THE EFFECT OF VARIOUS LEVELS OF DIETARY COPPER AND MOLYBDENUM ON COPPER AND MOLYBDENUM METABOLISM IN SHEEP

J.B.J. van Ryssen and W.J. Stielau

Department of Animal Science, University of Natal, Pietermaritzburg, 3200

OPSOMMING: DIE INVLOED VAN VERSKILLENDE PEILE KOPER EN MOLIBDEEN IN DIE DIEËT OP KOPER-EN MOLIB-DEENMETABOLISME IN DIE SKAAP

'n Proef is uitgevoer waarin skape verskillende peile Cu en Mo in hul rantsoene ontvang het. Die inname van S is konstant gehou teen 2,1 g/skaap/dag. Twee peile Mo is gevoer, nl. 38 mg/skaap/dag vir 92 dae of 21 mg/skaap/dag vir 182 dae. Elkeen van die Mo-groepe is verdeel in drie Cu-behandelings, nl. 24, 40 of 68 mg Cu/skaap/dag. Geen verskil in akkumulasie van Cu in die lewer is tussen die Mo-behandelings waargeneem nie. Die Cu-inhoud van die lewer het lineêr met totale Cu-inname toegeneem, ongeag tydperk van Cu-verskaffing. Tussen 1,18 en 1,97% van die Cu in die rantsoen is in die lewer opgeneem. Op grond van verskille in Fe- en Zn- konsentrasies in die lewers, is afgelei dat interaksies tussen Cu en Fe en tussen Cu en Zn respektiewelik plaasgevind het.

Die konsentrasies van Mo in die lewer, nierkorteks en plasma was betekenisvol hoër (P < 0,01) teen 'n Mo-inname van 38 mg/skaap/dag as met 'n inname van 21 mg Mo/dag, nieteenstaande die feit dat Mo-inname oor die proefperiode min of meer konstant was. Dit is afgelei dat die konsentrasie van Mo in hierdie weefsels van 'n redelike kortstondige aard is, afhanklik, by konstante S-innames, van die daaglikse inname van Mo en nie van totale Mo-inname oor 'n tydperk nie.

SUMMARY:

A trial was conducted in which the rations of sheep were supplemented with different levels of Cu and Mo. The S intake was kept constant at 2,1 g/sheep/day. Two levels of Mo were fed, viz. 38 mg/sheep/day for 92 days or 21 mg/sheep/day for 182 days. Each Mo group was sub-divided into three Cu treatments, viz. 24, 40 and 68 mg Cu/sheep/day. No difference in Cu accumulation in the livers was observed between the different levels of dietary Mo. A linear increase in hepatic Cu content was recorded, depending on total Cu intake and independent of duration of Cu feeding. Between 1,18 and 1,97% of the Cu taken in, was retained in the livers. Indications of the existence of interactions between Cu and Fe and between Cu and Zn were obtained from Fe and Zn concentrations in the livers.

Although total Mo intakes during the experimental periods were approximately the same, Mo concentrations in the livers, kidney cortices and plasma were significantly higher (P < 0.01) at a Mo intake of 38 mg/sheep/day than at 21 mg Mo/day. It was concluded that Mo concentrations in these body tissues are of a fairly transient nature, being related, at a constant S intake, not to total intake of Mo but to the daily amount of Mo consumed.

The metabolism of Cu in the body is characterised by its complexity. According to Abdellatif (1968) practically no other trace element exceeds Cu in the diversity of the factors which govern its absorption, excretion and utilization. This is clearly demonstrated by Suttle (1974a) who pointed out that diets of similar Cu content may produce clinical symptoms of either deficiency or toxicity. Therefore, although the Cu content of the feed can be used as a guide to evaluate the feed as a source of Cu, especially for potential Cu deficiencies (Truter & Louw, 1959) or excesses (Van Ryssen, Channon & Stielau, 1977), modifying factors will limit the value of such information.

