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Stream sediment, soil and forage chemistry as indicators of cattle mineral status in northeast Zimbabwe

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Abstract: Results of previous studies investigating the use of soil and forage chemistry as indicators of cattle mineral status have been somewhat equivocal, possibly due to the limited range of trace element concentrations in the areas investigated. This paper describes an investigation of the relationship between trace element concentrations in stream sediments, soils, forage (grass and leaves) and cattle blood (serum) in northeast Zimbabwe in order to identify which, if any, of the sample media provide a reliable guide to cattle mineral status. Soil, forage and cattle serum were collected from an area characterized by a wide range of Zn in stream sediments. The area was subdivided into three regions of relatively low, medium and high Zn concentration on the basis of stream sediment data and variations in the chemistry of cattle serum, forage, soil and stream sediment samples were examined. Significant correlations exist between element concentrations in stream sediments, soils and forage but there are no significant correlations with cattle serum. Although this lack of direct correlation may, in part, be due to a range of biological factors, it is suggested that high concentrations of Fe in soil and forage inhibit (i) the availability of P to plants and (ii) the absorption of Cu and Zn in cattle. This may have wide ranging implications due to the predominance of ferrallitic soils in many countries in tropical regions.

The main causes of low production and reproduction rates amongst grazing livestock in many developing countries are probably linked to undernutrition. However, mineral deficiencies and imbalances in forages also have a negative effect. Trials in South America have demonstrated that mineral supplementation significantly improves calving rates and weight gains (McDowell *et al.* 1993). Although dietary mineral supplementation is commonly practised in developed countries, in the developing world grazing livestock are often totally dependent on indigenous forage for their mineral intake. As farmers are encouraged to seek higher levels of productivity from forage fed livestock, it will become increasingly important to identify those areas where trace element deficiencies are negatively affecting animal productivity.

The majority of trace element imbalances in animals do not result in diagnostic clinical symptoms; effects are sub-clinical and difficult to detect without thorough investigations. The assessment of areas with trace element deficiency or toxicity problems in grazing livestock has traditionally been executed by mapping spatial variations in soil, forage, animal tissue or fluid compositions. Soil and forage surveys generally employ high density, detailed sampling techniques in order to obtain representative results because soil chemistry can vary considerably on a local scale and because the trace element content of vegetation varies between species, ecotype and with plant maturity (McDowell *et al.* 1993). In addition, animal studies often require that samples are refrigerated and analysed soon after collection. In developing countries, where there is often a lack of biological and pedological information over large areas, these methods may prove too expensive and logistically impractical for reconnaissance assessment.

Stream sediment geochemical mapping may provide a more practical alternative to soil, forage and animal assessment methods. It is generally accepted that stream sediment sampling is more representative and cost effective than soil or vegetation sampling for rapid reconnaissance geochemical surveys (Levinson 1980). In addition, stream sediment data can be used for several purposes including mineral exploration and environmental studies. Previous studies in temperate regions have demonstrated that stream sediment geochemical mapping can be used to delineate areas where trace element deficiencies or excesses could prejudice animal health (Plant & Thornton 1986; Aggett *et al.* 1988). Regional stream sediment geochemical datasets collected principally for mineral exploration already exist in many developing countries (Plant *et al.* 1988). The application of these data for animal health studies in tropical regimes has been examined in general terms (Appleton 1992; CTVM 1992; Appleton & Ridgway 1993). However, quantitative correlations between stream sediment trace element

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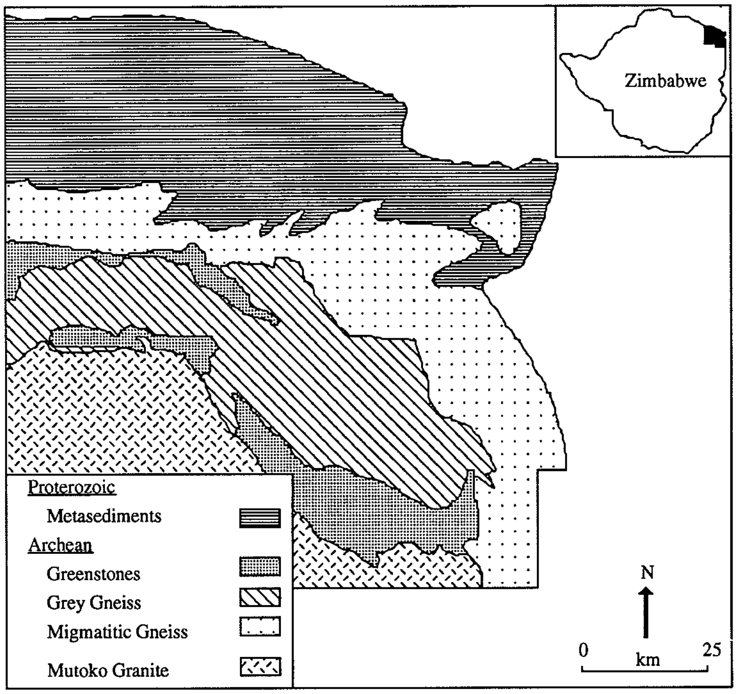


Fig. 1. Simplified geological map of northeast Zimbabwe (modified after Barton *et al.* 1991). Inset shows location of field area.

levels and livestock mineral levels have not been clearly established and no detailed investigations into these relationships in tropical environments have been carried out.

This paper describes an investigation of the relationship between trace element concentrations in stream sediments, soils, forage (grass and leaves) and cattle blood (serum) in northeast Zimbabwe in order to identify which, if any, of the sample media provide a reliable guide to cattle mineral status.

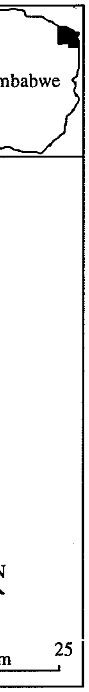
Methodology

Study area

An area of communal grazing land in northeast Zimbabwe, farmed on a subsistence basis by small family groups, was selected for the investigation because high quality stream sediment data already existed as a result of a previous ODA funded project (Dunkley 1987). The study area (Fig. 1) comprises 9000 km^2 of tropical, seasonally wet terrain in the districts of Mudzi, Mutoko, Murehwa and Rushinga. Annual rainfall of 600–800 mm occurs almost entirely in the months of November to March.

