# Reviews on the mineral provision in ruminants (XIII): MANGANESE METABOLISM AND REQUIREMENTS IN RUMINANTS

A.M. van den Top

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feeding values

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# 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 Manganese provision in ruminants the COMV expresses its gratitude to the author, dr. A.M. van den Top.

Utrecht/Lelystad, November 2005.

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| 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, Dr. A.M. van den Top, expresses his thanks to the COMV, especially prof. dr. A. Th. van ‘t Klooster, dr. H. Valk 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.

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# CONTENT

# LIST OF ABBREVIATIONS

| Abbreviation | Unit | Description |
|---|---|---|
| BW | kg | Body weight |
| DM | | Dry matter |
| DMI | kg | Dry matter intake |
| MnMet | | Manganese-methionine chelate |
| MnSOD | | Mn superoxide dismutase |

# 1 FUNCTIONS OF MANGANESE IN THE BODY

Manganese is needed for proper function of the enzymes galactotransferase and glycosyltransferase, which are essential for normal cartilage and bone growth and development (production of mucopolysaccharides and glycoproteins). Furthermore, Mn is involved in blood clotting (prothrombin (via glycosyltransferases), vitamin K), lipid and glucose metabolism (reduced back fat in Mn-deficient goat kids), resistance to oxygen radicals (manganese superoxide dismutase) and reproduction (cholesterol synthesis) [65;75].

# 2 DISTRIBUTION OF MANGANESE IN THE BODY AND MANGANESE KINETICS

In the body, Mn is mainly present in the wall of the gastrointestinal tract (± 40%), the skin (± 25%), the muscles, bones and the liver (± 10% each). Besides this, a proportion of total body Mn is present in wool [75].

Excess dietary Mn is not extensively stored in the body. In lambs fed rations[5] containing 13-45 ppm Mn (DM), liver and bone Mn concentrations did not differ significantly [55]. Similarly, in calves fed a ration[6] containing either 12 or 50 ppm Mn for 10 weeks, liver, kidney and heart Mn concentrations were hardly different [40]. Liver Mn concentrations were 7.7 and 9.6 ppm (DM) for the 2 treatment groups, respectively. However, in calves fed a milk replacer (5 ppm Mn) supplemented with either 40, 200, 500 or 1000 ppm Mn (DM) for 5 weeks, liver Mn concentrations were 7.2, 10.3, 15.6 and 26.7 ppm (DM). On the other hand, heart, muscle and kidney Mn concentrations did not significantly differ between the groups [43]. Bone Mn concentrations were not determined. In sheep fed a ration[7] containing either 30 or 4030 ppm Mn, Mn concentrations in liver, kidney, heart, spleen, brain and muscle were significantly higher in the 4030 ppm group [79]. In a group of 32 sheep fed extremely high Mn levels of 8000 ppm for 6 weeks, a breakdown of Mn homeostasis occurred in 3 sheep, resulting in liver Mn concentrations of 1522, 1172 and 970 ppm (DM)) [13]. Apparently, very high Mn concentrations cause Mn accumulation in the liver to a certain extent.

On the other hand, lambs fed diets containing either 0.8 or 29.9 ppm Mn for 22 weeks had heart Mn concentrations of 0.39 and 0.66 ppm and liver Mn concentrations of 1.51 and 2.28 ppm, respectively, whereas bone, kidney and muscle Mn concentrations hardly differed between the groups (± 5.4 ppm in ash) [53]. Intestinal Mn concentrations were not determined. In calves (from dams given 13-21 ppm Mn during pregnancy) given milk containing 14.5 ppm Mn for 7 days after birth, liver Mn concentrations ranged from 411-942 ppm (DM), whereas their non-supplemented counterparts had values of 4-9 ppm (DM) [35]. In goats fed a ration[8] containing > 90 ppm Mn, liver, kidney, spleen, heart, rib and hair Mn concentrations were significantly higher than corresponding values in a depletion group receiving a ration containing only 1.9 ppm Mn [9]. When the 90 ppm Mn-group was compared with a group on a ration containing 5.5 ppm Mn, hardly any significant difference in tissue Mn concentrations could be observed. Thus, in case of extreme Mn deficiency soft tissues (mainly liver and heart) seem to contribute to Mn homeostasis[9], whereas bone Mn is hardly mobilized.

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5 Oat straw/lupine seed/urea ration.

6 Barley/urea ration; extra Mn from $MnSO_4.H_2O$.

7 Grass hay/soybean meal/maize ration; extra Mn from $MnCO_3$.

8 No data on ration composition given.

9 Or, in other words, Mn distribution in the body differs between deficient and sufficient dietary Mn supply.

Manganese crosses the placenta, more than 50% of an oral dose of $^{54}Mn$ given to pregnant cows being accumulated in the foetus after 7 days [32].
Manganese uptake from the intestine in ruminants was shown to start in the rumen [80], although this could not be observed in other experiments [24]. Rapid uptake occurs from the small intestine, which is the main site of Mn absorption. Besides this, Mn uptake from the large intestine was shown to occur [24]. As $^{54}Mn$ accumulates in the intestinal tissues, whereas tissues outside the gastrointestinal tract are relatively poor in Mn, Mn uptake into the body may be regulated at the serosal level of the intestines [60]. After uptake, in the bloodstream Mn is mainly transported bound to transferrin [75].