The liver is the primary site of Cu storage in the ruminant body (Dick, 1954). Hepatic Cu levels can therefore be used to indicate the Cu status of animals, eg. concentrations below 20 mg Cu/kg dry liver could be indicative of Cu deficiency (MacPherson, Brown & Hemingway, 1964), while liver Cu levels above 600 mg/kg DM may indicate a potential Cu toxicity situation (Harker, 1976). However, to obtain hepatic Cu values for diagnostic purposes the animal has to be slaughtered or else liver biopsies must be taken. Harker (1976) suggested a formula to predict Cu levels from Cu intakes and the duration of feeding. The formula is based on a 10% Cu retention in the liver and assumes that no modifying factors are present.

Plasma Cu levels can remain within the normal range of 0,7 to 1,2 mg Cu/ℓ at high Cu intakes until the onset of the haemolytic crisis, the final stages of chronic Cu toxicity in sheep, when the plasma Cu level suddenly increases significantly (Todd, 1969). Elevated plasma Cu levels have been observed when high levels of Mo and of S were fed. The high plasma Cu levels were maintained up to the stage of induced Cu deficiency in the presence of high Mo and S intakes (Dick, 1956). Plasma Cu levels are, therefore, of no value as indicators of the Cu status of the animal except under conditions of Cu deficiency where MacPherson et al. (1964) found that low plasma Cu levels ($<$ 0,6 mg Cu/ℓ) could be associated with lower liver Cu concentrations.

The antagonistic effect of Mo in the presence of inorganic sulphate on the Cu metabolism in the ruminant was established before 1954 (Dick, 1954), and Suttle (1974c) proved that organic sulphur was as effective as inorganic sulphate in this interaction with Mo. Direct interactions between Cu, Mo and S in the body and in the digestive tract and between S and Cu in the digestive tract have been suggested (Huisingh, Gomez & Matrone, 1973; Dick, Dewey & Gawthorne, 1975; Suttle, 1975). These antagonistic effects of Mo and S on Cu metabolism have been exploited in practice to reduce the rate of hepatic Cu retention and the risk of Cu toxicity (Pope, 1975). However, caution is still necessary when using Mo and S to control Cu toxicity in sheep because of the complex nature of Cu metabolism in the body and the difficulty in predicting and monitoring the responses of Mo and S on Cu in the body (Harker, 1976). The danger exists that a state of Cu deficiency may be induced due to excess Mo consumption. The wide range of recommendations of Mo and S levels for treating or preventing Cu toxicosis in sheep, as summarised by Pope (1975), stresses the uncertainty prevalent in this field. Interactions of this kind complicate interpretations and also predictions regarding Cu metabolism in sheep. Against this background a trial was carried out in which different levels of Cu and Mo were fed to sheep in order to examine the responses in the body due to these minerals.

Procedure

Experimental animals, treatments and procedures

In this trial 56 Corriedale wethers between 1½ and 2 years of age were divided into seven groups of 8 sheep each. The treatments were:

Treatment P — a pre-experimental slaughter group;
Treatment 1 — high Cu, high Mo for 92 days;
Treatment 2 — medium Cu, high Mo for 92 days;
Treatment 3 — low Cu, high Mo for 92 days;
Treatment 4 — high Cu, medium Mo for 182 days;
Treatment 5 — medium Cu, medium Mo for 182 days;
Treatment 6 — low Cu, medium Mo for 182 days.

The groups receiving treatments 1, 2 and 3 were slaughtered after 92 days and the remaining 3 treatment groups after 182 days on the treatments. During the 182 days Groups 4, 5 and 6 received approximately the same total quantity of Mo as groups 1, 2 and 3 over 92 days.

Milled veld hay (predominantly *Themeda triandra*) and a concentrate mixture consisting of 69,4% maize meal, 22,8% commercial beef concentrate high in urea, 6,2% blood meal and 1,6% monocalcium phosphate were fed.

