Tropical Grasslands (1995) Volume 29, 47–52

Effects of soil origin and mineral composition and herbage species on the mineral composition of forages in the Mount Elgon region of Kenya.
2. Trace elements

I.O. JUMBA[1], N.F. SUTTLE[2], E.A. HUNTER[3] AND S.O. WANDIGA[1]

[1]*Department of Chemistry, University of Nairobi, Nairobi, Kenya*
[2]*Moredun Research Institute, Edinburgh, Scotland*
[3]*Scottish Agricultural Statistics Service, The University of Edinburgh, Edinburgh, Scotland*

Abstract

Samples of topsoil and herbage from 135 sites in the Mt Elgon region of Kenya were classified according to farm, site altitude, underlying soil bedrock (6 types) and botanical composition (6 classes). Effects of altitude, bedrock and species on pasture concentrations of Co, Cu, Fe, Mn, Mo, Se and Zn were determined using a mixed model for unbalanced data sets and the Wald statistic (W) to assess statistical significance. Extractable concentrations of each element in the soil were measured at each site except for Se where total Se was used.

Cu values were particularly low in forages associated with tertiary volcanic bedrock (3.8 ± 0.34 mg/kg DM), but even the maximal values (5.4 ± 0.34 mg/kgDM on metamorphosed sedimentary material) were marginal for ruminants. Se and Cu concentrations were usually low at low altitudes but no other significant effects of altitude or geology on herbage trace element concentrations were found. For Cu and Se alone, geological and topographical maps may help to delineate areas where risks of deficiency are high or low. Herbage composition was poorly correlated with total (Se) or extractable (other trace elements) concentrations in the soil.

Species differences were important for all elements except Se, with kikuyu grass (*Pennisetum clandestinum*) the richest in all but Mn. For Cu and Zn, deficiencies were most likely to occur with rhodes grass (*Chloris gayana*) with 3.5 mg Cu and 19.5 mgZn/kg DM and setaria (*Setaria sphacelata*) with 3.9 mg Cu and 17.7 mg Zn/kg DM. Species differences in Mo were within a low range of values (derived means < 1.6 mg/kgDM) but may, in combination with S, influence Cu availability. The lowest mean Se value (0.047 mg/kgDM in setaria) was inadequate for ruminants. Species variation in Co, Fe and Mn was significant but values were consistently above animal requirements and for Co and Fe were probably influenced by soil contamination.

Introduction

It has been reported that the mineral concentrations of herbage samples taken from the Mt Elgon region of Kenya were low enough to suggest a risk of deficiency in grazing livestock for 7 of the 11 macro- and trace elements studied (Jumba *et al.* 1994). In searching for factors associated with low macro-mineral levels, it was found that herbage species had considerable influence on the Ca, Mg and S concentrations in forages in the area but underlying soil bedrock and altitude exerted little influence (Jumba *et al.* 1995). Herbage P concentrations were weakly affected by altitude, increasing with height above sea level. Altitude, geology and soil pH have been reported to affect the Se, Mo and Co status of pastures (Long and Marshall 1973; Thornton and Alloway 1974; Burridge *et al.* 1983) or the animals that graze them (Blaxter 1963; Langlands *et al.* 1981a, 1981b). We therefore investigated the influence of altitude, geology, soil mineral composition and herbage species on the concentrations of 7 trace elements (Cu, Co, Fe, Mn, Mo, Se and Zn) in the same forages from 135 sites on 84 different farms in Kenya.

Correspondence: N.F. Suttle, Moredun Research Institute, 408 Gilmerton Road, Edinburgh EH17 7JH, Scotland

Materials and methods

Details of the procedures used for sampling herbage and soil, for chemical analysis of the samples and for statistical analyses have been reported previously (Jumba *et al.* 1994; 1995). All samples were collected in the dry season (January–March) with herbage at the hay stage. Four principal grass species were compared: kikuyu (*Pennisetum clandestinum*), napier (*Pennisetum purpureum*) and rhodes (*Chloris gayana*) grasses and setaria (*Setaria sphacelata*). Concentrations of extractable trace elements in the soils were estimated using the following extractants: 1M ammonium acetate, pH 7.0 for Mn and Mo; 0.1M HCl + 0.0125M H_2SO_4 for Cu and Zn; 0.5M acetic acid, pH 2.5 for Co; 1M ammonium acetate, pH 4.8 for Fe. Methods were chosen on the basis of recovery tests and the choice validated by comparisons with other extractants for correlations with herbage mineral concentrations (Jumba 1989). Total soil Se was measured by the method given previously for herbage Se (Jumba *et al.* 1994).

