliva flow (= 2 x parotis flow) for resting, eating and ruminating, respectively. Based on the fact that sheep spent 22% time on eating, 20% on ruminating and 58% on resting (Cirio et al., 2000), total daily saliva flow is 8.6 L on a diet containing 54% alfalfa pellets and 46% hay from which 1 kg DM is consumed. Using the saliva production data of Imamidoost and Cant (2005) and the times spent on eating, resting and ruminating (Cirio et al., 2000), a total daily flow of 11.6 L is estimated. When offered an alfalfa hay diet, Tomas and Potter (1975) measured a parotis flow of 8.6 L which corresponds with 17.2 L of total saliva flow. From the work of Milton and Ternouth (1985), a total saliva production of 11,5 l per kg DMI can be estimated. When the saliva flow data of the four above mentioned literature references are averaged, 12.2 L saliva is produced by sheep per kg DM intake. In our recommendation system it is assumed that sheep and goat produce 12 L/kg DMI.

Huber (2003) concluded that the ratio between saliva P and blood plasma P content is about 7 even under normal and depleted levels of dietary P. Pfeffer et al. (2005) came to the conclusion that plasma P concentration is about 1.8 mmol/L at normal dietary P supply. However, a P-depleted ration offered to sheep reduced the plasma P concentration from 1.7 to 0.7 mmol/L (Breves et al., 1987) and from 1.6 to 0.5 mmol/L (Rodehutscord et al., 1994). A more marginal blood plasma P concentration could be set at 1.5 mmol/L (Rodehutscord et al., 1994). Using the factor 7 (ratio between saliva and plasma P), a saliva P concentration of 10.5 mmol/L is estimated using 10 mmol/L in the recommendation system.

As a consequence and using also 75% as absorption rate, the net maintenance requirement for sheep and goats was set on 0.93 g P/kg DMI.

4.3.2 Pregnancy

The net requirement for pregnancy for sheep and goats is estimated using the equation of ARC (1980):

$$\text{abs. P to meet demands of the conceptus (g/d)} = 10^{(1.981-(5.862 \times e^{(-0.0165 \times d)})}$$

where d = day of gestation, for twin pregnancy the outcome is multiplied by 1.975.

This equation only predicts the P accretion of the conceptus after 91 days of gestation. Before 91 days the requirement of the conceptus is very small and assumed to be negligible.

4.3.3 Growth and milk production

The net requirement for growth in sheep is estimated using the AFRC (1991) formula:

$$P\ (\text{g/day}) = (1.2 + (3.188 \times MW^{0.28} \times BW^{-0.28})) \times WG$$

where MW = expected mature live body weight (kg)
BW = current body weight (kg)
WG = weight gain (kg/day)

For goats the cow formula (4.1.3) is used. The expected mature live weight for ewes, rams and goats are set at 75 kg, 100 kg and 70 kg, respectively.
The milk P concentration in sheep and goats is set at 1.5 g per kg milk (Annenkov, 1982).

4.4 Coefficient of absorption

In a P-depleted situation, Koddebusch and Pfeffer (1988) concluded that ruminants utilize P from the different relevant sources with very high efficiency (greater than 0.9). Also from the work of Valk and Beynen (2002) absorption rates of more than 80% are realistic. Based on this information and including a safety margin, the absorption rate of feed P is set at 75% for all ruminant categories.

4.5 P requirements of cows, sheep and goats

In Table 1 all factors influencing the P requirement of dairy cows, sheep and goats are shown. The recommendations for some different categories are given in Table 2.

Table 1. Factors for calculating the P requirements of dairy cattle, sheep and goats.

Factor	**Cows**				**Goats**	**Sheep**
	Dairy cows		**Beef cattle**	**Young stock/ *veal calves***		
	Non-lactating	**Lactating**				
Net maintenance (g/kg DMI)	1.04	0.81	0.83	0.83/0.95	0.93	0.93
Pregnancy (g/day)						
8–3 weeks before partus	4.1	-	-	-	0.4	0.4
3–0 weeks before partus	5.1	-	-	-	0.5	0.5
Growth (g/kg gain)	$1.2 + (4.635 \times MW^{0.22} \times BW^{-0.22})$					$1.2 + (3.188 \times MW^{0.28} \times BW^{-0.28})$
Milk (g/kg)	-	1.0	-	-	1.5	1.5
Absorption rate (%)	75	75	75	75	75	75

Table 2. P recommendations for the different ruminant categories.

