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Demarcation of potentially mineral-deficient areas in central and northern Namibia by means of natural classification systems

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ABSTRACT

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Mineral deficiencies that lead to production losses often occur concurrently with climatic and management changes. To diagnose these deficiencies in time to prevent production losses, long-term monitoring of mineral status is advisable. Different classification systems were examined to determine whether areas of possible mineral deficiencies could be identified, so that those which were promising could then be selected for further monitoring purposes. The classification systems addressed differences in soil, vegetation and geology, and were used to define the cattle-ranching areas in the central and northern districts of Namibia.

Copper (Cu), iron (Fe), zinc (Zn), manganese (Mn) and cobalt (Co) concentrations were determined in cattle livers collected at abattoirs. Pooled faecal grab samples and milk samples were collected by farmers, and used to determine phosphorus (P) and calcium (Ca), and iodine (I) status, respectively.

Areas of low P concentrations could be identified by all classification systems. The lowest P concentrations were recorded in samples from the Kalahari-sand area, whereas faecal samples collected from cattle on farms in the more arid areas, where the harder soils are mostly found, rarely showed low P concentrations.

In the north of the country, low iodine levels were found in milk samples collected from cows grazing on farms in the northern Kalahari broad-leaved woodland. Areas supporting animals with marginal Cu status, could be effectively identified by the detailed soil-classification system of irrigation potential. Copper concentrations were lowest in areas of arid soils, but no indication of Co, Fe, Zn, or Mn deficiencies were found. For most minerals, the geological classification was the best single indicator of areas of lower concentrations. Significant monthly variation for all minerals could also be detected within the classification system.

It is concluded that specific classification systems can be useful as indicators of areas with lower mineral concentrations or possible deficiencies.

Keywords: Classifiction systems, mineral-deficient areas, Namibia, natural

INTRODUCTION

Mineral deficiencies have been shown to constrain range-animal production in many parts of the world, including Namibia (Committee on Animal Nutrition 1973; McDowell 1976). Minerals implicated for particular districts of Namibia include P, Cu, Co, Mg, Zn,

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I and Mn (Du Toit, Louw & Malan 1940; Schroeder 1959; Freyer 1967; Boyazoglu 1976), with P deficiencies being the most widespread.

Extensive collection and analyses of samples for mineral analysis can normally be conducted over only a short period of time, owing to laboratory expenses and cost of obtaining samples (McDowell & Conrad 1977; Mtimuni 1982). Furthermore, mineral intake is influenced by soil, plant and climatic factors (Reid & Horvath 1980; Smart, Gudmundson & Christensen 1981) which cannot all be taken into account in a short-term survey. For concentration on those areas that are more likely to be deficient, an indicator of possible areas of low mineral concentrations can be useful. To find such an indicator, the effect of grouping mineral concentrations in animal-tissue samples according to different classes of supporting vegetation, soil types and geology, was examined. Thereby it was hoped to identify and characterize those zones and climatic conditions that are more likely to be associated with mineral deficiencies in the grazing, so that monitoring programmes could be concentrated in these areas.

Different classification systems were investigated, and they related mineral concentrations in animal tissues with those in soil or vegetation with variable measures of success (Reid & Horvath 1980; McDowell, Kiatako, Bertrand, Chapman, Patae, Martin & Conrad1982). Although Leech, Thornton & Howarth (1983) were able to predict areas of hypocupraemia in England on the basis of geochemical analysis and geology, poor correlations were often reported. The present investigation dealt more extensively with the problem, and used more divergent systems.

The objective of this study was to determine areas of low mineral availability or mineral-deficient areas. The null hypothesis stated that no differences exist in the mineral concentrations of tissue samples from cattle grazing in areas differing in respect of geology, vegetation and soil type.