# 3 MANGANESE ABSORPTION AND METABOLISM

## 3.1 General

Clear data on true Mn absorption in ruminants are not available. Absorption of Mn is generally assumed to be low (3-4% [60] or even 0.75% [65]). It is not clear what kind of absorption is mentioned. In an experiment with calves on a milk diet containing 0.04 ppm Mn (DM) and given a single oral dose of $^{54}Mn$ [10] only 43% of the activity could be recovered from the faeces during the next 7 days. Urinary excretion was 14% of dose. When the dietary Mn concentration was raised to 14.5ppm (DM), 77 and 8% of dose could be recovered from the faeces and the urine, respectively [35]. At supplemental Mn levels of 40, 500, 700 and 1000 ppm (DM) apparent Mn absorptions in calves[11] were 49.2, 31.5, 21.3 and 19.9%, respectively [43]. In adult sheep fed 4030 ppm Mn, apparent absorption was 2.3 % [79].
For a detailed review of Mn metabolism see reference [37].

## 3.2 Differences in manganese metabolism due to different manganese sources

Both inorganic ($MnSO_4.H_2O$, MnO, $MnO_2$, $MnCO_3$, $MnCl_2$) and organic (MnMet) Mn sources are available for use in ruminant rations. The MnMet is a chelate of Mn and methionine. There have been no reports on differences in Mn availability between forages and concentrates.

### 3.2.1 Cattle and goats

No experimental evidence is reported on differences in bioavailability between Mn sources for cattle or goats.

### 3.2.2 Sheep

Hardly any data are available on differences in absorption between different Mn sources for sheep. In an experiment with wether lambs (42 kg BW), the relative bioavailability of different inorganic Mn sources was compared [81]. The basal diet (38 ppm Mn (DM)[12]) was supplemented with 1500, 3000 or 4500 ppm Mn (from $MnSO_4.H_2O$) or 3000 ppm from either $MnSO_4.H_2O$, MnO, $MnO_2$ or $MnCO_3$. Based on multiple linear regression of bone, kidney and liver Mn concentrations on total dietary Mn concentrations the relative bio-availabilities of these sources were 100, 58, 33 and 28% for $MnSO_4.H_2O$, MnO, $MnO_2$ and $MnCO_3$, respectively. In two other experiments with wether lambs (42 kg BW), performed by the same research group, the availabilities of $MnSO_4.H_2O$, MnO and MnMet were compared [30]. In the first experiment (21 days), dietary Mn concentration of the basal diet was 34 ppm (DM). The basal diet was supplemented with either 900, 1800 or 2700 ppm Mn (from either $MnSO_4.H_2O$ or MnMet). In the second experiment, the basal diet contained 32 ppm Mn (DM), whereas the experimental groups were supplemented with either 900, 1800 or 2700 ppm (from $MnSO_4.H_2O$) or 1800 ppm Mn from either MnMet or MnO (two sources). Based on multiple linear regression of bone, kidney and log-transformed liver Mn concentrations on total dietary Mn concentrations the relative bio-availabilities of these sources were 100, 121, 70 and 53% for $MnSO_4.H_2O$, MnMet or the two MnO sources.

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10 The oral dose was 100 µCi from $^{54}MnCl_2$ in 0.5 N HCl solution.
11 Milk replacer containing 5 ppm Mn (DM); the calves were 3 days old at the start of the experiment
12 This level is considered to be more or less sufficient (see 14.5).

### 3.2.3 Conclusion

The scarce data virtually preclude any conclusion as to differences in availability between Mn sources for sheep. However, $MnSO_4.H_2O$ and MnMet seem to be the best available sources, the other inorganic sources being less available. As MnMet may be the most expensive of these sources, the differences in availability are not sufficiently large to justify the recommendation of this source and, in turn, $MnSO_4.H_2O$ may be the source of choice [65]. Unless proven otherwise, this is assumed to be valid for all ruminants.

## 3.3 Interactions influencing manganese absorption

### 3.3.1 General

As discussed in paragraph 6, hardly any suitable indicators of Mn status in the animal are available. However, in several experiments investigating interactions of dietary components with Mn metabolism certain parameters of Mn metabolism (Mn in liver, blood, bone etc.) have been employed. These criteria have to be judged with caution.

### 3.3.2 Lacking data

No experimental evidence on the influence of Fe, Al and/or P (goats), Cd or Zn (cattle and goats) and Ni (small ruminants) on Mn metabolism is available.