Additional Cu in the form of cupric sulphate and Mo as ammonium molybdate were included in the concentrates supplied. The sheep were group-fed once a day in concrete floored pens. Tap water was available *ad libitum*. The body masses of the sheep were determined once a month after 18 hours of starvation. Jugular blood samples were taken at regular intervals for the determination of haemoglobin and packed cell volume (PCV) in whole blood and Cu and Mo in the plasma. The sheep were slaughtered at the Pietermaritzburg abattoir and livers and kidneys were collected from each sheep. Samples were dried at 80° C for dry matter determinations. These dried samples were kept for further analyses.

Analytical methods

Cu, Fe, Zn and Mn contents of feeds and tissues were obtained using atomic absorption spectrophotometry after wet acid digestion. Plasma Cu was determined directly on diluted plasma. Ca, P and crude protein determinations were done on an auto-analyser and S according to the method of Blanchar, Rehm & Caldwell (1965). A molybdenum-iron-thiocyanate method as modified by Blamey (1971) was used for the Mo determination after a wet acid digestion. However, a 50 : 50 mixture of iso-amyl alcohol and chloroform was used as the extractant instead of carbon tetrachloride and iso-amyl alcohol. PCV was determined by a microhaematocrit method and haemoglobin with a Boehringer standard kit.

The F- and Student's t- tests were used to compare differences between treatments. Logarithmic transformations were employed to reduce differences in variance between treatments when this was indicated by Bartlett's test of homogeneity of variance (Snedecor, 1959).

Results

Feed intake and composition of rations

Each sheep consumed an average of 236 g of

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concentrate DM/day while the average veld hay intake per sheep was 770 g DM/day. The daily and total Cu, Mo and S intakes of the sheep are presented in Table 1. Total Mo intakes amounted to approximately the same quantity for each group, although the daily intakes per sheep differed depending on the length of the experimental period. The Cu : Mo ratios varied between 0,61 and 3,05. The average daily intakes of other nutrients per sheep were: 87 g crude protein, 10,8 g Ca, 3,3 g P, 41 mg Zn, 258 mg Mn and 707 mg Fe. The high level of Fe intake during this trial was due mainly to a high Fe content in the veld hay used (804 mg Fe/kg DM) and the contribution derived from the blood meal.

Table 1

Treatments and average copper, molybdenum and sulphur intakes

Treatments		Duration	Copper		Molybdenum		Sulphur	
		days	per day mg	total mg	per day mg	total mg	per day g	total g
P	Pre-experimental	0	—	-	—	—	—	—
1	High Cu, High Mo	92	69,7	6 412	37,7	3 468	2,13	196
2	Med Cu, High Mo	92	39,2	3 606	38,8	3 570	2,19	201
3	Low Cu, High Mo	92	24,2	2 226	39,7	3 652	2,06	190
4	High Cu, Med Mo	182	67,7	12 321	22,2	4 040	2,17	395
5	Med Cu, Med Mo	182	40,6	7 389	21,3	3 877	2,22	404
6	Low Cu, Med Mo	182	25,5	4 641	20,5	3 731	2,05	373

Clinical condition and body mass

No clinical sign of abnormality due to any treatment was observed during the trial. Changes in body mass at any one stage of the trial were not significantly different between treatments. An average increase in mass of 6,1 kg was recorded for the first 92 days of the trial and a further increase of 4,0 kg was observed in Groups 4, 5 and 6 during the last 90 days of the trial.

Mineral content of body tissues

(a) *Liver*

The amount and the concentration of Cu in the livers increased in direct proportion to the total amount of Cu consumed during the trial. This increase occurred independently of the daily amount of Cu consumed and was not influenced by the daily intake of Mo (Table 2). The linear increase in hepatic Cu content (Y) with increase in total Cu intake (X) is depicted in Fig. 1. The regression $Y = 8,55 + 0,0133X$ with $n = 48$ and $r = 0,719$ describes this relationship. Average hepatic Cu retentions during the trial were therefore relatively constant and represented between 1,18 and 1,97% of the total Cu intake. Variations in liver Cu, both within and between treatments, were large, eg. in Treatment 4 the liver Cu concentrations varied between 630 and 2 680 mg/kg DM. The variations in liver Cu content within treatments tended to increase with increasing Cu intakes and this tended to reduce the statistical significance of differences between treatment means.