The study area includes five major rock types (Fig. 1; Barton *et al.* 1991). In the centre of the area, the Migmatitic Gneisses include biotite and hornblende rich migmatites, mafic to felsic granulites and tonalite gneisses. The Greenstones and Grey Gneisses form a volcano-plutonic complex separated from the Migmatitic Gneisses by a major Archean tectonic break. Greenstones range in composition from basaltic andesite to dacite whereas the Grey Gneisses comprise trondhjemitic and tonalitic granitoid intrusives. In the south of the area, the Greenstone–Grey Gneiss complex is intruded by the Mutoko Granite which itself is intruded in places by basic and ultrabasic rocks. Proterozoic metasedimentary rocks in the north of the area include leucomigmatite with horizons of mafic gneiss and garnet granulite.

Soils are mostly fersiallitic, with high Fe and Al contents (Thomson & Purves 1978). Greyish brown, coarse sands and sandy loams characterize areas underlain by granitic rocks whereas brown to reddish-brown sandy loams overlying sandy clays are more common over siliceous gneisses and schists. Reddish-brown granular clays occur over the greenstones and basic and ultrabasic intrusive rocks, such as those that



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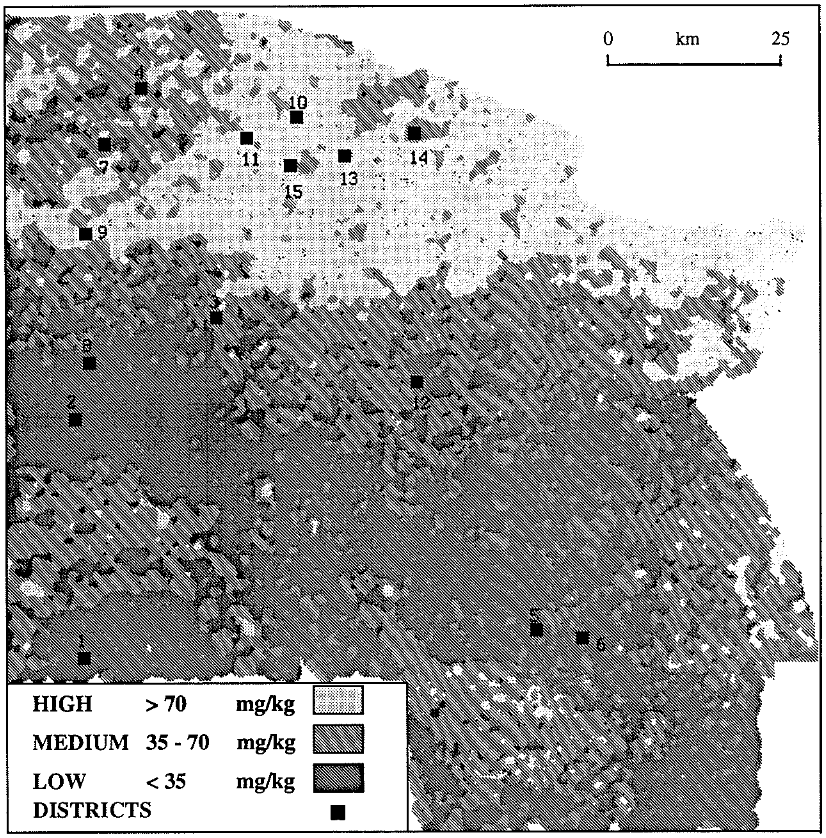

Fig. 2. Geochemical map of Zn in stream sediments in northeast Zimbabwe showing the location of blood, soil and forage sampling districts 1 to 15.

intrude the Mutoko Granite in the southwest. Lithosols characterize areas of rugged terrain. Soils are acid, with pH values of 4.4–6.4 (Nyamapfene 1991).

Much of the area is covered by medium to dense, mixed woodland savannah. Above 600 m the species *Julbernardia globiflora*, *Brachystegia bohemia* and *Brachystegia spiciformis* dominate whereas below 600 m, *Adansonia digitatas*, *Colophospermum mopane*, *Diopsyros*, *Terminalia*, *Combretum* and *Commiphore* (spp) are more common (Anderson 1986*a*,*b*; Brinn 1986).

Cattle form an important component of the local economy and family wealth is measured in terms of the number of cattle owned. In addition to the monetary revenue generated by the sale of animals, cattle provide a valuable source of milk for the family. Despite the importance of cattle for the local economy and family, no mineral supplementation is currently practised in the area.

Sampling and analysis

The study area in northeast Zimbabwe was selected to provide a wide range of Zn in stream sediments. The area was subdivided into three regions of relatively low (< 35 mg/kg), medium (35–70 mg/kg) and high (> 70 mg/kg) Zn, on the basis of existing stream sediment data (Fig. 2) and a sampling strategy was devised to test whether these geochemical differences were reflected in soil, forage and cattle serum. Cattle serum was selected for this study as it is easier to collect than bone and liver samples. Zn was the principal trace element investigated because Zn in cattle serum is generally accepted as a reliable indicator of cattle Zn status (McDowell *et al.* 1993).

Sampling was carried out from April to June 1993 over a period spanning the end of the wet season and the start of the dry season. Cattle were resampled for Zn analysis from April to

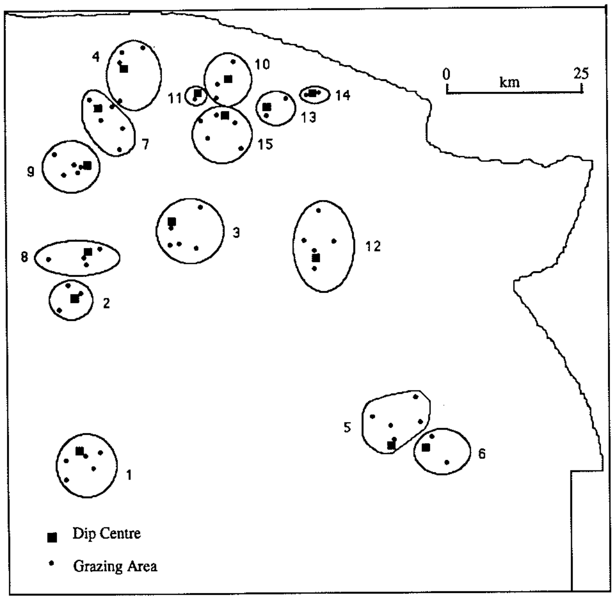

Fig. 3. Map of northeast Zimbabwe showing the relationship of grazing areas to dip centres in each district (1 to 15).