As both Mn and Fe compete for at least some binding sites in the intestinal wall of rats, mutual inhibition of absorption occurs [74]. Therefore, it would not be unlikely that this antagonism also takes place in ruminants.

### 3.3.3 Interactions of manganese and iron.

#### *3.3.3.1 Cattle*

In ruminating calves (89 kg BW) fed a diet[13] supplemented with 1000 ppm Fe no significant differences in Mn content of tissues (liver, kidney, pancreas, spleen, small intestine, muscle, rib) or bile could be observed when compared with a control group not receiving extra Fe [33].

#### *3.3.3.2 Sheep*

In sheep lambs (18 kg BW) fed concentrates containing either 250, 100 or 1750 ppm Fe (DM; from $FeSO_4.7H_2O$) and hay[14] for 84 days, no differences in tissue Mn concentrations (brain, kidneys, spleen, liver, muscle, rib, wool) between the different groups could be observed [20;25].

### 3.3.4 Interactions of manganese and cadmium

Loading of mice and rats with Cd has been shown to reduce Mn levels in their tissues as compared with non Cd-loaded ones [18]. Therefore, this interaction might occur in ruminants either.
When Cd (0, 5, 15, 30 or 60 ppm) was added to the diet (0.2 ppm Cd, Mn content not given) of ram lambs, liver Mn concentrations were significantly decreased in the highest Cd-group (60 ppm Cd) when compared with the other groups [18]. No differences in Mn concentrations

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[13] Maize/soybean meal diet; 220 ppm Fe and 55 ppm Mn (DM); extra Fe from $FeCO_3$
[14] No data on Mn content of the ration

due to Cd loading were observed in rumen, abomasum, ileum, heart, spleen, lungs, testicles or kidneys. The experiment lasted for 191 days.

### 3.3.5 Interactions of manganese and zinc

In sheep given a grain / hay ration containing either 2667 (weeks 0-4) or 4000 (weeks 5-14) ppm Zn, significantly lower Mn concentrations in pancreas tissue were observed when compared with control animals not supplemented with Zn[15] [4]. In the control animals, pancreas Mn concentration was 205 µmol/kg, whereas Mn concentrations were 106 (no histological kidney lesions) or 66 ppm (histological kidney lesions) in the Zn-treated group.

### 3.3.6 Interactions of manganese and aluminium, calcium and phosphorus

#### *3.3.6.1 Cattle*

##### *3.3.6.1.1 Aluminium*

In growing beef steers (226 kg BW) fed additional Al for 84 days[16],[17]), no significant differences in Mn concentrations of liver, kidney, muscle or brain could be observed [77]. Added Al levels were 0, 300, 600 or 1200 ppm. Performance was not significantly influenced.

##### *3.3.6.1.2 Calcium and phosphorus*

In calves fed a ration[18] containing either 1.7, 6.7, 13.1 or 23.5 g Ca/kg, Mn content of rib tissue was significantly increased in the 6.7 g Ca/kg-group, whereas rib Mn content in all other Ca groups as well as liver and pancreas Mn concentrations were not different between the groups [3]. In cows fed a diet[19] supplemented with 30 g dicalcium phosphate/kg for one year compared with non-supplemented animals, no differences in blood, bone and kidney Mn levels were observed [70]. Liver Mn concentrations tended to be higher and breaking strength of the humerus was considerably higher in the supplemented group (767 kg of vertical pressure) compared with the non-supplemented group (443 kg). However, no statistical data were given. Similarly, calves from Hereford heifers fed milk diets supplemented with 15 g Ca/kg[20] of diet for 7 days after birth, liver and bone Mn concentrations were higher than in non-supplemented calves [35]. Again, no clear statistical evidence on these differences was given.

#### *3.3.6.2 Sheep*

Two experiments using wether lambs were carried out investigating the influence of Al and P on tissue mineral composition [71;76]. Rations[21] were similar and contained 1.5 or 1.7 g P/kg DM, 168 ppm Al (DM), 24 or 26 ppm added Mn (DM; basal diet) and 3.2 or 4.2 g P/kg DM and 2168 or 1618 ppm Al (DM; experimental diet). In both experiments, additional Al significantly depressed DMI and growth. In the first experiment [76], added Al significantly depressed liver Mn concentrations (10.4 and 12.8 ppm (DM) for high- and low Al groups,

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[15] No data on the Zn content of the control ration.

[16] Maize/soybean meal/cottonseed hulls ration (210 ppm total Al); 26 ppm Mn added; extra Al from $AlCl_3.6H_2O$.

[17] Although data on normal Al concentrations in feeds and Al requirements are scarce, sweet clover was reported to contain 139 ppm Al (DM) [21]. In the ration of young goats, 25 ppm Al (DM) seemed to be sufficient [6].