Table 2

The levels and accumulation of Cu in the livers of sheep receiving different levels of Cu and Mo

Treatments	Total Cu intake mg	Concentration mg Cu/kg DM	Total Cu content mg	Liver (± SE of mean) Average* Cu retention %	Mean log Cu concentration	Mean log Total Cu
P	0	346 ± 51	41 ± 6,8	0	2,500	1,563
1	6 412	1 013 ± 94	131 ± 13,1	1,49	2,994	2,104
2	3 606	715 ± 49	94 ± 7,1	1,59	2,846	1,963
3	2 226	592 ± 73	80 ± 13,3	1,97	2,730	1,846
4	12 321	1 730 ± 215	218 ± 26,8	1,47	3,205	2,310
5	7 389	1 023 ± 87	123 ± 12,8	1,18	2,998	2,076
6	4 641	888 ± 82	111 ± 14,1	1,60	2,934	2,021
LSD 5%					0,162	0,176
1%					0,216	0,236

*Given as % of total Cu intakes after subtraction of pre-experimental liver Cu levels. These levels were calculated from body mass of sheep at onset of trial relative to that of pre-experimental slaughter group and its average liver Cu concentration.
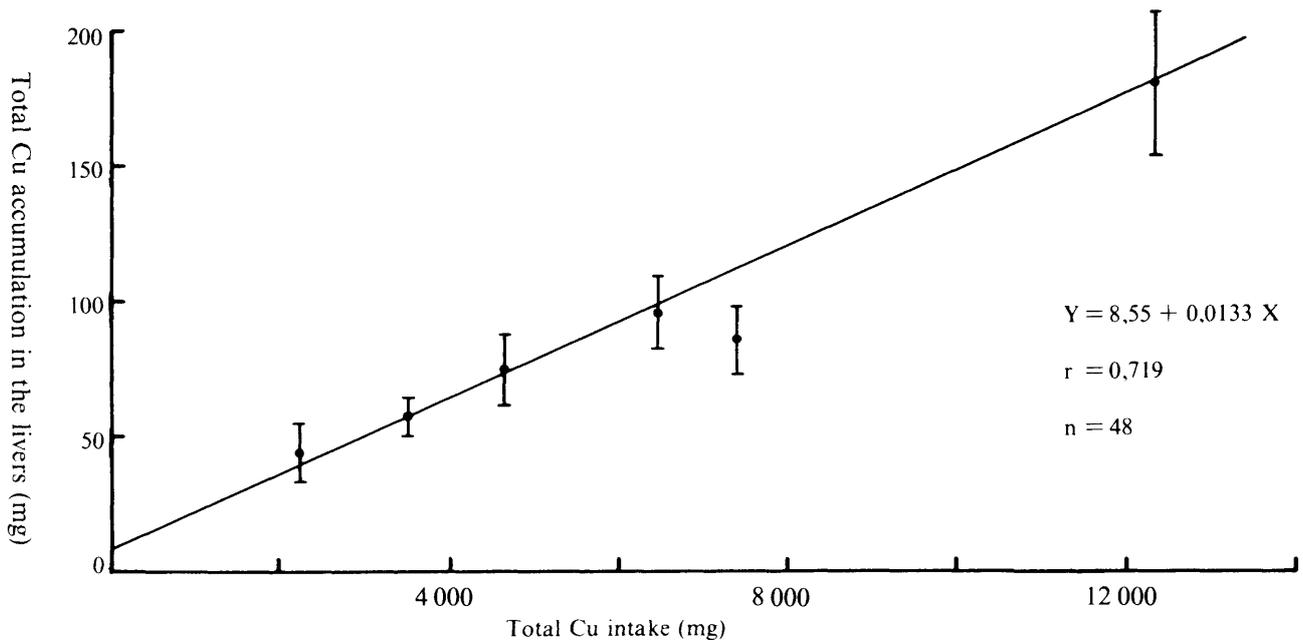