June 1994 because it was suspected the 1993 serum samples had been contaminated with Zn from the sample tube caps. This was confirmed by lower Zn concentrations in the 1994 serum samples.

Blood sampling was conducted at government-run dip centres when cattle from the surrounding villages were gathered together. Dip centres therefore form the focal points for sampling districts (Fig. 3). Fifteen sampling districts in northeast Zimbabwe were selected for the study, five in each of the three Zn regions. Although small-scale geochemical variations occur within districts, this is not considered to affect the overall classification of districts as low, medium and high Zn in stream sediments (Figs 2, 3). A total of 300 cattle, 20 from each district, were sampled in 1993. However, during the Zn resampling programme in 1994, it was only possible to collect 245 samples. None of the cattle had received mineral supplements. Ca, Cu, Mg and Zn were determined in serum by AAS and P in serum by colorimetry. Analyses for Ca, Cu, Mg and P in the 1993 samples were carried out by the Veterinary Research Laboratory in Zimbabwe whereas Zn analysis of the 1994 samples was conducted at the Ministry of Agriculture, Fisheries and Food Veterinary Investigation Centre, Sutton Bonnington, UK. Analytical precision for Zn was 11% (95% confidence level) (Fordyce *et al.* 1994).

Forage and soil samples were collected from the areas grazed by the cattle sampled in the study. Cattle often shared grazing areas therefore only up to five grazing areas were sampled in each district (Fig. 3). Separate grass and shrub leaf samples comprising a representative range of grazed and browsed species were collected. Unwashed forage samples were dried at 60°C, ground to < 1 mm and dry ashed at 550°C prior to digestion in hot concentrated hydrochloric acid (Fick *et al.* 1979) and analysis by ICP-AES for Ca, Cu, Fe, Mg, Mn, P and Zn. The effectiveness of the hydrochloric acid digestion method for forage was confirmed by the results for an international standard (Table 1). Mass balance calculations indicate that soil contamination is not a significant factor influencing major and trace element concentrations in forage samples.

Composite soil samples were collected from a depth of *c.* 10–15 cm, sieved to pass a 2 mm mesh, ground to < 120 mm, digested in hot concentrated hydrochloric acid and analysed by ICP-AES for Ca, Cu, Fe, Mg, Mn, P and Zn. A hydrochloric acid digestion was selected so that soil geochemical data would be directly comparable with data from the earlier reconnaissance stream sediment survey (Dunkley 1987).

Table 1. *Comparison of analytical results for international forage and soil standards with published data*

Standard	Mn	Fe	P	Mg mg/kg	Ca	Zn	Cu	Co
B2/81	78.8	167	2407	1490	6644	31.5	8.1	na
B2/81*	81.6	164	na	na	na	31.5	9.6	na
GXR3	28817	216397	1167	8313	165896	224.7	16.6	50.4
GXR3 †	22308	190000	1100	8100	135800	207.0	15.0	43.0
GXR5	231	30327	220	6373	6655	40.8	333.5	21.7
GXR5 †	310	33900	310	11900	6400	49.0	354.0	30.0
GXR6	1241	63615	383	4744	1645	135.6	75.6	13.6
GXR6 †	1007	55800	350	6100	1800	118.0	66.0	13.8

B2/81, average of 5 analyses of International Rye Grass Standard B2/81; *, recommended values from Office of Reference Materials (1991); GXR3, average of 3 analyses of International Soil Standard GXR3; GXR5, average of 3 analyses of International Soil Standard GXR5; GXR6, average of 3 analyses of International Soil Standard GXR6; † recommended values from Potts *et al.* (1992); na, not available.

Table 2. *Limits of detection for soil and forage analysis by ICP-AES*

Element	Limit of detection (mg/kg)		
	Soil	Grass	Leaves
Mn	3.0	0.02	0.02
Fe	6.6	0.36	0.26
P	9.0	0.56	0.76
Mg	17.0	1.12	0.98
Ca	4.2	0.34	0.44
Zn	0.8	0.06	0.08
Cu	2.0	0.12	0.14
Co	3.2	nd	nd

nd, not determined.

Results suggest the digestion may be less effective for soils containing a significant proportion of primary minerals (GXR5, Table 1). However, since the soils in northeast Zimbabwe are fersiallitic, the HCl digestion is likely to extract elements such as Fe, Mn, Zn, Cu and Co which are contained, for the most part, in secondary Fe-oxides. Analytical precision, based in repeat analysis of samples, for soil and forage was 12% and 16% respectively (95% confidence level) whereas within sample site variation was generally ±20% (Fordyce *et al.* 1994). Detection limits for soil and forage analyses are listed in Table 2. Results for soil and forage samples are presented on a dry matter basis.

Stream sediments collected at an average density of one per km^2 were sieved to < 177 mm prior to digestion in hot concentrated hydrochloric acid and analysis by AAS for Co, Cu, Mn and Zn (Dunkley 1987). Data for streams draining the grazing areas were selected for comparison with soil, forage and cattle serum analytical data. Additional information on sampling and analytical methodologies is given in Fordyce *et al.* (1994).

Each district is represented by different numbers of samples for each sample medium. Relationships between media were therefore assessed by calculating district average values. Correlation coefficients were employed to identify significant inter-element and inter-media relationships. Spearman Rank non-parametric correlation coefficients were calculated as they are less sensitive to outlying values than product moment (Pearson) correlation coefficients.