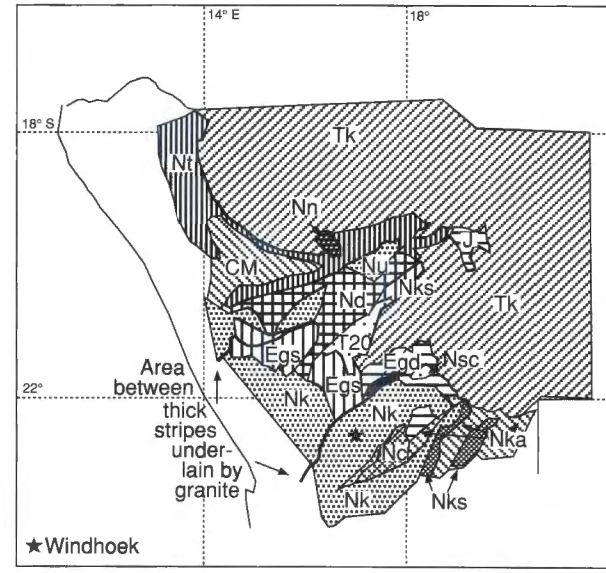

FIG. 1 Geological classification of the study area (Geological Survey 1980)

T20	Omingonde formation of mudstone and sandstone
Je	Aeolian sandstone, of the Etjo group
EGS	Granite and granediorite intrusions into the Damara system
EGD	Undefined granite intrusions of the Damara system
J	Basalt and minor sandstone from the Kalkrand formation of the Karoo system
NSC	Undefined marble and mixtite beds of the Damara system
ND	Undefined schist marble or quartzite in the Damara system
NT	Dolomite and limestone in the Tsumeb formation of the Damara system
CM	Metamorphic complexes
NC	Mixtite and schist from the Karibib formation of the Damara system
Nu	Marble schist and quartzite in the Damara system
NK	Mica schist and marble from the Kuiseb formation of the Damara system
NKA	Quartzite schist and marble from the Khomas formation of the Damara system
NN	Quartzite, schist and dolomite of the Varianto formation in the Damara system
NM	Fillite quartzite and schist of the Nama group
TK	Deep sand with calcrete and gravel

MATERIALS AND METHODS

This study was undertaken in the commercial cattle-ranching areas in the central and northern districts of Namibia. The vegetation in the central part of the study area is predominantly *Acacia* Veld. The dry forests of the north-east contain fairly dense stands of broad- leaved woodland, whereas the vegetation in the north- west is dominated by *Colophospermum mopane* Shrubveld. The study area has summer rainfall which increases from the south-west (average 200 mm/year) to the north-east (average 500 mm/year) (Van der Merwe1983).

All the farms where samples were collected, were classified according to underlying geology, soil and vegetation type (Grant 1989). For this purpose, the geological-classification system of Kent (1980), as displayed in the geological map of Namibia (Geological Survey 1980) was used (Fig. 1).

Three different soil-classification systems were investigated.

- A broad classification system according to satellite images, dividing the country into six areas (F.A.O.-Unesco 1974) (Fig. 2)
- A very complex classification system based on irrigation potential consisting of 24 different soil types (Loxton, Hunt & Associates 1970).
- These were regrouped into six main classes, according to the Macvicar system (Macvicar, Loxton, Lambrechts, Le Roux, De Villiers, Verster, & Merryweather 1977).

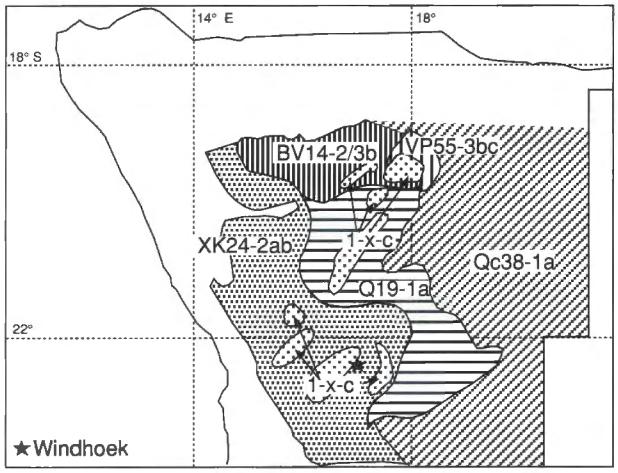

FIG. 2 Soil classification of the study area (FAO-UNESCO 1974)