Fig. 1   Total Cu accumulation in the livers of sheep at different intakes of Cu. Vertical bars represent SE of means

In contrast to Cu, the accumulation of Mo in liver was related not to the total intake of Mo, but to the daily amount of Mo consumed (Table 3). Significantly more Mo (P < 0,01) was retained at the high daily intake levels than at the low, even though the total amount of Mo fed in each treatment was the same. When compared with Cu, however, the fraction of the total Mo consumed which accumulated in the liver was considerably less.

Table 3

The level and accumulation of Mo in the livers of sheep receiving different dietary levels of Cu and Mo

Treatment	Intake mg	Molybdenum** (± SE of mean) Concentration mg/kg DM	Molybdenum** (± SE of mean) Total content mg	Retention* %
P	0	$2,9^a \pm 0,31$	$0,34^a \pm 0,047$	0
1	3 468	$28,1^{bd} \pm 1,60$	$3,62^b \pm 0,211$	0,095
2	3 570	$24,4^{bd} \pm 3,01$	$3,18^b \pm 0,350$	0,080
3	3 652	$27,6^{bd} \pm 2,41$	$3,69^b \pm 0,412$	0,092
4	4 040	$9,5^b \pm 0,83$	$1,21^a \pm 0,123$	0,022
5	3 877	$9,9^b \pm 0,68$	$1,19^a \pm 0,096$	0,022
6	3 731	$9,5^b \pm 0,60$	$1,15^a \pm 0,067$	0,022

* Pre-experimental level subtracted; % of total Mo intake

**Values within columns with different superscripts denote significance at $P < 0,01$

The concentration of Fe in the liver (Table 4) during the trial tended to increase as the Cu intakes decreased. This was particularly evident in Treatment 6 (low Cu, medium Mo) where the Fe content of the liver was significantly higher ($P < 0,05$) than in the other treatments. The relatively low Fe concentration in the livers from Treatment 5 is difficult to explain; low Cu levels in the livers were also observed in this group.

Table 4

The concentration of Fe and Zn in the livers of sheep receiving different levels of dietary Cu and Mo (± SE of mean)

Treatment	Liver Fe* mg/kg DM	Liver Zn* mg/kg DM
P	$530^a \pm 52$	
1	$434^a \pm 49$	$115^a \pm 4,0$
2	$552^c \pm 51$	$109 \pm 3,3$
3	$548^c \pm 45$	$104^{bf} \pm 2,2$
4	$496^a \pm 81$	$128^{de} \pm 6,2$
5	$400^{ad} \pm 34$	$110^c \pm 5,6$
6	$697^b \pm 45$	$110^c \pm 3,5$

*Different superscripts within columns designate differences between treatment averages : a — b and c — d at $P < 0,05$ and e — f at $P < 0,01$ levels of significance.

The amount of Zn which accumulated in liver tended to follow the pattern of Cu storage (Table 4). Significantly higher amounts of Zn were present in the livers of sheep in Treatments 1 and 4 (high Cu). The presence of Mo had no apparent effect on the final Zn content of liver.

(b) *Kidney cortex*

The concentration of Cu in the kidney cortex increased significantly above the pre-experimental slaughter level. Differences between the other treatments were not statistically significant (Table 5). Although the difference in Zn level between Treatments 3 and 4 was significant ($P < 0,05$), no trend according to Cu or Mo treatment was apparent.