Category	DMI (kg/d)	Requirement	
		(g/day)	(g/kg DM)
Cattle			
Young stock[1]			
4 month, 850 g gain/day	3.9	13	3.4
9 month, 700 g gain/day	5.6	13	2.3
16 month, 625 g gain/day	7.3	13	1.8
Dairy cows (BW = 650 kg)			
Non-lactating, 8-3 weeks before partus	11.5	21	1.9
Non-lactating, 3-0 weeks before partus	11.0	22	2.0
Lactating, 20 kg/day	18.5	47	2.5
Lactating, 40 kg/day	23.5	79	3.3
Beef cattle[2]			
BW = 100 kg, gain 1000 g/day	3.0	15	5.1
BW = 250 kg, gain 1200 g/day	6.0	19	3.1
BW = 500 kg, gain 1100 g/day	9.0	20	2.2
Veal calves			
BW = 150 kg, gain 1150 g/day	4.5	19	4.4
BW = 275 kg, gain 1400 g/day	7.0	23	3.3
Sheep			
Growing lamb[3], 40 kg, 300 g growth/day	1.6	4.2	2.6
Pregnant ewe (twin), (BW = 75 kg), 3-0 weeks before partus	1.9	3.7	1.9
Lactating ewe (BW = 75 kg), 3 kg milk/day, nursing twins	2.6	9.2	3.5
Goats (BW = 70 kg)			
Pregnant goat (twin), 8-3 weeks before partus	1.7	3.2	1.9
Lactating goat, 4 kg milk/day	3.2	12	3.7

[1]: Expected mature body weight 650 kg.
[2]: Expected mature body weight 1100 kg.
[3]: Expected mature body weight of ram lambs 115 kg.

5. COMPARISON OF SOME P RECOMMENDATION SYSTEMS FOR DAIRY COWS

Table 3 shows the P recommendations in four different countries (UK, Germany, USA, and The Netherlands) over a range of milk yields. The DMI rates are used from Pfeffer et al. (2005) and assumed to be similar at a certain milk yield in the different countries. However, due to differences in diet composition, type of roughage and concentrates within these countries, the relationship between DMI and milk yield level may be different for the various countries. It is clearly shown that the UK recommends the highest P supply, while The Netherlands recommend the lowest P amount. The German and USA standards advise levels between the UK and Dutch figures. Although the systems in the USA and Germany are more or less comparable, low yielding dairy cows in the USA are recommended a lower amount of P and high yielders a higher amount of P than in the German system. The new Dutch standard is about 15-17% lower than in the German system for low yielding dairy cows (<30 kg) and about 7% lower than the USA system for high yielding cows (> 40 kg milk). So, especially for low producing dairy cows, the Dutch recommendation is reduced compared to most requirement systems and also compared to the recommended levels described by Valk and Beynen (2002). However, high yielding dairy cows are supplied now even more P than suggested by Valk and Beynen (2002).

Table 3. Four recommendation systems for P supply to non-pregnant, lactating dairy cows at different milk yield levels.

Milk (kg/d)	DMI (kg/d)	Recommended P supply[a] (g/d)			
		UK	Germany	USA	NL
15	17.0	56	46	51	38
25	20.3	77	65	65	55
35	23.6	99	84	83	72
45	26.9	121	103	96	89
55	30.0	142	121	114	106

[a] Recommendations calculated according to: UK – AFRC, 1991; Germany – GfE, 1993; USA – NRC, 2001; The Netherlands, this report.

6 COMPARISON OF SOME P RECOMMENDATION SYSTEMS FOR SHEEP AND GOATS

The recommendations for sheep given by Annenkov (1982) are lower for growing lambs (2.2 g P/kg DM) and lactating ewes (3.2 g P/kg DM), but higher for pregnant ewes (2.8 g P/kg DM) before parturition than those shown in Table 2. Compared to pregnant ewes, AFRC (1991) recommends 2.0 – 2.3 g P/kg DM for pregnant ewes before parturition and NRC (1985) suggest 2.0-2.9 g P/kg DM for pregnant and lactating ewes. The AFRC (1991) and NRC (1985) recommendations for pregnant ewes are in line with the Dutch recommendations, but are lower than the amount suggested by Annenkov (1982). The high P recommendation given by Annenkov (1982) is a result of a higher P deposition during twin pregnancy (2.25 *versus* 0.98 g P/day in this report). In this report the recommendation for growing lambs of 2.6 g P/kg DM is somewhat higher than the 2.4 g P/kg DM suggested by AFRC (1991). Also our recommendations for lactating ewes are high compared to the AFRC (1991) and NRC (1985) requirements. This means that there is some room for declining the P recommendations for sheep and goats. However, before reducing the recommendations more data about saliva production and saliva P concentration in sheep should be available at marginal P supply.

LITERATURE

AFRC, Agricultural and Food Research Council - Technical Committee on Responses to Nutrients, 1991. A reappraisal of the calcium and phosphorus requirements of sheep and cattle, report 6. Nutrition Abstracts and Reviews (Series B) 61: 573-608.

Annenkov, B.N., 1982. Mineral feeding of sheep. In: Mineral nutrition of animals Eds: V.I. Georgievskii, B.N. Annenkov and V.I. Samokhin. Butterworth, London.