A mixed model was used to test for main effects of bedrock, species and altitude (Jumba *et al.* 1995). Any data set which was not normally distributed was transformed using $\log_{10}$ prior to model fitting. The model allowed comparisons of soil characteristics to be made between species. Although the species will obviously not affect soil composition, species might have been chosen according to soil characteristics, creating bias; for simplicity these will be termed 'species-site' effects. The model for herbage composition was augmented, where appropriate, by including soil characteristics as covariates (e.g. for herbage Cu, covariates were soil Cu and soil pH).

Results

Effects of geology

There were significant effects of geology on the extractable concentrations of all elements in the soil (Table 1), the effect being largest for Cu ($P < 0.001$) and least for Mo ($P < 0.01$). The igneous granites were associated with low values for all extractable elements other than Fe, whereas soils with volcanic associations were low in Fe but high in all other extractable elements. The correlation matrix thus showed significant negative correlations between soil Fe and other extractable elements, particularly Mn ($r = -0.46$), and positive correlations amongst the other elements, notably Mn and Cu ($r = 0.56$). Total soil Se concentrations were not related to soil bedrock.

The influence of geology on soil composition was not translated to the herbage. The only element to be affected by soil bedrock associations was herbage Cu which was low over volcanic and metamorphic gneiss bedrock and high over metamorphosed sedimentary material. There was a tendency for herbage Fe to be lowest in association with igneous granite and metamorphosed sedimentary material.

Herbage species

Botanical composition (Table 2) affected herbage concentrations of all the trace elements except Se, effects being greatest for Cu ($P < 0.001$) and Fe ($P < 0.001$) and smallest for Mo ($P < 0.01$). The effects of species were not biased in that species-site effects on soil composition were confined to Mn and Se and did not correlate with differences in herbage composition. There was a tendency for sites with kikuyu to be associated with higher soil pH. Kikuyu had the highest concentrations of Cu, Co, Se and Zn; it was, however, relatively low in Mn. By contrast, setaria was generally a poor source of all elements with the exception of Mn. Rhodes grass was a poor source of Cu, Mo and Zn and napier grass a relatively poor source of Co and Fe. The natural mixed grasses were of intermediate value as trace element sources.

Altitude

The mixed model indicated several significant W statistics for effects of altitude on herbage composition but significant regression coefficients in the augmented model were less common, only Cu and Se being affected (Table 2). No high Cu (> 6 mg Cu/kg DM) or Se (> 0.1 mg Se/kg DM) values were found below 1520 m although values ranged widely at higher altitudes.

Discussion

Effects of geology

The effects of soil bedrock on trace element concentrations in soils were stronger than those on macro-element composition (Jumba *et al.* 1995)

Table 1. Effects of soil bedrock on the trace mineral composition of herbage (H) and soils (S) (mg/kg DM) and soil pH at 135 sites in Kenya. Arithmetic or derived means are given together with the range of standard error of differences between means (s.e.d.m.) and Wald (W) statistics.

Soil bedrock[1] No. of samples	TV 20	IG 17	MS 10	MG 60	SSG 9	AD 19	s.e.d.m. min (60)	 max (9)	W	Signif.[4] of diff.
H Mo	0.81	1.19	0.66	0.99	0.99	0.77	0.089[3]	0.187[3]	4.5	ns
H Fe	355	270	280	349	341	338	42.9	80.4	9.2	ns
H Mn	210	240	213	236	231	228	22.0	41.4	5.7	ns
H Zn	22.7	25.1	24.7	27.6	27.6	26.1	3.01	5.68	1.1	ns
H Se[2]	67	52	70	75	95	61	0.105[3]	0.217[3]	3.0	ns
H Cu	3.75	4.14	5.43	4.13	4.00	4.48	0.335	0.699	15.1	**
H Co	0.25	0.23	0.22	0.21	0.18	0.21	0.037[3]	0.068[3]	2.9	ns
S pH	5.67	5.24	4.95	5.23	4.96	5.17	0.163	0.303	13.2	*
S Mo	2.26	1.14	1.26	1.74	1.64	1.63	0.250	0.464	15.6	**
S Fe	289	616	554	559	341	509	97.5	181.5	11.3	*
S Mn	1408	629	770	1014	1194	1043	129	239	7.1	***
S Zn	4.23	1.75	1.81	2.70	3.29	2.09	0.085[3]	0.158[3]	18.6	**
S Se[2]	298	269	333	305	297	301	49.8	92.5	0.9	ns
S Cu	4.65	0.68	1.17	1.56	5.61	1.33	0.120[3]	0.222[3]	45.6	***
S Co	1.47	0.70	0.79	1.02	1.86	1.17	0.189	0.349	22.5	***