[18] Maize/soybean meal/grass pellets/cottonseed hulls ration; ± 3.4 g P/kg; 30 ppm Mn added; extra Ca from $CaCO_3$.

[19] Barley (straw)/cottonseed meal/urea diet.

[20] Extra Ca from limestone.

[21] Maize/soybean meal/cottonseed ration; extra Al from $AlCl_3.6H_2O$.

respectively). Muscle Mn levels were significantly lower (0.2 ppm (DM)) in the high-P group when compared with the low-P group (0.3 ppm (DM)). In the second experiment [71], only in heart tissue Mn concentrations were lower in the high-P than in the low-P group. No differences due to either Al or P were found in Mn concentrations of liver, kidney, muscle or spleen tissues.

In wethers fed diets[22] containing either 0 or 2000 ppm added Al/kg for 60 days, no significant ($p < 0.05$) influences of Al treatment on Mn concentrations in bone, liver, kidney, brain, spleen, pancreas, parathyroid gland or pituitary gland could be observed, although liver Mn concentrations tended to be lower due to Al treatment [5].

### 3.3.7 Interactions of manganese and nickel

In dairy calves (74 kg BW), no influence of the addition of 5 ppm Ni to a ration[23] containing on average 0.5 ppm Ni and 8 ppm added Mn[24] on performance and Mn concentrations in liver, kidney, spleen, lung, heart and muscle could be demonstrated [72].

### 3.3.8 Interactions of manganese and lead

In cattle[25], ingestion of a ration[26] supplemented with either 6.3, 7.8, 9.8 of 12.2 mg Pb/kg BW[27] even the lowest Pb dose significantly depressed renal Mn concentrations as compared with the unsupplemented control group (3.6 vs. 6.0 µg/kg DM) [19]. Manganese concentrations in liver, spleen, heart and brain were not affected by Pb loading. Assuming a DMI of 7 kg/day, the lowest Pb concentration in the supplemented rations would be ± 300 ppm (DM). For comparison, in the past Pb concentrations of ± 200 ppm (DM) were reported in forage from the verges of motorways [78].

### 3.3.9 Conclusion

#### *3.3.9.1 Iron*

Although the Fe levels used in all experiments are thought to be more or less comparable with those occurring in practice (e.g. from contamination of feeds with soil) [36], no effects of additional Fe on Mn metabolism could be observed. Therefore, under practical conditions the influence of Fe on Mn metabolism in cattle and sheep will be largely unimportant. Until more information is available, this is assumed to be also the case for goats.

#### *3.3.9.2 Cadmium*

As only one experiment with sheep reports on the influence of Cd on Mn metabolism, hardly any conclusion can be drawn. Moreover, only the highest Cd concentration (60 ppm) depresses liver Mn concentrations. This concentration considerably exceeds those normally found in herbage under practical conditions (0.1-0.8 ppm (DM)) or even in Cd-contaminated areas (1-21 ppm (DM))[61]. In sheep, the influence of Cd on Mn metabolism does not seem to be of practical importance.

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[22] Maize (kernels/cobs/gluten meal)/grass hay diet (242 ppm Al; extra Al from $AlCl_3$ no Mn content given.

[23] Maize/cottonseed hulls; extra Ni from $NiCl_2.6H_2O$.

[24] From MnO.

[25] Two to 3 years of age, mean BW 335 kg.

[26] 35% Lucerne, 35% Bermuda grass and 30% maize; DMI not given.

[27] From Pb acetate.

*3.3.9.3 Zinc*

Evidence is very scarce and the Zn levels applied extremely exceed normal Zn requirements (see CVB Documentation report Nr. 44). Only when Zn is administered to combat facial eczema [75], such high dietary Zn levels can occur. As yet, there is no evidence that dietary Zn will hamper Mn metabolism under normal practical circumstances.

*3.3.9.4 Aluminium, calcium and phosphorus*

The Al concentrations used in the experiment mentioned above, substantially exceed even those found in plants from polluted areas (e.g. 237 ppm Al (DM) in sweet clover grown on fly ash [21]). Nevertheless, evidence on influences of Al on Mn metabolism is conflicting, whereas effects are minor. Even very high Ca concentrations do not significantly influence Mn metabolism. If any, dietary Ca increases tissue Mn concentrations, in contrast with the NRC statement that Ca might reduce Mn absorption [65]. Although the employed P (and Ca (partial)) levels are practical, in a conclusion, the practical importance of Al, Ca and P on Mn metabolism in ruminants seems to be minor.

*3.3.9.5 Nickel*

Under practical circumstances, influences of Ni on Mn metabolism in ruminants are considered to be irrelevant.

*3.3.9.6 Lead*

In Pb-contaminated areas, Mn metabolism may be impaired, although it is difficult to judge the relative importance of lowered renal Mn concentrations as compared with the unaffected Mn concentrations in other organs.

## 3.4 Recycling

Hardly any data are available on the recycling of Mn in ruminants. Re-uptake of Mn excreted via the bile is very limited [75].