VP55-3bc	Pelvic vertisol
1-x-c	Lithosol
BV14-2/3b	Vertic cambisol
XK24-2ab	Calsic xerosol
Q19-1a	Luvic arenosol
Qc38-1a	Cambic arenosol

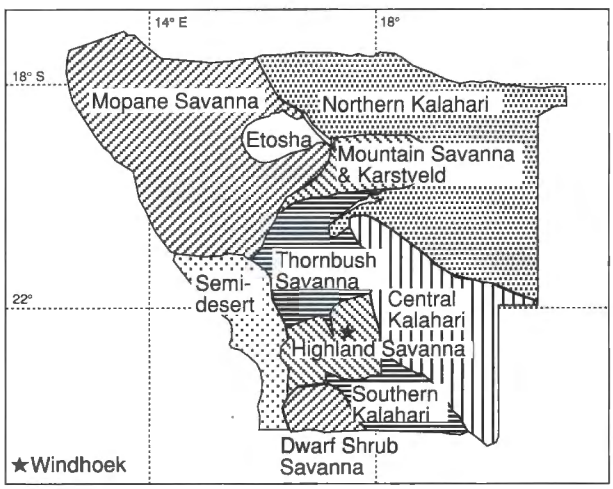

FIG. 3 Vegetation classification of the study area (Giess 1971)

Vegetation was classified into seven vegetation groups, according to Giess (1971) (Fig. 3).

As this classification was very broad, the more detailed classification according to production potential by the Department of Agricultural Technical Services (1979) was also investigated. The production-zone classification considers vegetation, soil type and rainfall, dividing the country into 19 areas of similar production potential (Fig. 4).

Collection of samples

Most comparable studies used the liver as indicator of the status of Cu, Fe, Zn, Mn, and Co (Tartour 1975;

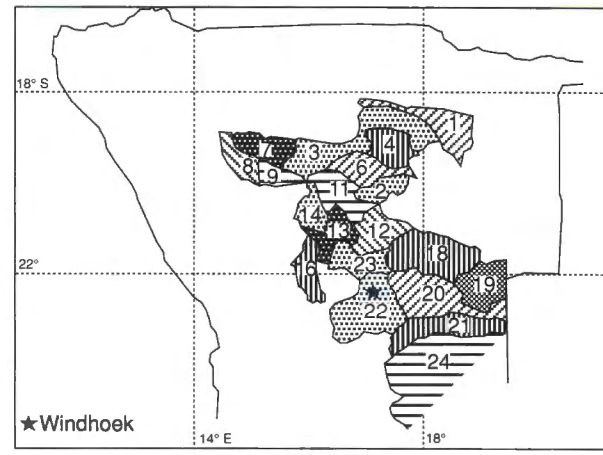

FIG. 4 Classification of the study area according to production potential (Department of Agricultural and Technical Services 1979)

1. High-potential Northern Kalahari sandveld
2. Waterberg sand
3. Shallow turf
4. Mealie triangle
5. Palm flats
6. Otjenga flats
7. Biermanskool mopane savanna
8. Kamanjab mopane savanna
9. Otjikondo mopane savanna
10. Ugab mopane savanna
11. Otjiwarongo thornbush savanna
12. Osire sand
13. Etjo catchment area
14. Kalkveld thornbush savanna
16. Omaruru plateau transition zone
17. Central-west thornbush savanna
18. Summerdown camelthorn savanna
19. Gobabis yellowwood sandveld.
20. Gobabis camelthorn savanna
21. Spatzenveld camelthorn savannah
22. Highland savanna
23. Okahandja thornbush savanna
24. Osono-western Khomas Highland

Boyazoglu 1976; McDowell *et al.* 1982; Mtimuni 1982; Abu Damir, Tartour & Adam 1983). The iodine status of animals has been determined from milk samples, as I concentrations in milk are directly related to the amount of I consumed (Craven & Griffith 1977). No single indicator has yet been proved to give an accurate account of the P status of animals (Committee on Mineral Nutrition 1973). Faecal samples have been used by investigators studying the nutritional status of game (Erasmus, Penzhorn & Fairall. 1978; Leslie & Starkey 1985), and of cattle under ranching conditions (Moir 1966; Falvey 1985). Moir (1960) and Belonje (1978) proved that pooled faecal samples could be used as a reliable indicator of the nutritional status of the herd. Consequently, faecal samples were used in this study to determine P status.