Results and discussion

Rock, stream sediment and soil geochemistry

Comparison of the Zn in stream sediments geochemical map (Fig. 2) with the geological map (Fig. 1) and with maps for Co, Cu and Mn in stream sediments (Appleton 1992), shows that the Greenstones are characterized by elevated levels of Co, Cu, Mn and Zn. Copper, Mn and Zn concentrations are generally high over the metasedimentary rocks, with localized high Co values. The Migmatitic Gneisses and Grey Gneisses in the centre of the area are characterized by very low levels of Co, Cu, Mn and Zn reflecting the low levels of these trace elements in the parent rocks (Barton *et al.* 1991) and the sandy infertile soils derived from them. Similarly low levels of Co, Cu, Mn and Zn are associated with those parts of the Mutoko Granite in the

Table 3. *Comparison of average values for elements in rocks, sediments and soils in northeast Zimbabwe.*

Sample medium	Element	Average element composition in rock type (mg/kg)		
		Mutoko granite and grey gneiss*	Migmatitic gneiss	Metasedimentary
Rock	Ca	15700	32200	35100
	Fe	13200	40100	66300
	Mg	3860	17100	13800
	Mn	290	840	1300
	P	290	700	800
	Samples taken	22	16	37
Sediments	Co	6	10	12
	Cu	11	20	22
	Zn	28	34	86
	Mn	381	436	975
	Samples taken	34	50	101
Soils	Ca	1293	2189	3649
	Fe	8314	14718	36870
	Mg	1644	3356	4480
	Mn	249	321	800
	P	115	159	381
	Co	3	7	11
	Cu	6	14	20
	Zn	18	27	66
	Samples taken	15	14	27

Average rock compositions calculated from data in Barton *et al.* (1991). * No grazing areas were underlain by greenstones therefore average rock data do not include analyses of greenstones.

Table 4. *Spearman Rank correlation coefficients between elements in stream sediments and soils for the 15 districts*

	Co soil	Cu soil	Fe soil	Mg soil	Mn soil	P soil	Zn soil	Co sed	Cu sed	Mn sed	Zn sed
Ca soil	.821	.643	.671	.896	.750	.639	.814	.553	.715	.557	.725
Co soil		.793	.686	.929	.696	.521	.743	.713	.765	.564	.646
Cu soil			.786	.718	.711	.607	.689	.627	.722	.632	.675
Fe soil				.643	.936	.825	.896	.458	.543	.796	.786
Mg soil					.675	.507	.721	.647	.803	.489	.614
Mn soil						.825	.957	.415	.465	.821	.814
P soil							.861	.416	.468	.829	.757
Zn soil								.468	.511	.782	.796
Co sediment									.854	.517	.670
Cu sediment										.518	.706
Mn sediment											.921

r 95% = 0.457; r 99% = 0.612; r 99.95% = 0.780 (Koch & Link 1970).

southwest of the area that are not intruded by basic rocks. There is, therefore, a strong geological control on the levels of trace elements in stream sediments (Table 3). In addition, the chemistry of soils generally reflects bedrock chemistry, especially for Ca, Fe and Mn (Table 3).

The trace and major element chemistry of soils correlates strongly with stream sediment geochemistry thus confirming the dominant influence of bedrock composition on regional variation in both these sample media (Table 4). Sorption of trace elements by secondary Fe and Mn oxides also influences the trace element content of soils as indicated by the strong correlations between Fe and Mn with Co, Cu, P and Zn in soils (Table 4).

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Metasedimentary
35100
66300
13800
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800
37
12
22
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975
101
3649
36870
4480
800
381
11
20
66
27

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and soils for the 15 districts

ed	Cu sed	Mn sed	Zn sed
53	.715	.557	.725
13	.765	.564	.646
27	.722	.632	.675
58	.543	.796	.786
47	.803	.489	.614
5	.465	.821	.814
6	.468	.829	.757
58	.511	.782	.796
	.854	.517	.670
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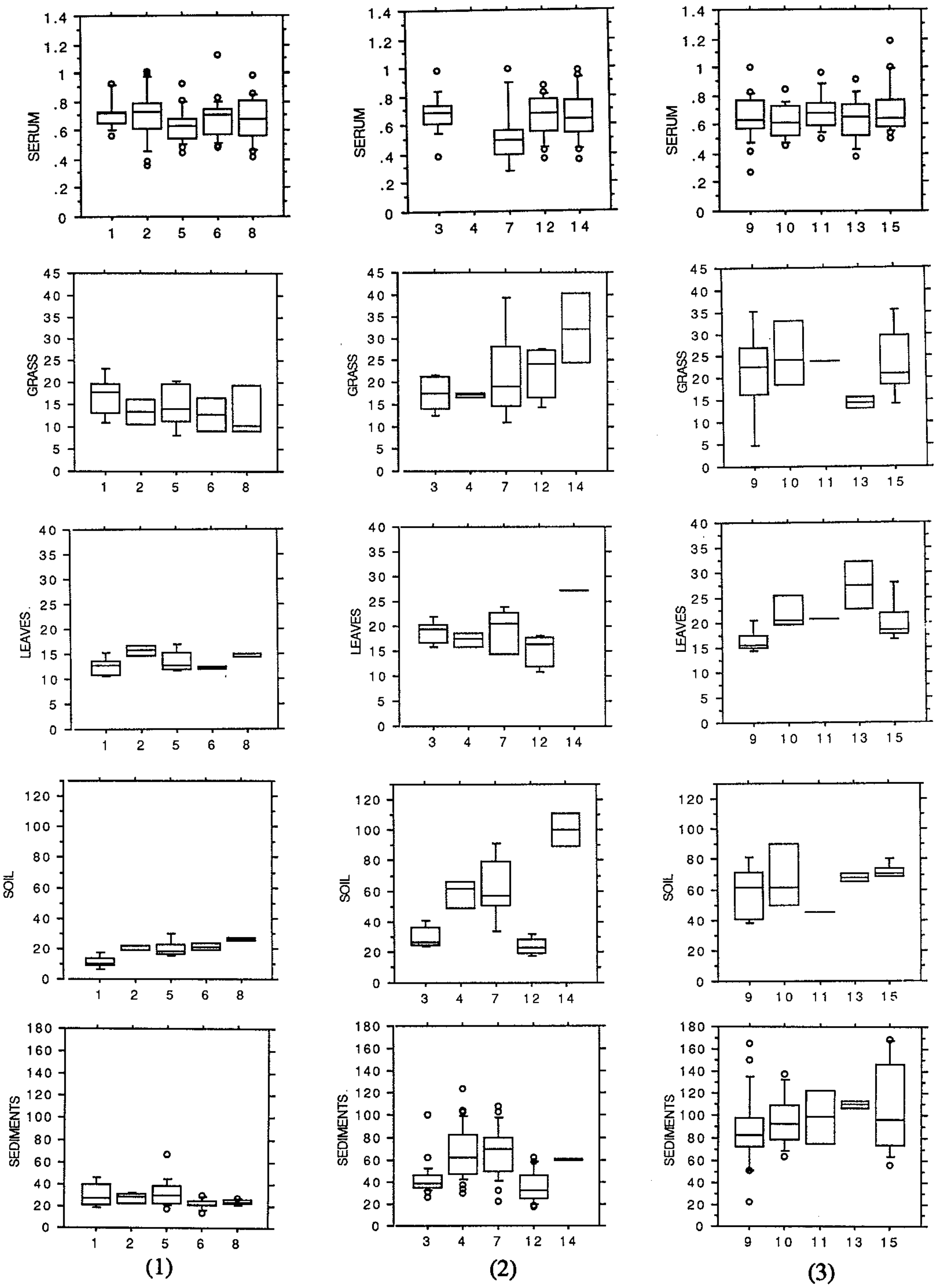