## 3.5 Excretion

The bile is one of the main routes of excretion of excess absorbed Mn, whereas the amount of Mn excreted via the urine is negligible [75]. In steers intravenously loaded with Mn (from $MnCl_2$), the maximum biliary Mn concentration was 193 ppm, whereas the maximum biliary excretion rate was 1210 µg Mn/min. [28]. Calves on a diet[28] supplemented with 1000 ppm Mn for 18 days had more than 7-fold higher Mn concentrations (6.48 ppm (DM)) in their bile than control calves not supplemented with Mn (0.87 ppm (DM)) [33]. Kidney Mn concentrations were not different between the groups. Similarly, in calves fed milk replacer containing either 40, 200, 500 or 1000 ppm (DM) supplemental Mn for 5 weeks, corresponding bile Mn concentrations were 2.1, 3.5, 14.3 and 17.1 µg/mL, respectively, whereas kidney Mn concentrations were not different between the groups [43]. As already suggested by the unchanged kidney Mn concentrations at different dietary Mn intakes, the contribution of urinary Mn excretion is minor. In calves fed a barley/urea ration containing either 12 or 50 ppm Mn (extra Mn from $MnSO_4.H_2O$), urinary Mn excretion was 0.45 and 0.15% of daily Mn intake, respectively [40]. Similarly, in rams on a grain diet[29] and dosed with 10 µCi/kg BW of $^{54}Mn$ (from $MnCl_2$), within 96 hours 59.2% of dose was excreted via the faeces, whereas 0.17% of dose was excreted via the urine [39]. In sheep fed different maize and lucerne silages faecal Mn excretion ranged from 86-99% of intake, whereas urinary Mn

[28] Maize/soybean meal (55 ppm Mn (DM)); extra Mn from $MnCO_3$.
[29] Mn content of the ration not given.

excretion ranged from 0.5-1% of intake [42]. In sheep fed 3431 mg Mn/day, 3352 mg was excreted via the faeces, whereas 1.5% was excreted via the urine [79]. In wethers receiving diets[30] containing 38-39 ppm Mn for 18 days, faecal Mn excretion was 31.91 mg, whereas urinary excretion was only 0.06 mg [50].

[30] Semi-purified diets containing 83% of either cellulose, native starch or steam-flaked starch.

# 4 MANGANESE REQUIREMENTS

Although factorial estimation of Mn requirements is preferred, vital information to employ this method (both true Mn absorption and endogenous Mn losses) is lacking for ruminants [60]. Therefore, factorial estimation of Mn requirements is precluded. However, known components of the factorial approach are listed below.

## 4.1 Cattle

### 4.1.1 Dairy cattle

During gestation, the pregnant bovine uterus requires about 0.3 mg Mn/day from 190 days of gestation until parturition [34]. This estimate is made employing rations containing as much as 50-60 ppm Mn (DM). No qualification ("minimal" etc.) is given for this estimate.
Growing tissues are reported to contain 0.85 mg Mn/kg [73] or 2.5 mg/kg DM [65]. As these values allow for tissue storage of Mn, they are not truly "minimal".
Colostrum is reported to contain (mg Mn/kg) 0.13-0.16 [49], 0.13 [48], 0.06-0.16 [47] or 0.16 [65]. The Mn content of mature milk is assessed to be (mg/kg) 0.01-0.04 [44], 0.03 [1;65], 0.02-0.1 [49] 0.02-0.11 [47], 0.07 [54] or 0.11 [48]. Moreover, milk Mn concentrations vary depending on soil type [47].
The influence of dietary Mn concentrations on milk Mn content is limited, although results do not fully agree. Manganese intakes of 3-12 g (during 10 days) per day did not influence milk Mn content [49]. Only long-term feeding of 11.3 g Mn (from $MnSO_4$) to dairy cows[31] (for 5 months) raised the Mn content of the milk from 0.02 to 0.06 mg/kg [11].
The Mn content of bovine hair depends i.a. on the age, feeding and region of the body and ranges from 1.3-13.9 ppm (DM) [29]. For dairy cows, the Mn requirement for hair growth is neglected.

### 4.1.2 Beef cattle

No separate calculations need to be made for the Mn requirements of beef cattle.

## 4.2 Sheep

Similarly to growing cattle, growing lambs accumulate 0.85 mg Mn/kg growth [73]. The Mn content of the whole body (except liver and kidney) of Merino sheep (96 ewes) can be calculated using the equation [51]:

Mn content (µg) = 2460 x BW (kg) – 12.91 x age (months) x BW (kg).

In Merino sheep bearing singletons, Mn content of the conceptus was related to time from mating. Based on slaughter experiments (85 ewes), the Mn content of the conceptus can be calculated using the equation [52]:

$$\text{net Mn storage in the conceptus } (\mu g) = e^{(9.233 - 13.75 \times e(-0.019 \times t))}$$

in which t = time from mating (days). Average daily Mn accretion into the conceptus increased from 19 (70 days) to 73 µg (150 days from mating) [52]. As only three ewes bore twins, no calculations could be carried out for Mn accretion during twin pregnancy.