Table 5

Mean concentration of Cu, Mo and Zn in the kidney cortices of sheep receiving different dietary levels of Cu and Mo ($\pm$ SE of mean)

Treatment	Cu* mg/kg DM	Mo* mg/kg DM	Zn* mg/kg DM
P	11,9[a] $\pm$ 1,0		
1	23,4[c] $\pm$ 1,3	59,2[a] $\pm$ 5,3	90,4 $\pm$ 2,9
2	24,2[c] $\pm$ 1,0	49,1[a] $\pm$ 7,4	87,0 $\pm$ 3,4
3	22,2[c] $\pm$ 1,0	64,0[a] $\pm$ 7,7	93,6[a] $\pm$ 4,0
4	21,6[c] $\pm$ 1,6	16,2[c] $\pm$ 3,0	84,3[b] $\pm$ 3,2
5	17,7[b] $\pm$ 0,3	13,1[c] $\pm$ 1,6	90,1 $\pm$ 3,3
6	17,5[b] $\pm$ 0,5	12,2[c] $\pm$ 0,7	95,8 $\pm$ 2,4

*Different superscripts within columns designate differences between treatment averages:
a — c at $P < 0,01$ and a — b at $P < 0,05$ levels of significance.

The Mo concentration in the kidney cortex followed a similar pattern to that seen in livers, i.e. high liver concentrations in those groups receiving the high daily Mo intakes and low levels at the low daily intakes. The Fe concentrations of some kidney cortices in each of the treatments were exceptionally high, and for this reason these values are not reported here.

(c) Blood plasma

The Cu and Mo levels of plasma during the trial remained more or less constant during the different stages and averages are therefore presented (Table 6). No statistically significant differences were observed in the plasma Cu levels between treatments. Plasma Mo levels followed the same pattern as Mo concentrations in the livers and kidney cortices, with substantially higher levels at the high daily Mo intakes than at the low intakes.

Table 6

Average concentrations of Cu and Mo in plasma of sheep fed different levels of Cu and Mo

Treatments	Cu (mg/l) First 92 days	Cu (mg/l) Second 90 days	Mo (mg/l)* First 92 days	Mo (mg/l)* Second 90 days
1	1,10	—	7,5[a]	—
2	1,13	—	7,5[a]	—
3	0,93	—	6,4[a]	—
4	1,14	0,92	2,5[c]	2,5
5	1,03	1,00	3,7[c]	2,9
6	0,96	0,96	2,8[c]	1,8

*Different superscripts within columns designate differences at $P < 0,01$ level of significance.

Haematological parameters

No changes or significant differences were observed between treatments in PCV and haemoglobin levels. PCV levels remained fairly low from the onset of the trial and varied between 20 and 26%, while haemoglobin levels varied between 9 and 13 g/100 ml blood. Faecal worm egg counts revealed no traces of

internal parasite infestation as a possible explanation for this.

Discussion

Copper-molybdenum interaction

The presence of S is considered to be essential to the Cu-Mo interaction (Dick, 1954; Dick et al., 1975) and S is also believed to reduce Mo retention in the body. A dietary S intake of less than 2 g/sheep/day was effective in reducing hepatic Cu retention, presumably by its effect on the Cu-Mo interaction (Dick, 1954; Ross, 1966; Marcilese, Ammerman, Valsecchi, Dunavant & Davis, 1970; Bremner & Young, 1978). However, Grace & Suttle (1979) concluded that diets low in degradable SO_4^{2-} content did not favour the formation of thiomolybdates, compounds suggested by Suttle (1974b) and Dick et al. (1975) to bind Cu. Dick (1954) had previously found that increasing levels of SO_4^{2-} (rising from 1 g to 6 g/sheep/day) served to decrease hepatic Cu retention. The extent of the reduction depended on the concurrent intake of Mo. When the Cu and the SO_4^{2-} intakes were held constant, increased amounts of dietary Mo (from 20 mg to 100 mg/sheep/day) had little effect on liver Cu retention by sheep.

In the present trial the daily S intakes of all sheep were held constant at about 2,0 g per day, a level shown to be adequate for the promotion of the Cu-Mo interaction. The Cu and Mo intakes were varied in the different treatments giving Cu : Mo ratios over the range 0,6 to 3,0. Under these circumstances Mo failed to affect hepatic Cu retention. This finding is unexpected in the light of other reports (Dick, 1954; Ross, 1966; Harker, 1976).