Fig. 4. Box and whisker plots of the 10th, 25th, 50th, 75th and 90th percentiles of Zn distributions in each sample type for each district (1 to 15) in the low (1), medium (2) and high (3) Zn regions. Circles indicate values < 10th and > 90th percentiles. Zn concentrations in mg/kg except serum (mg/l) (No cattle serum data are available for district number 4.)

Zinc

The distributions of Zn within each district and between districts vary considerably for all sample media (Fig. 4). Concentrations of Zn in sediment, soil, leaves and grass from districts in the low Zn region generally have lower Zn concentrations than samples from districts in the medium or high Zn regions. However, within each region there is no consistent relationship between district Zn concentrations in sediment, soil, leaves and grass. There is no apparent relationship between Zn in sediment, soil and forage and Zn in serum at the district level.

Table 5. *Results of ANOVA statistical probability test comparing populations for Zn in each sample media from the low, medium and high Zn regions*

ANOVA	F-value	P-value
Zn sediment v. Zn region		
224 samples	119.37	< 0.001
15 district mean values	45.939	< 0.001
Zn soil v. Zn region		
56 samples	29.662	< 0.001
15 district mean values	6.754	0.0108
Zn grass v. Zn region		
56 samples	5.429	0.0072
15 district mean values	5.343	0.0219
Zn leaves v. Zn region		
56 samples	13.254	< 0.001
15 district mean values	6.612	0.0116
Zn serum v. Zn region		
245 samples	1.424	0.2428
15 district mean values	1.691	0.2289

At the regional level, there are statistically significant differences between the regions for Zn in sediment, soil, grass and leaves but not in cattle serum (Table 5). Zn concentrations in soil and forage reflect the geochemical trend from low to high Zn in stream sediments (Fig. 5). In grass and leaves, more overlap occurs between the concentration ranges for the low, medium and high Zn regions. In contrast to the other sample media, the ranges for Zn in cattle serum are approximately the same in the three regions. These observations are reiterated in Table 6 which shows there are significant (95% confidence level) correlations between district average values for Zn in grass, leaves, soils and sediments but no significant correlations between Zn in serum and the other sample media. Therefore, at both the district and regional levels, cattle serum Zn does not directly reflect environmental Zn concentration.

Many biological factors such as the species type and state of maturity of plants, and the age and gender of animals, exert significant controls on the uptake of major and trace elements by living organisms (Mertz 1987). In addition, infection and vaccination are known to enhance Cu and deplete Zn in cattle serum. A large number of serum samples were collected in this study to minimize the effects of biological factors on district means. Despite this precaution, these biological factors may largely explain why the levels of Zn in cattle serum do not directly reflect environmental Zn in northeast Zimbabwe. Another explanation for the lack of correlation between cattle serum Zn and forage Zn may be the uncertain contribution of individual grass and browse species and the proportion of grass and browse material in the dietary intake of cattle in this study.

Table 6. *Spearman Rank correlation coefficients between Zn in serum, grass, soil and leaves for the 15 districts and other elements in various media (based on district mean concentrations).*

	Zn serum	Zn grass	Zn leaves	Zn soil
Zn grass	–.200			
Zn leaves	–.293	.575		
Zn soil	.392	.732	.886	
Zn sediment	–.359	.600	.836	.796
Cu grass	.150	.461	.300	.271
Cu leaves	–.117	.521	.793	.654
Cu soil	–.112	.586	.725	.689
Fe grass	–.299	.511	.843	.775
Fe leaves	–.112	.357	.764	.618
Fe soil	–.392	.621	.857	.896
Mn grass	–.035	.214	.411	.214
Mn leaves	– 273	.368	.735	.175
Mn soil	–.366	.632	.893	.957
Ca leaves	–.350	–.461	–.909	–.186
Ca soil	–.442	.582	.625	.814
P soil	–.317	.807	.825	.861

r 95% = 0.457; r 99% = 0.612; r 99.95% = 0.780 (Koch & Link 1970).