31 No data on DMI or BW given, so calculation of Mn concentrations per kg DM or per kg BW is precluded.

Lambs consuming a semi-purified diet containing 30 ppm Mn for 22 weeks had a mean wool Mn content of 18.7 ppm [53]. As clean wool yield is 1.0-3.8 kg/year [10], Mn need for wool growth is assessed to be 19-71 mg/year or 52-195 µg/day.
Sheep milk is reported to contain 0.057 [15] or 0.05-0.09 mg Mn/kg [47].

### 4.3 Goats

Goat milk is reported to contain (mg Mn/kg) 0.014 [15], 0.033 [66], 0.06 [59] 0.08 [47] or 0.16 [54]. Milk of goats fed either > 90 ppm Mn or 1.9 ppm Mn for several years[32] contained 0.28 and 0.15 mg/kg, respectively [9]. In this experiment, colostrum contained 0.21 and 0.14 mg/kg for the two groups, respectively. The reason for these relatively high Mn concentrations is not clear.
The Mn content of goat hair (Barbari goats) is reported to be 0.65 ppm [27]. However, the Mn content of the ration was not given. Goats given a ration[33] containing 100 ppm Mn for 3 years, had a hair Mn content of 11.1 ppm, whereas the hair of control goats receiving 20 ppm Mn (first year) or 6 ppm Mn (next 2 years) contained 3.5 ppm [8]. Goats given rations[10] containing either > 90, 5.5 or 1.9 ppm Mn had hair Mn concentrations of 2.9-7.6, 5.5 and 1.5 ppm Mn [9]. As Mn content of hair is very variable and influenced by external deposition from the environment (see paragraph 6), assessment of Mn requirements for hair production is hampered. Arbitrarily choosing a value of 6 ppm Mn, Mn requirement for fibre-production in goats (0.63-3.5 kg fibre/year [10]) will be 10-58 µg Mn/day. However, considering the value of 0.65 ppm for Barbari goats, much lower requirements are possible.

[32] No data on ration composition or Mn source given; several goats in the Mn-deficient group died.
[33] No data on ration composition or Mn source given.

# 5 ALLOWANCES

As factorial estimation of Mn requirements is precluded by lack of data, only rough assessments are possible. Different estimates are given in Table 1.

**Table 1 Different estimates of Mn requirements of ruminants.**

| Ref. | Category | Dietary Mn concentration (ppm (DM)) | Remarks |
|---|---|---|---|
| [75] | Growing cattle | 10 | Sufficient for growth, not for maximum fertility |
| [35;70] | Heifers | 20 | Sufficient for growth and |
| [29] | Dairy cattle | 25 | 16-21 ppm (DM) did not result in clinical deficiency symptoms |
| [10] | Growing cattle | 10 | |
| | | 20-25 | Needed for normal skeletal development and reproduction |
| [65] | Dairy cattle | 40 | |
| | Pregnant heifers | 22 | |
| [64] | Growing/finishing beef cattle | 20 ppm | |
| | Breeding beef cattle | 40 ppm | Adding 14 ppm Mn to a diet containing 32 ppm Mn reduces the number of services per conception |
| [63] | All sheep | 20 ppm | |
| [55] | Growing rams | 13 | Adequate growth and wool growth |
| | | 16 | Adequate testicular growth |
| [38] | Cattle and sheep | 40 | |
| [46] | All goats | 40 | |
| [2] | All goats | 60 | Relatively high, "safe" value |

All assessments mentioned in Table 1 are relatively rough. Although under Dutch circumstances 25 ppm (DM) was recommended [29], the improvement of fertility caused by addition of Mn to a maize-based ration containing 32 ppm Mn (as fed, Table 1; ref. [64]) seems to plead against the 25 ppm (DM) value with respect to breeding cattle. Therefore 40 ppm (DM) is recommended for breeding cattle, whereas 25 ppm (DM) is recommended for other categories. The value of 40 ppm (DM) is also adopted for goats, whereas 20 ppm (DM) is recommended for sheep.