Hepatic copper retention

The linear increase in Cu accumulation in the liver with the increase in Cu intake observed in this trial corresponded well with similar observations by Dick (1954), Hemingway & MacPherson (1967). However, much higher dietary Cu levels were required in the present trial to achieve liver Cu levels approximating those reported by Dick (1954) and Hemingway & MacPherson (1967). The proportion of dietary Cu retained in the liver was between 1,2 and 2,0% as compared to 3,3 to 5%, 2,96 to 3,01%, 4,4% and 3,2 to 8,3% reported by Dick (1954), MacPherson & Hemingway (1965), Hemingway & MacPherson (1967) and Suttle, Munro & Field (1978) respectively. With the use of hypocupraemic ewes and the Cu depletion-repletion technique, Suttle (1974a) found that the true availability of dietary Cu in the body of sheep varied between 4,1 and 11,4%.

The relatively low retention of dietary Cu in the livers of the sheep used in the present trial is difficult to explain. With the fixed level of dietary S, the two levels of Mo tested, had no apparent effect on Cu storage in the liver. However, since higher amounts of dietary Cu were necessary to achieve Cu levels in the liver similar to those reported by Dick (1954), it is possible that the Mo : SO_4^{2-} combination did have some inhibiting effect on the body storage of Cu. On the other hand, Huisingh & Matrone (1976) suggested the formation of CuS to be more significant in rendering Cu unavailable to the ruminant than the interaction of Cu with Mo, and a dietary S level of above 2 g/kg feed was suggested by Suttle (1974c) as essential for eliciting a depressing effect of S on Cu absorption. Availability of Cu will depend on the pool of ruminal S^{2-}. Huisingh & Matrone (1976) pointed out that Mo affected the pool of sulphide by inhibiting the reduction of SO_4^{2-} . However, with methionine as the source of S, Mo did not inhibit S^{2-} formation. They observed that Mo aggravated a state of Cu deficiency in sheep when methionine was the source of S but alleviated the Cu deficiency when SO_4^{2-} was supplying the S. In the present trial the S was probably mainly in the amino acid form which could lead to considerable S^{2-} formation even at a level of about 2 g/sheep/day. This may have contributed to the low Cu retention observed, similar to the observations by Huisingh & Matrone (1976).

It was not possible to establish to what extent the high Fe intakes during the trial contributed to the low liver Cu retention. Standish, Ammerman, Simpson, Neal & Palmer (1968) reported that high levels of dietary Fe (at 400 mg Fe/kg DM and above) decreased the availability of dietary Cu to cattle. Abdellatif (1968) made similar observations in sheep, but tested the effect only at very high Fe intakes. The decrease in liver Fe concentrations with increased Cu intakes, observed in the present trial, indicated that some interaction must have taken place between Cu and Fe.

The daily Zn intake of the sheep (41 mg/sheep/day) was well below the levels of 220 and 420 mg Zn/kg diet at which Bremner, Young & Mills (1976) observed decreased hepatic Cu retentions due to the Zn intakes. A tendency for hepatic Zn concentrations to increase with increased Cu intakes was observed in the present trial. This is in agreement with observations by Suttle & Mills (1966) and Gipp, Pond, Kallfelz, Tasker, Van Campen, Krook & Visek (1974) on pigs, and suggests the existence of some interaction between Cu and Zn in the body. The increase in liver Zn concentrations at high Cu intakes as observed by Suttle & Mills (1966) was considered to be a manifestation of Cu-induced Zn deficiency in pigs (Bremner & Marshall, 1974).