Although statistical correlations do not prove a causal relationship, the strong spatial and statistical correlations between sediment, soil and forage Zn suggest that increased levels of Zn in soils result in increased uptake of Zn by plants. However, ingestion of plants containing higher levels of Zn does not result in an increase in the Zn levels found in cattle serum. In fact, Zn in serum appears to decrease slightly as Zn in

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grass	Zn leaves	Zn soil
575		
732	.886	
600	.836	.796
461	.300	.271
521	.793	.654
586	.725	.689
511	.843	.775
357	.764	.618
621	.857	.896
214	.411	.214
368	.735	.175
632	.893	.957
461	−.909	−.186
582	.625	.814
807	.825	.861

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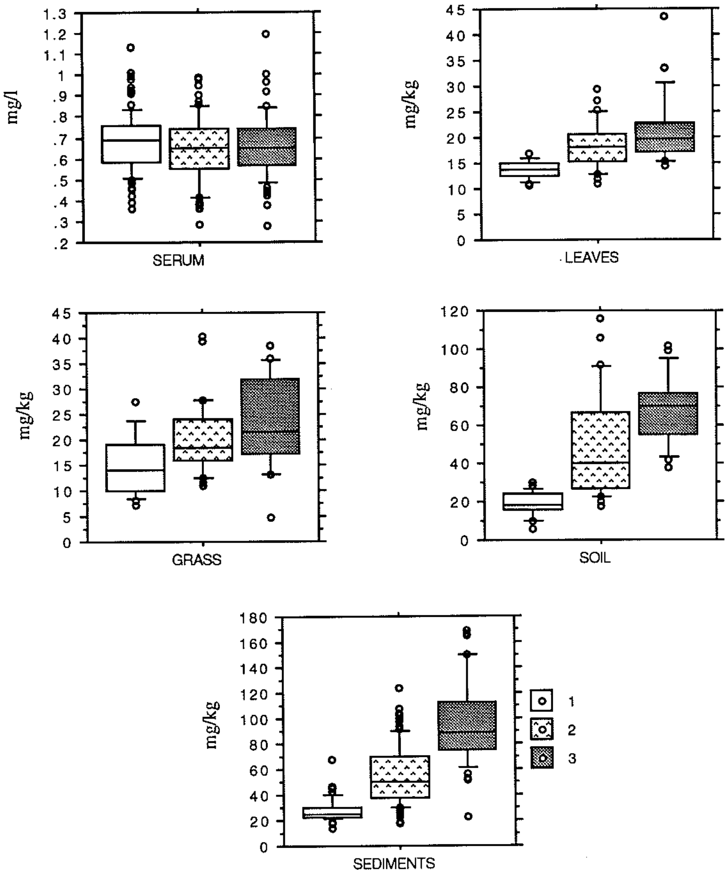

Fig. 5. Box and whisker plots of the 10th, 25th, 50th, 75th and 90th percentile of Zn distributions in each sample type for the low (1), medium (2) and high (3) Zn regions. Circles indicate values < 10th and > 90th percentiles.

forage increases (Table 6). One possible explanation may be the antagonistic relationships present between elements as they are absorbed during digestion by the cattle. Fe and Zn are known to have an antagonistic relationship during absorption in humans (Sandstrom *et al.* 1985; Mertz 1987) and in rats (Quarterman 1985). In addition, antagonistic relationships between Mn, Fe and Zn have been reported in humans (Christophersen 1994). Lebdosoekojo *et al.* (1980) suggest that high levels of Fe and Mn may interfere with the metabolism of other trace elements in cattle. Several clinical studies in animals and humans have identified a mutually antagonistic relationship between Cu and Zn (Mertz 1987). In northeast Zimbabwe, the area of high Zn in soils and forage coincides with high Cu, Fe and Mn in soils and forage (Tables 4, 6), therefore it is possible that uptake of these elements is inhibiting the absorption of Zn in cattle.

Zn concentrations in serum tend to decrease slightly as the Ca content of leaves and soil and the P content of soil increase (Table 6). High Ca and P ingestion have been shown to reduce Zn absorption in humans, pigs and poultry but these relationships are less clear in cattle (Mertz 1987).

Copper

There are significant correlations between district average values for Cu in sediment and soil (Table 4) and between Cu in soil and leaves (Table 7). However, Cu in serum exhibits no correlation with Cu in soil, grass or leaves (Table 7) or average forage (Fig. 6). Therefore although there is some evidence to suggest that higher levels of Cu in the environment are taken up by vegetation, these higher levels are not reflected in the Cu content of serum. Similar results are reported by McDowell (1976) who found that the Cu content of soils and forage did not correlate with the Cu status of cattle. Evidence from the present study suggests that, as with Zn, this lack of correlation may partly reflect antagonistic relationships between elements during uptake.

Table 7. *Spearman Rank correlation coefficients between Cu in serum, grass and leaves for the 15 districts and other elements in various media (based on district mean concentrations)*

	Cu serum	Cu grass	Cu leaves
Cu grass	–.195		
Cu leaves	.032	.446	
Cu soil	.009	.371	.696
Cu sediment	–.019	.452	.374
Zn grass	–.496	.461	.521
Zn leaves	–.356	.300	.793
Zn soil	–.347	.271	.645
Zn sediment	–.489	–.398	.500
Mn grass	–.593	.204	.354
Mn leaves	–.675	.464	.139
Mn soil	–.340	.204	.614
Mn sediment	–.640	.504	.543
Fe grass	–.381	.329	.657
Fe leaves	–.349	.189	.486
Fe soil	–.277	.336	.629

r 95% = 0.457; r 99% = 0.612; r 99.95% = 0.780 (Koch & Link 1970).

The most significant negative correlations are between serum Cu and (i) Mn in stream sediment, grass and leaves and (ii) Zn in stream sediment and grass (Table 7). In addition the correlations between Cu in serum and Fe in soil and forage are slightly negative (Fig. 6). These negative relationships suggest that Zn, Mn and possibly Fe ingested in forage and soil may be inhibiting the absorption of Cu in cattle. Clinical trials have demonstrated that high levels of dietary Zn reduce Cu absorption in rats, pigs and sheep although the relationship in cattle is less clear (Mertz 1987). The inhibitory effects of dietary Fe on Cu absorption are well documented (Mertz 1987). For example, Humphries *et al.* (1985) found dietary intakes of 350 mg kg^{-1} of Fe in forage were sufficient to significantly reduce the Cu content of the liver in young calves. Russell *et al.* (1985) demonstrated that Fe ingested from soil has a negative effect on Cu absorption in sheep. Up to 25% of the Fe content of soils can be extracted during simulated digestion in sheep (Brebner *et al.* 1985). Since the level of Fe in soils is 100 times the content of forage in northeast Zimbabwe (Table 8), ingestion of high Fe soils may exert a greater inhibitory effect on Cu uptake than Fe in forage.