[1] TV = tertiary volcanic; IG = igneous granite; MS = metamorphosed sedimentary; MG = metamorphic gneisses; SSG = sedimentary sandstone and grits; AD = alluvial deposits.

[2] Se in ug/kg DM.

[3] Log$_{10}$ transformation needed; back-transformed means given but standard errors are for the transformed values.

[4] $P < 0.05$, *; $P < 0.01$, **; $P < 0.001$, ***; $P > 0.05$, ns.

Table 2. Effects of botanical composition on trace element concentrations in herbage (H) samples from Kenya (mg/kg DM). Standard errors of differences between means (s.e.d.m.) are given along with Wald (W) statistics to indicate significant contrasts. Significant differences in soil (S) characteristics between sites are also shown.

Botanical composition[1] No. of samples	Pp 39	Ss 9	Cg 48	Pc 9	Mng 14	s.e.d.m. min (48)	 max (9)	S	Signif.[5] of diff.
H Mo	0.85	0.66	0.64	1.50	1.05	0.070[4]	0.147[4]	13.7	*
H Fe	179	264	311	416	406	34.3	73.0	37.8	***
H Mn	181	304	239	152	205	17.8	38.0	32.6	***
H Zn	22.8	17.7	19.5	39.1	7.7	2.48	5.28	29.5	***
H Se[2]	64.7	47.2	73.8	73.8	80.0	0.058[4]	0.124[4]	7.0	ns
H Cu[3]	4.11	3.94	3.47	5.73	4.5	0.249	0.533	32.3	***
H Co	0.16	0.20	0.19	1.31	0.2	0.052	0.113	15.0	*
S pH	5.2	5.1	5.1	5.4	5.2	0.07	0.16	9.5	ns
S Mn	914	1046	1135	1046	1033	0.039[4]	0.083[4]	18.5	**
S Se	265	288	279	353	259	49.8	92.5	15.7	**

[1] Pp, *Pennisetum purpureum*; Ss, *Setaria sphacelata*; Cg, *Chloris gayana*; Pc, *Pennisetum clandestinum*; Mng, mixed natural grasses.

[2] Se in ug/kg DM.

[3] REML model for H Cu included significant quadratic effect of altitude^2 ($0.58 \pm 0.197 \times 10^{-6}$) as did that for log$_{10}$ H Se ($-0.125 \pm 0.0563 \times 10^{-6}$).

[4] Back-transformed means given with s.e.d.m. as log^{10} value for the transformed data.

[5] $P < 0.05$, *; $P < 0.01$, **; $P < 0.001$, ***; $P > 0.05$, ns.

but they were not expressed in the herbage. The only significant effect of geology on the herbage was that on Cu. This may reflect the fact that Cu is a relatively immobile element in the soil and does not yield readily to chemical extraction (Bowell and Ansah 1994). Geological maps may not be particularly useful in delineating areas of Cu deficiency within the Mt Elgon region because the soil types associated with the most Cu-deficient herbages, tertiary volcanics and metamorphic gneisses, cover about 75% of the region. Furthermore, the same 2 soil types were associated with relatively low concentrations of S in the herbage and this would enhance Cu availability (Suttle 1983).

Effects of soil composition

The striking feature of the soil composition data was the weak relationships with herbage composition (Table 3). For a given element, the strongest relationships (for Co and Se) accounted for less than 13% of the variation. For Cu, there was an 8-fold variation in extractable soil Cu but no relationship with the concentration in herbage, tertiary volcanics being distinguished by relatively low herbage Cu and high soil Cu. Of particular concern was the failure of soil analysis to predict the nutritionally inadequate Cu levels in herbages (cf. ARC 1980) on sedimentary sandstone and grits soils which contained nearly 4-times the extractable value regarded as borderline (1.5mg Cu/kg DM; COSAC 1982). The limited usefulness of extractable Cu concentrations in soils has been reported by others (e.g. McFarlane 1989).