ARC, Agricultural Research Council, 1980. The Nutrient Requirements of Ruminant Livestock. CAB International: Wallingford, UK.

Breves, G., C. Rosenhagen and H. Höller, 1987. Die Sekretion von anorganischem Phosphor mit dem Speichel bei P-depletierten Schafen. Journal of Veterinary Medicine A 34: 442-47.

Centraal Veevoederbureau (CVB), 2005. Fosforgehalte in koemelk (Brandsma, G.G. and M.C. Blok), CVB Documentatierapport nr. 32.

Cirio, A., F. Meot, M.L. Delignette-Muller and R. Boivin, 2000. Determination of parotid urea secretion in sheep by means of ultrasonic flow probes and a multifactorial regression analysis. Journal of Animal Science, 78: 471-476.

GfE, Ausschuss für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie, 1993. Überarbeitete Empfehlungen zur Versorgung von Milchkühen mit Calcium und Phosphor. Proceedings of the Society of Nutrition Physiology, 1: 108-113.

Huber, K., 2003. Molekulare Grundlagen der Phosphor-Homöostase beim kleinen Wiederkäuer. Habilitationschrift zur Erlangung der Venia legendi der Tierärzlichen Hochschule Hannover.

Imamidoost, R. and J.P. Cant, 2005. Non-steady-state modelling of effects of timing and level of concentrate supplementation on ruminal pH and forage intake in high-producing, grazing ewes. Journal of Animal Science, 83: 1102-1115.

Koddebusch, L. und E. Pfeffer, 1988. Untersuchungen zur Verwertbarkeit von Phosphor verschiedener Herkünfte an laktierenden Ziegen. Journal of Animal Physiology and Animal Nutrition 60: 269-275.

McDowell, L.R., 2003. Minerals in animal and human nutrition. Elsevier Science, The Netherlands.

Milton, J.T.B. and J.H. Ternouth, 1985. The effects of phosphorus upon in vitro microbial digestion. Animal Production in Australia, 15: 472-475.

NRC, National Research Council, 2001. Nutrient requirement of dairy cattle. Seventh revised edition.

NRC, National Research Council, 1985. Nutrient requirement of sheep. 5e edition, National Academy of Science, Washington, DC.

Plomp, M., J. Th. Schonewille en J.J. Heeres - van der Tol, 1999a. Fosforbehoefte rosé vleeskalveren. Praktijkonderzoek Rundvee, Schapen en Paarden, publicatie 139.

Plomp, M., J. Th. Schonewille en J.J. Heeres - van der Tol, 1999b. Verlaging fosforgehalte in rantsoen vleesstieren. Praktijkonderzoek Rundvee, Schapen en Paarden, publicatie 137.

Pfeffer, E., D.K. Beede and H. Valk. 2005. P Metabolism in Ruminants and Requirements of Cattle. In: Nitrogen and Phosphorus Nutrition in Cattle. Eds. E. Pfeffer & A. Hristov. CAB International, Wallingford, UK, in press.

Rodehutscord, M., A. Pauen, P. Windhausen, R. Brintrup and E. Pfeffer, 1994. Effects of drastic changes in P intake on P concentrations in blood and rumen fluid of lactating ruminants. Journal of Veterinary Medicine A 41: 611-619.

Spiekers, H., R. Brintrup, M. Balmelli and E. Pfeffer, 1993. Influence of dry matter intake on faecal phosphorus losses in dairy cows fed rations low in phosphorus. Journal of Animal Physiology and Animal Nutrition, 69: 37-43.

Ternouth, J.H., 1989. Endogenous losses of phosphorus by sheep. Journal of Agricultural Science, Cambridge, 113: 291-297.

Ternouth, J.H., 1990. Phosphorus and beef production in Northern Australia. 3. Phosphorus in cattle – a review. Tropical Grasslands, 24: 159-169.

Ternouth, J.H. and D.B. Coates, 1997. Phosphorus homeostasis in grazing breeder cattle. Journal of Agricultural Science, 128:331-337.

Tomas, F.M. and B.J. Potter, 1975. Influence of saline drinking water on the flow and mineral composition of saliva and rumen fluid of sheep. Australian Journal of Agricultural Research, 26:585-598.

Valk, H. and A.C. Beynen, 2002. Proposal for the assessment of phosphorus requirements of dairy cows. Livestock Production Science, 79: 267-272.

Valk, H., J.A. Metcalf and P.J.A. Withers, 2000. Prospects for minimising phosphorus excretion in ruminants by dietary manipulation. Journal of Environmental Quality, 29: 28-36.

Valk, H., L.B.J. Sebek and A.C. Beynen, 2002. Influence of phosphorus intake on excretion and blood plasma and saliva concentrations of phosphorus in dairy cows. Journal of Dairy Science, 85: 2642-2649.

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)