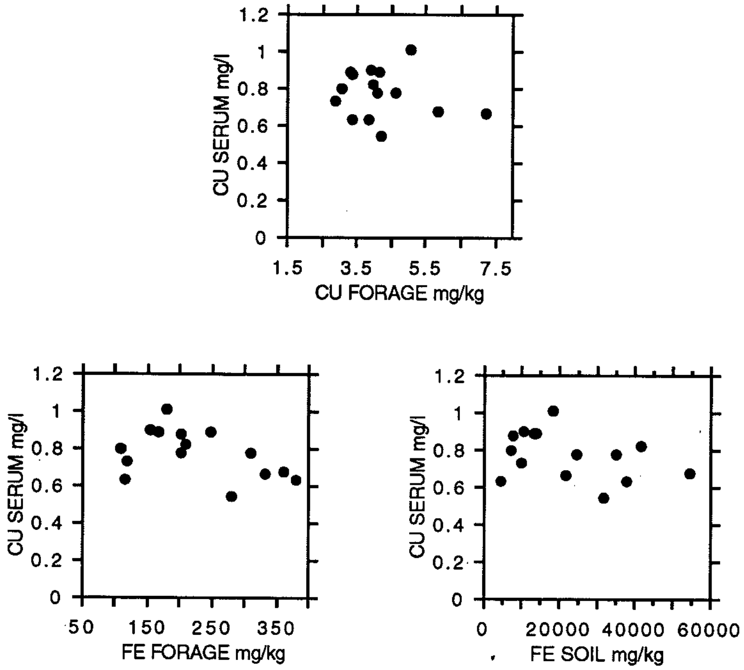

Fig. 6. Plots of district average values of Cu in serum versus Cu in forage, Fe in forage and Fe in soil. (Average forage values represent the average of grass and leaf compositions for each district.)

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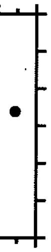

e and Fe in soil. (Average

Table 8. *Average element values in serum, forage and soils from the present study compared to studies from other areas of mineral deficiency in grazing ruminants*

Media		Country	Ca	Mg	P	Fe	Mn	Co	Cu	Zn
Serum (mg/l)	a	Zimbabwe	80	23	45	nd	nd	nd	0.8	0.7
	b	Swaziland	na	na	39	na	na	na	na	na
	h	Malawi	76	na	56	na	na	na	0.3	na
	d	Indonesia	na	na	na	na	na	na	0.6	0.8
	e	Bolivia	112	18	70	na	na	na	0.9	1.0
	f	Bolivia	80	21	67	na	na	na	0.6	1.1
Forage (mg/kg)	a	Zimbabwe*	4409	1713	1444	234	109	nd	1.9	19.0
		†	16189	3575	1750	165	179	nd	6.1	17.0
	b	Swaziland	4050	1500	5500	224	86	na	5.6	9.0
	c	Guatemala	3100	1850	2500	520	92	0.4	14.0	32.5
	d	Indonesia	na	na	na	742	88	0.3	9.3	5.0
	e	Bolivia	4400	1850	1900	170	390	0.5	5.2	24.0
	f	Bolivia	2100	1600	1500	134	133	0.2	5.9	30.0
	g	Colombia	1300	1550	1300	563	143	0.1	1.8	13.5
	g	Brazil	5050	2550	5000	238	145	0.1	4.0	26.5
Soil ‡ (mg/kg)	a	Zimbabwe	2807	3653	251	23537	517	8.1	15.4	43.1
	b	Swaziland	524	191	12	na	4	na	1.0	1.1
	c	Guatemala	1860	387	10	52	59	na	2.4	5.8
	d	Indonesia	na	na	na	98	24	na	1.6	4.6
	e	Bolivia	648	204	4	115	17	na	0.5	3.0
	f	Bolivia	192	34	1.2	24	0.3	na	0.3	1.3

a, present study; b, Ogwang (1988); c, Tejada *et al.* (1985); d, Prabowo *et al.* (1991); e, McDowell *et al.* (1982); f, Peducassé *et al.* (1983); g, Miles *et al.* (1989); h, Mtimuni *et al.* (1983). nd, not determined; na, not available. * Mean concentrations for grass samples; † mean concentrations for leaf samples; ‡ soils were digested with hot concentrated HCl in the present study whereas published results from Guatemala, Indonesia, Bolivia and the USA are for partial extraction with 0.05 N HCl + 0.025 N H_2SO_4. Soil data for Swaziland are for partial extraction with ammonium acetate.

Table 9. *Spearman Rank correlation coefficients between Ca in serum, grass and leaves and Mg in serum for the 15 districts and other elements in various media (based on district mean concentrations)*

	Ca grass	Ca leaves	Ca soil	P grass	P leaves	Mg grass	Mg leaves
Ca serum	–.279	–.039	–.093	–.461	–.007	–.254	.321
Ca grass		–.207	.136	.257	–.218	.446	.089
Ca leaves			–.209	–.096	.543	–.286	–.479
Mg serum	–.157	.389	.043	.318	.625	–.296	–.282

r 95% = 0.457; r 99% = 0.612; r 99.95% = 0.780 (Koch & Link 1970).

Table 10. *Spearman Rank correlation coefficients between P in serum for the 15 districts and other elements in various media (based on district mean concentrations)*

	P soil	P grass	P leaves	Fe soil	Fe grass	Fe leaves
P serum	–.079	–.025	.243	–.311	–.343	–.321

r 95% = 0.457; r 99% = 0.612; r 99.95% = 0.780 (Koch & Link 1970).

Calcium and magnesium

Ca and Mg in soils correlate closely with all the other elements in soils as a result of the strong influence of bedrock geochemical variations (Table 4). Ca and Mg in soils do not correlate significantly with Ca and Mg in forage or serum samples (Table 9). Increased uptake of these elements by plants and animals as a result of higher levels in soils is not evident.