For some elements, the lack of relationship between soil and plant composition was unimportant because the soil status was uniformly high (e.g. Co). For others, such as Mn, 'inadequate' levels in soils (< 3 mg/kg DM; Minson 1990) were not reflected in the herbage which greatly exceeded the ruminant's Mn requirement (ARC 1980). Comparisons made between 3 different extractants on 12 soil samples showed excellent agreement between methods (Jumba 1989), so that prediction of herbage composition is unlikely to be improved by choosing a different extraction method from those now in common use. These results agree with those forming part of a collaborative FAO study of the value of 3 different soil extractants for predicting the Cu, Fe, Mn and Zn concentrations of winter wheat at the beginning of flowering. It was concluded that none gave sufficiently precise estimates of trace element concentration (Piotrowska *et al.* 1989). During the dry season, soil trace element analysis would appear to be of little value in predicting the composition of herbage. Both soil composition and its relationship with herbage composition may, however, change during the rainy season.

Effects of herbage species

Few field studies have been made of the effects of plant species on the trace element composition of tropical pastures, although, in a large study (1812 samples) in which effects on soil type were probably small, large species differences in Co, Cu, Mn, Mo and Zn were reported (Long *et al.* 1970). Long and Marshall (1973) reported relatively low Se concentrations in legumes compared with grasses. The results now presented indicate that the replacement of mixed natural pasture with single-species, sown leys will affect mineral nutrition, sometimes improving it, sometimes diminishing it, depending on the species and the element. The apparent benefits of kikuyu over other species for most elements have not been reported before but they may disappear when livestock requirements are related to digestible energy concentration and rate of production. On the other hand, the improvement of digestibility

Table 3. Correlation coefficients for the linear relationships between concentrations of a given trace element in herbage (H) and soil (S).

H Mo	-0.038	–0.132	–0.039	0.278	–0.097	–0.067	–0.047	0.345
H Fe	-0.227	–0.117	0.336	0.141	–0.028	0.183	0.183	0.040
H Mn	0.122	0.203	0.034	–0.237	0.034	–0.010	0.073	–0.330
H Zn	0.065	0.072	–0.002	0.055	–0.052	0.056	0.018	–0.001
H Se	-0.125	–0.191	0.156	0.202	0.287	0.097	0.030	–0.042
H Cu	-0.059	–0.177	0.049	0.282	0.006	0.085	0.080	0.053
H Co	0.272	–0.269	0.337	0.159	0.073	0.201	0.353	–0.019
	S Mo	S Fe	S Mn	S Zn	S Se	S Cu	S Co	S pH

of stemmier species by providing rumen-degradable energy and nitrogen without trace elements would exacerbate their shortcomings.

The ranking of the Cu concentrations (rhodes > setaria > napier grass) agrees with Long *et al.* (1970) despite the much lower absolute values in the present study. However, the effects of botanical composition on the mineral value of forages may be influenced by interactions between minerals and this is particularly true for Cu. Species differences in herbage S (Jumba *et al.* 1994) may influence Cu absorption in grazing animals, through the Cu by S and Cu by Mo by S antagonisms (e.g. Whitelaw *et al.* 1979), despite the fact that conservation of grass as hay weakens these antagonisms (Suttle 1983) and most of the grasses were sampled at the hay stage. The antagonisms can be quantified by expressing herbage copper in terms of absorbable or available copper using separate equations for grass and hay which predict the interdependent effects of Mo and S on Cu absorption (Suttle 1983). Predicted available Cu values for the 4 main species are given in Table 4. Appropriate values for napier and kikuyu grasses may be closer to those given by the "Grass equation" as nearly all the sampled material was green. The "Grass equation" predicted values which were 2–3 times less than those for the "Hay equation" and the differences were biggest for kikuyu. Thus, the apparent advantage of animals grazing kikuyu swards high in Cu may be largely offset by the parallel increases in Mo and particularly in S. The higher Mo concentration in napier grass than in setaria agrees with Long *et al.* (1970).

Table 4. Species differences in available copper calculated by prediction equations (Suttle 1983) from Cu, Mo (Table 2) and S (Jumba *et al.* 1995) concentrations in the pastures.