# 6 CRITERIA TO JUDGE MANGANESE STATUS

## 6.1 Potential indicators of Mn status

Assessment of Mn status of ruminants is difficult. Serum, hair, liver and dietary Mn concentrations have been suggested to be suitable. Suggested levels are given in Table 2. However, Mn concentrations in all parts of the body are reported not to bear an accurate relationship to dietary Mn concentrations[34] [16;22]. On the other hand, in cases of gross overdosing of Mn (22, 300 or 3000 ppm Mn[35]) a significant relationship of dietary and liver Mn could be observed [41]. Similarly, in sheep fed diets containing either 70, 300, 600, 1200 or 2400 ppm supplemental dietary Mn) to sheep[36], significant relationships could be calculated between dietary Mn and either liver Mn concentrations and (log) liver Mn superoxide dismutase (MnSOD) activities [56]. When dietary Mn concentrations ranged from 8.7 to 45 ppm, no significant relationships of dietary Mn concentrations and liver Mn or liver MnSOD activities could be observed. Activities of MnSOD increase during growth [67]. Finally, in pregnant sheep fed diets[37] containing either 8 or 68 ppm Mn for 4 months, significant higher blood Mn concentrations were observed in the 68 ppm Mn group [31], whereas pregnant cows fed 25 ppm Mn[38] for 12 months had significantly higher blood Mn concentrations than similar cows fed 16-17 ppm Mn [70]. The calves of the cows fed 25 ppm Mn were clinically normal, whereas those in the other groups revealed Mn deficiency symptoms (see paragraph 7).

**Table 2 Suggested levels for potential indicators of Mn status in ruminants**

| Ref. | Qualification | Category | Ration | Liver | Hair | Serum |
|---|---|---|---|---|---|---|
| | | | ppm (DM) | | | µg/L |
| [68] | Deficient | | < 1.0 | < 4 | 0.5-50[a] | |
| | Marginal | | 10-20 | 6-12 | 0.5-15[a] | < 5 |
| | Adequate | | 40-200 | 10-24 | 0.5-70[a] | 6-70 |
| | High | | 1000 | 16-920 | > 80 | |
| | Toxic | | 2000-4000 | | | 80-1450 |
| [22] | Adequate | | | 6-12 | | 6-700 |
| [29] | Marginal | | < 25[39] | < 9 | | |
| [58] | Normal | | | | 0.6 | |
| [69] | ???? | | | | 0.5-25 | |
| [75] | Marginal band | Cattle | 10-20 | 5.0-7.5 | | 5-6 |
| | | Sheep | 8-20 | 8.0-9.0 | | 1.8-2.0 |
| | | Goat | 10-20 | 3.0-6.0 | | |

[a] it is not clear why the lower limit is the same for all categories.

Pigmented hair contains higher Mn concentrations than white hair [68]. Calves fed a ration[40] containing either 36 or 9 ppm Mn (DM) for 136 days had hair Mn concentrations of 13.9 and 4.1 ppm, respectively [7]. However, after feeding 1.11 g Mn (from $MnCl_2.4H_2O$) per day to cows for 12 days[41], no differences in either serum or hair Mn concentrations with pre-treatment values could be observed. Moreover, the Mn content depended on the length of the hairs, the tip of the hairs being approximately 10 times as rich in Mn as the basis. Therefore, sequestration of Mn from the body into the hair does clearly not significantly

34 No indication of the range of these dietary Mn concentrations given; maybe up to 200 ppm (as fed) [22].
35 Hay/barley/soybean meal diet; extra Mn from $MnSO_4.H_2O$.
36 Oat straw/lupine seed ration containing 8.7 or 30 ppm Mn; extra Mn from $MnCl_2$.
37 Torula yeast/dextrose/cellulose diet; extra Mn from $MnSO_4.H_2O$.
38 Barley/cottonseed meal/urea ration; extra Mn from $MnCl_2.4H_2O$.
39 "Including a certain safety margin"; no further quantification of this margin given.
40 Milk/concentrate ration; Mn-source not given.
41 No data on ration composition given.

contribute to hair Mn content, rendering the hair Mn content useless as an indicator of body Mn status [57]. In summary, hair Mn content represents the exposure of the animal to external deposition of environmental Mn rather than the dietary Mn supply and has, therefore, been rejected as a suitable indicator [29;58;68;69].
Probably the dietary Mn concentration is the best indicator of Mn status in ruminants [16]. However, even when dietary Mn concentrations are adequate Mn deficiency symptoms can occur [45].

### 6.2 Conclusions

Due to lack of clear evidence, dietary Mn concentrations seem to be the best indicator of Mn status in ruminants [16;29]. Dietary Mn concentrations are easier to check than liver Mn concentrations, whereas as yet no clinical Mn deficiencies are reported from the Netherlands [29]. The reference values as given in Table  2 can be used. When gross overdosing of Mn is suspected, liver and / or serum Mn values can be determined to roughly assess Mn status.

# 7 DEFICIENCY

## 7.1 General

Although Mn deficiency is mainly a problem of birds, clinical signs of Mn deficiency can be observed in ruminants as well. One of the first symptoms is a tremor of the tongue. Later on, generalized ataxia and muscle tremors occur [8]. Other symptoms of Mn deficiency are impaired growth and reproduction (reduced estrous behaviour, irregular estrous cycles, lower conception rate, abortion), the development of skeletal abnormalities (weak legs, enlarged joints, stiffness, twisted legs and reduced bone strength) in young animals [10;64;65;70;75]. Growth of young animals is usually not affected at the onset of the clinical symptoms. Moreover, both in cows and goats Mn deficiency resulted in the birth of more male than female offspring, whereas mortality of female calves and kids was also higher than that of male ones [8;22]. Finally, frequent tongue rolling is suggested to be related to Mn deficiency [7;45].