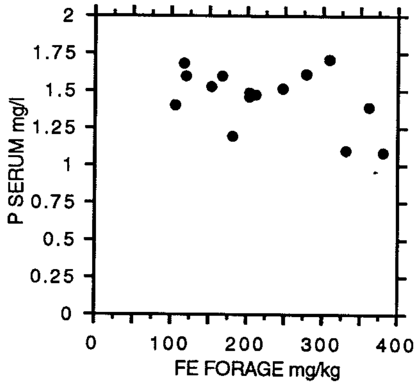

Fig. 7. Plots of district average values of P in serum versus Fe in forage. (Average forage values represent the average of grass and leaf compositions for each district.)

Phosphorus

P in serum does not correlate significantly with P in any of the other sample media (Table 10). Although there is a strong positive correlation between Fe and P in soil, strong sorption of P by Fe oxides in soils normally reduces the availability of P to plants. This may explain why P in forage and cattle serum does not increase with P in soils; indeed P in serum tends to decrease slightly as Fe in soil and forage increases (Table 10; Fig. 7). This suggests that elevated levels of Fe in soil and forage may cause P deficiency in cattle. Additional significant relationships between P and other elements are mentioned in previous sections.

Iron and manganese

In addition to the relationships discussed above, significant correlations exist between Fe in soil with grass and leaves (Table 11) and Mn in sediment with soil (Table 4), grass and leaves (Table 11). This demonstrates that Fe and Mn in sediments and soils can be used as indicators of levels of these elements in forage. No indicators of cattle mineral status were obtained for Fe and Mn.

Deficiency levels

Table 8 shows the average element concentrations in cattle serum, forage and soil from the present study compared with published data from other parts of the world where deficiencies in cattle serum, forage and soils have been recorded. Cattle mineral status studies commonly classify animal, forage and soil samples with respect to deficient, marginal and toxic element concentrations (McDowell *et al.* 1993). Samples below the critical level are termed deficient. The use of marginal bands acknowledges the uncertainty of predicting the precise level at which deficiency is induced. Applying the critical levels and marginal bands used in the published studies (Table 12) to the data from northeast Zimbabwe, it is clear that a high proportion of cattle serum and forage samples are marginal in Zn (Table 13).

Discrepancies between the percentage of samples below the critical levels and marginal bands in serum, forage and soil have been observed in previous studies (references from Table 8). This is confirmed by the present study

Table 11. *Spearman Rank correlation coefficients between Fe in grass, leaves and soil for the 15 districts and Mn in various media (based on district mean concentrations).*

	Fe leaves	Fe soil	Mn leaves	Mn soil	Mn sediment
Fe grass	.428	.743	.346	.828	.825
Fe leaves		.671	.089	.628	.632
Fe soil			.314	.936	.796
Mn grass			.578	.246	.486
Mn leaves				.225	.493

r 95% = 0.457; r 99% = 0.612; r 99.95% = 0.780 (Koch & Link 1970).

in which only 26% of the cattle are Cu deficient whereas nearly 100% of forage samples are below the critical concentration (Table 13).

Table 12. *Deficiency critical levels and marginal bands for elements in cattle serum and forage*

Media	Element	Critical value deficient	Marginal band
Serum (mg/l)	Ca*	< 80	
	Mg		< 10–20
	P*	< 45	
	Cu	< 0.65	
	Zn		< 0.6–0.8
Forage (mg/kg)	Ca	< 3000	
	Mg	< 2000	
	P	< 2500	
	Co	< 0.1	
	Cu	< 10	
	Fe	< 30	
	Mn		< 30–40
	Zn	< 30	

All values taken from McDowell *et al.* (1993) except * from Peducassé *et al.* (1983)

Summary and conclusions

1. Stream sediment geochemical maps for Zn and Mn provide a reliable indication of the relative distribution of these elements in soil and forage (grass and leaves). Cu in stream sediments can be used to predict the levels of these elements in soil and grass, but less reliably in leaves. Fe in soils provides a reliable indication of levels in grass and leaves. Although hot hydrochloric acid extractable Ca, P and Mg in soil reflect variations in the chemical composition of the underlying rocks, this information cannot be used to predict relative concentrations of these elements in forage.
2. Ca, Cu, Mg, P and Zn in cattle serum do not correlate positively with these elements in forage, soil and sediment samples. Therefore, it appears that it is not possible to use the concentrations of these elements in forage, soil or stream sediments to predict the mineral status of cattle.
3. The lack of direct relationship between cattle mineral status and forage status probably reflects the influence of biological factors including plant species and maturity and cattle gender and age on element uptake. The relationship may also be influenced by the uncertain contribution of grass and leaf species in the dietary intake of the cattle.
4. The results of this study suggest that interactions and antagonistic effects between elements as they are absorbed by plants and animals may influence the mineral status of cattle in northeast Zimbabwe. High concentrations of Fe and Mn in soil and forage appear to inhibit the availability of P to plants and the absorption of Cu and Zn in cattle. These findings may have wide ranging implications due to the preponderance of ferrallitic soils in many countries in tropical regions.
5. Although stream sediment, soil and forage geochemical maps cannot be used to predict the mineral status of grazing ruminants directly, they can serve to indicate those areas where Zn, Cu and P are likely to be low in soils and forage and those areas where higher levels of Fe (and/or Mn) may induce low Zn, Cu and P status in cattle despite higher levels of these elements in soils and forage.
6. Discrepancies between the percentage of deficient serum and percentage of deficient forage samples found in previous studies are also apparent in northeast Zimbabwe. This suggests that the critical levels used to determine deficiency may require further investigation.
7. The limitations inherent in the use of univariate rank statistical tests to assess what are almost certainly multivariate relationships are acknowledged. A multivariate

Table 13. *Percentages of northeast Zimbabwe serum and forage samples with elements below critical levels and marginal bands (Table 12)*

	% Deficient						% Marginal		
	Ca	Mg	P	Cu	Fe	Zn	Mg	Mn	Zn
Serum	47	–	55	26	nd	–	17	nd	86
Grass	10	77	94	100	0	92	–	6	–
Leaves	0	2	88	98	0	100	–	0	-

Marginal, < 20 mg/l Mg serum; < 0.8 mg/l Zn serum and < 40 mg/kg Mn forage. nd = no data.

statistical approach to data interpretation is currently under investigation and will include consideration of Fe in cattle serum.

8. It is recommended that additional studies should be carried out over a variety of geographical and geological conditions in order to confirm the findings of this study.

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