Species	Available copper (mg/kg DM)	
	Grass equation	Hay equation
P. purpureum (napier grass)	0.135	0.303
S. sphacelata (setaria)	0.141	0.308
C. gayana (rhodes grass)	0.107	0.251
P. clandestinum (kikuyu grass)	0.127	0.383

The marginal Se status of most Kenyan pastures may reflect the high annual rainfall (1440–1515 mm) in the area, since the Se status of pasture and grazing livstock decreases as rainfall increases (Caple *et al.* 1980; Langlands *et al.* 1981b). All the species had mean Se levels slightly above the ruminant requirement (0.05 mg Se/kg DM; ARC 1980) except setaria which may adapt poorly to a low soil Se concentration (Johnson 1975). Ruminants grazing napier grass on igneous or alluvial soils at low altitudes may also be at risk from Se deficiency in the Mt Elgon region. It is under such conditions that the first Se supplementation trials should be initiated. Seasonal fluctuations in herbage Se have been reported in neighbouring Uganda with minimum values being found in October and November (Long and Marshall 1973). If such trends are repeated in Kenya, risk of Se deficiency may have been underestimated by a dry season (January–March) survey.

Species variation in herbage Co and Mn was much greater in wet season pastures (Long *et al.* 1970) than in our dry season pastures. Long *et al.* (1970) found deficient Co concentrations in napier grass. Soils can contaminate herbage with Co (Fleming 1973) and species of different habit may vary in Co concentration, not because of differences in accumulation but through differences in soil contamination. These differences may vary with rainfall. The higher Co values in kikuyu than in napier grass (Table 2) may reflect higher soil contamination of the former species due to a more prostrate growth habit (Bogdan 1977). Soil also contaminates herbage with Fe and kikuyu had the highest Fe concentrations. When herbage Fe was used as a covariate in the mixed model, species effects on herbage Co were much less significant. Since soil ingestion lowers Cu availability (Suttle *et al.* 1984), kikuyu may lose more of its apparent superiority as a source of Cu for ruminants through increases in soil ingestion.

Long *et al.* (1970) reported greater species variation in herbage Zn than observed in our study although the overall means were similar. They too reported a low value for rhodes grass. While there should be no risk of Zn deficiency on kikuyu pastures, mean values for setaria and rhodes grasses in the Mt Elgon region are sufficiently close to the minimum requirement (see ARC 1980) to suggest problems at the lowest levels, since livestock do not store Zn in times of excess. If Zn deficiencies are confirmed in supplementation trials, the higher concentrations in kikuyu may be usefully exploited as an alternative to dietary Zn supplementation.

The effects of botanical composition on trace element concentrations does not explain the lack of influence of soil composition or geology; soil-herbage relationships remained weak when all factors were included in the mixed model.

Acknowledgements

We are indebted to the British Council, the German Academic Exchange (DAAD) and the Scottish Office Agriculture and Fisheries Department (SOAFD) for financial support.

References

Agricultural Research Council (ARC) (1980) *The Nutrient Requirements of Ruminant Livestock.* (Commonwealth Agricultural Bureaux: Farnham Royal).

Blaxter, K.L. (1963) The effect of selenium administration on the growth and health of sheep on Scottish farms. *British Journal of Nutrition,* **17,** 105–115.

Bogdan, A.V. (1977) Ed. *Tropical Pasture and Fodder Plants (Grasses and Legumes).* Tropical Agriculture Series. (Longman: London and New York).

Bowell, R.J. and Ansah, R.K. (1994) Mineral status of soils and forages in the Mole National Park Ghana and implications for wildlife nutrition. *Environmental Geochemistry and Health.* (in press).

Burridge, J.C., Reith, J.W.S. and Berrow, M.L. (1983) Soil factors and treatments affecting trace elements in crops and herbage. In: Suttle, N.F., Gunn, R.G., Allen, W.M., Linklater, K.A. and Wiener, G. (eds) *Trace Elements in Animal Production and Veterinary Practice.* pp.77–86. *Occasional Publication No. 7. British Society of Animal Production.*

Caple, I.W., Andrewartha, K.A., Edwards, S.J.A. and Halpin, C.G. (1980) An examination of the selenium nutrition of sheep in Victoria. *Australian Veterinary Journal,* **56,** 160–167.