British sheep breeds have been found to be more susceptible to Cu toxicosis than Corriedales, with the Merino being the least susceptible of the sheep breeds

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tested (Edgar, Hindmarsh, Keast & Rose, 1941; Marston & Lee, 1948). Wiener & Field (1969) reported variations depending on breed, in the relationship between liver Cu levels and hypocuprosis observed in British sheep breeds. Variations in liver Cu content at the onset of the trial and possibly uneven Cu intakes, because of the group feeding regime, must have contributed to the wide variation observed in hepatic Cu content within treatments. This may explain the lower Cu and Fe retentions observed in Treatment 5 of this trial as compared with the other treatments. However, differences within treatment groups in the genetic ability of the sheep to absorb and/or to retain Cu may have been responsible for some of the variation. Todd, Gracey & Thompson (1962) observed a wide variation in hepatic Cu concentrations in sheep receiving the same dietary Cu levels. This would explain why usually only a small proportion of a flock succumb to Cu toxicity (Todd, 1969). It therefore seems possible that genetic differences due to sheep breeds may have been partly responsible for the lower hepatic Cu retentions observed in the present trial as compared with those of other workers.

Corbett, Saylor, Long & Leach (1978) suggested that the close relationship between dietary Cu and liver Cu as observed by Dick (1954) indicated the existence of very little homeostatic control over Cu absorption by sheep; this is contrary to the position reported for other species (Beck, 1963; Milne & Weswig, 1968; Fisher, Wise & Filmer, 1972; Hedges & Kornegay, 1973). However, Suttle et al. (1978) noticed some evidence for the existence of homeostatic control in the Cu absorption and retention in sheep at high Cu intakes. In the present trial this linear relationship extended to well within the range of hepatic Cu concentrations at which Cu toxicity can be expected (Harker, 1976) and well above the levels recorded by Suttle et al. (1978). Dick (1954) had also observed a slightly decreased Cu retention at his highest level of dietary Cu intakes. Neethling, Brown & De Wet (1968) measured not only a reduced absorption of Cu⁶⁴ at high doses, which they ascribed to some regulatory mechanism at high Cu intakes, but also increased Cu absorptions in Cu-depleted sheep. In view of these observations by Neethling et al. (1968), true Cu availability estimates calculated with the use of the Cu depletion-repletion technique (Suttle, 1974a) may not give a true reflection of Cu availability under natural conditions.

Molybdenum metabolism

Mo concentrations in the liver, kidney cortex and plasma in the present trial seemed to follow the level of Mo intake. This implies that the Mo concentration in these organs may be used as parameters of the Mo status of sheep. Cunningham & Hogan (1959) found the Mo concentrations of the bone, kidneys and spleen to be related to Mo intakes. Lesperance & Bohman (1963) suggested the use of Mo levels in plasma and liver as indicators of the Mo status and the danger of Mo toxicity in cattle. Symptoms of molybdenosis per se, viz. diarrhoea and anorexia, as observed in cattle, are seldom encountered in sheep (Cunningham & Hogan, 1959; Ward, 1978). Furthermore, the observation in the present study that the Mo levels in the organs and plasma tended to vary depending on levels of daily Mo intake, rather than total Mo intake during the trial, indicates that Mo in the sheep body is fairly transient, irrespective of Cu intake. This would limit the value of tissue Mo concentrations in predicting the overall Mo status of an animal, though high plasma Mo levels would indicate excessive Mo intakes on a short term basis (Lesperance & Bohman, 1963).

Molybdenosis as observed in sheep is usually expressed in the form of induced hypocuprosis. The presence of S in the diet was found to be essential to elicit this action of Mo on Cu in the body (Dick, 1954; Suttle, 1974c). However, the addition of S to a diet is also accompanied by a decrease in tissue Mo concentrations (Dick, 1956). Plasma and tissue Mo levels would be, therefore, of little value in predicting induced hypocuprosis in sheep. In fact, low plasma and tissue Mo levels may be even potentially more dangerous than high levels. The use of a Cu : Mo ratio in feed as suggested by Miltimore & Mason (1971) for predicting the risk of molybdenosis in cattle, would also be unreliable for predicting induced hypocuprosis in sheep if the S content of the diet is unknown. This is well demonstrated in the present trial where 6 different ratios of Cu : Mo were fed, without affecting hepatic Cu retentions.

Acknowledgements

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