## 7.2 Direct measures in deficiency cases

### 7.2.1 Direct continuous supplementation

To cure or prevent Mn deficiency, Mn can be added to the ration of ruminants as $MnSO_4$. Approximate daily doses should be 4 g (cows), 2 g (heifers) or 1 g (calves) and should be continued as long as the deficient feed is fed [75]. For small ruminants, no exact doses have been reported. Based on metabolic BW, ± 1 g [42] should be sufficient for this class of ruminants. For maize (silage)-based rations, supplementation with 20 ppm Mn (DM) is recommended [75].

### 7.2.2 Direct discontinuous and slow release oral supplementation

No information on direct discontinuous supplementation or slow release oral supplementation of Mn is available.

[42] Metabolic BW of cows and small ruminants differ by a factor of ± 5, resulting in a dose of 0.8 g for small ruminants. This value is rounded up to 1 g, which is similar to that of calves.

# 8 TOXICITY

## 8.1 General

Besides the faulty use of mineral supplements, Mn toxicity can be evoked by the consumption of Mn-rich forages [75], although reports on Mn toxicity in ruminants are rare [65]. In veal calves fed milk replacer containing either 40, 200, 500, 1000 or 5000 ppm Mn (DM) for 5 weeks, performance was slightly worse in the 1000 ppm group, whereas none of the calves survived the 5000 ppm-treatment [43]. Calves from the 5000 ppm Mn group were listless, had poor appetite and performance. No other clinical signs due to Mn toxicity were observed. In wethers fed 22, 300 or 3000 ppm Mn[43] for 8 weeks (extra Mn from $MnSO_4.H_2O$), the animals on the 3000 ppm diet had lower growth and higher feed/gain ratios [41]. No other clinical signs were observed. Adult sheep fed levels of 8000 ppm Mn for 6 weeks survived the experiment [13].
Currently, Mn overload (together with Cu deficiency) is suggested to be involved in the development of spongiform encephalopathies such as scrapie, bovine spongiform encephalopathy (BSE) and Creutzfeld Jakob disease [14].
The NRC suggests a maximum tolerable dietary level of 1000 ppm Mn for dairy and beef cattle [64;65] and sheep [63]. However, sheep fed either 0, 1500, 3000 or 4500 ppm supplemental Mn (basal diet 38 ppm Mn (DM)) showed reduced feed intake only in the 4500 ppm group [81]. No maximum allowable dietary Mn concentration is recommended for goats.
In conclusion, 500 ppm (DM; pre-ruminant animals) [43] or 1000 ppm (DM, ruminating animals) can be considered safe, although dietary levels considerably exceeding these limits may not cause serious detrimental effects [81]. Unless proven otherwise, these values are supposed to be also valid for goats.

## 8.2 Direct measures in toxicity cases

Except lowering the Mn content of the ration no direct measures to be taken in Mn toxicity cases are reported for ruminants.

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[43] Hay/barley/soybean meal diet.

# 9 PREVENTION OF DEFICIENCY

## 9.1 Short-term prevention strategies

No separate short-term prevention measures except the application of Mn-containing supplements (see paragraph 7.1.1) have been recommended.

## 9.2 Long-term prevention strategies

In the long term, Mn-containing fertilizers (15 kg $MnSO_4$/ha) have been proven to be successful to increase Dutch soil and plant Mn contents. However, this measure is rarely practised [75]. In cases liming of soils is needed, care has to be taken of Mn supply to animals grazing pastures growing on these soils, as excessive liming of soils has been suggested to cause low uptake of Mn by plants and subsequent Mn deficiency in animals [17].

**Table 3 Inventory of Mn allowances for cattle, sheep and goats as used in some foreign countries (ppm (DM))**

| | | ***Allowance*** | | | | |
|---|---|---|---|---|---|---|
| **Country** | **Ref.** | **Cattle** | **Ref.** | **Sheep** | **Ref.** | **Goat** |
| Great Britain | [10;75] | 20-25 | | | [2] | 60 |
| USA[a,b] | [82] | 22-40 (DM; dairy cattle)<br>beef cattle:<br>20 (growth)<br>40 (breeding) | [63] | 20 | [62] | ? |
| Germany | [23] | 40-50 (growth)<br>50 (mature) | | ? | [12] | 60-80 |
| France | [26] | 50 (45 is deficiency limit) | | | | |

[a] Allowances for cattle are expressed in mg/kg feed as fed; as DM contents of the feeds are not given, allowances cannot be calculated in ppm (DM).
[b] minimum requirements.

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- 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)