Council Of Scottish Agricultural Colleges (COSAC) (1982) Trace element deficiency in ruminants. Report of a Scottish Agricultural Colleges and Research Insitutes Study Group, Edinburgh.

Fleming, G.A. (1973) Mineral composition of herbage. In: Butler, G.W. and Bailey, R.B. (eds) *Chemistry and Biochemistry of Herbage.* pp.529–563. (Academic Press: London).

Johnson, C.M. (1975) Selenium in soils and plants: contrast in conditions providing safe but adequate amounts of selenium in the food chain. In: Nicholas, D.J.D. and Egan, A.R. (eds) *Trace Elements in Soil-Plant-Animal Systems.* pp.165–180. (Academic Press: London).

Jumba, I.O. (1989) *Tropical soil-plant-animal interactions in relation to mineral imbalances in grazing livestock.* Ph.D. Thesis. University of Nairobi, Kenya.

Jumba, I., Suttle, N.F. and Wandiga, S.O. (1994) The macro mineral composition of forages in the Mount Elgon region of Kenya. *Tropical Agriculture (Trinidad).* (in press).

Jumba, I., Suttle, N.F., Hunter, E.A. and Wandiga, S.O. (1995) Effects of soil origin and mineral composition and herbage species on the mineral composition of forages in the Mount Elgon region of Kenya. 1. Calcium, phosphorus, magnesium and sulphur. *Tropical Grasslands,* **29,** 40–46.

Langlands, J.P., Wilkins, J.F., Bowles, J.E., Smith, A.J. and Webb, R.F. (1981a) Selenium concentrations in the blood of ruminants grazing in northern New South Wales. I. Analysis of samples collected in the National Brucellosis Eradication Scheme. *Australian Journal of Agricultural Research,* **32,** 511-521.

Langlands, J.P., Bowles, J.E., Smith, A.J. and Donald, G.E. (1981b) Selenium concentrations in the blood of ruminants grazing in Northern New South Wales. II. Relationship with geological, pedological and other variables. *Australian Journal of Agricultural Research,* **32,** 523–533.

Long, M.I.E., Thornton, D.D., Nydanabo, W.K., Marshall, B. and Ssekaalo, H. (1970) The mineral status of dairy farms in parts of Buganda and Busoga bordering Lake Victoria, Uganda. II Nitrogen and mineral content of pastures. *Tropical Agriculture (Trinidad),* **47,** 37–50.

Long, M.I.E. and Marshall, B. (1973) The selenium status of pastures in Uganda. *Tropical Agriculture (Trinidad),* **50,** 121–128.

McFarlane, J.D. (1989) The effect of copper supply on vegetative and seed yield of pasture legumes and the field calibration of a tissue test for detecting copper deficiency. I. Subterranean clover *(Trifolium subterraneum* and *Trifolium yanninicum). Australian Journal of Agricultural Research,* **40,** 817–832.

Minson, D.J. (1990) *Forages in Ruminant Nutrition.* (Academic Press: London).

Piotrowska, M., Kabata-Pendias, A. and Dudka, S. (1989) Testing of common soil extractants for Cu, Fe, Mn and Zn available to winter wheat. *Proceedings of 6th International Trace Element Symposium, Friedrich-Schiller Universitat, Jena.* Vol 2, pp.403–410.

Suttle, N.F. (1983) Assessment of the mineral and trace element status of feeds. In: *Feed Information and Animal Production. Proceedings of the Second Symposium of the International Network of Feed Information Centres,* pp.211–237. (Commonwealth Agricultural Bureaux: Farnham Royal).

Suttle, N.F., Abrahams, P. and Thornton, I. (1984) The role of a soil x dietary sulphur interaction in the impairment of copper absorption by ingested soil in sheep. *Journal of Agricultural Science,* **103,** 81–86.

Thornton, I. and Alloway, B.J. (1974) Geochemical aspects of the soil-plant-animal relationship in the development of trace element deficiency and excess. *Proceedings of the Nutrition Society,* **33,** 257–267.

Whitelaw, A., Armstrong, R.H., Evans, C.C. and Fawcett, A.R. (1979) A study of the effects of copper deficiency in Scottish Blackface lambs on improved hill pasture. *Veterinary Record,* **104,** 455–460.

(Received for publication December 8, 1993; accepted July 29, 1994)