Samples were collected from as many farms in the study area as possible, to cover all the classification types and to make sampling as random as practically possible.

Liver samples

Liver samples (caudate lobe) were collected at abattoirs during all seasons, over a period of 6 years. Samples were preserved in analytical formalin. Liver samples originating from 15 randomly selected cattle were grouped for each farm. These cattle were mostly young animals and animals past breeding age. A total of 590 out of 2 500 farms in the commercial farming area were eventually represented by liver samples from 6 000 animals.

Faecal samples

Faecal samples were collected by farmers interested in determining the P status of their cattle herds. Faecal samples, representing about 10 000 animals on 600 farms, were collected during all seasons over a period of 6 years. Fresh faecal grab samples were collected directly from the rectums of 15 free-ranging cattle representing all age groups [young growing animals (post weaning), pregnant and lactating females and fattened animals]. For each age group, 15 faecal samples were pooled to represent the herd. Samples were stored at 4 °C for not more than 2–3 d, otherwise they were frozen.

Milk samples

Milk samples for iodine determination were collected directly from 15–20 cows per herd, into a plastic container with 2 g/ℓ of potassium dichromate. Samples were thoroughly mixed and immediately frozen. They were transported in the frozen state and analysed within 14 d of collection.

Analytical procedures

Preparation of faecal samples

Pooled faecal samples were well mixed, and approximately 10 g of wet faeces were dried at 70 °C to constant mass. Because the main purpose of this study was to determine mineral deficiencies, undigested material such as grass stalks were removed before analyses. This was done by breaking up samples with a pestle and mortar, and then sieving them through a coarse tea-strainer. Exactly 1 g of the sieved sample was ashed at 400 °C for 4 h and cooled down before the ashing procedure was repeated. The ash was dissolved with 5 mℓ of 20% hydrochloric-acid solution over a hot-water bath and then diluted in 50 mℓ of distilled water.

CALCIUM

From the 1:50 dilution, 0,5 mℓ was further diluted with distilled water containing 0,75 g of lanthanum nitrate, to a volume of 50 mℓ. The samples were then read against standards by means of an air-acetylene flame in an Atomic absorption spectrophotometer (Varian Techtron 1979). Results were expressed as g/kg on an organic-matter basis (OM) as suggested by Moir (1960).

PHOSPHORUS

For P determination, 1 mℓ of the 1:50 diluted sample was made up to 10 mℓ with a diluted phosphovanado complex prepared by diluting the reagent as described by Hanson (1950) and adapted by Belonje (1978) and read against standards on a spectrophotometer. Results were expressed as g/kg on an OM basis as suggested by Moir (1960).

TRACE MINERALS

To cut analytical costs, the possibility of grouping liver samples according to the method used by Belonje (1978) for faecal samples, was investigated. Twenty groups of ten liver samples each, were analysed separately and as a pooled sample. The arithmetic mean of the ten individual samples was compared with the result of the pooled sample. The arithmetic mean of the 20 groups of liver samples and that of the pooled samples showed no significant differences, and the correlations between them were 0,96 for Cu; 0,99 for Fe; 0,89 for Zn and 0,89 for Mn. Pooled samples were subsequently used.

Preparation of liver samples

Liver samples for Cu, Fe, Zn and Mn analysis, were sliced after they had been rinsed in distilled water and the cut edges had been removed. Samples were oven-dried at 70 °C to constant mass and then pulverized. To make sure that an individual sample that deviated vastly from the mean did not adversely influence results, samples of each half of the group were pooled separately and again as a group sample, which was analysed in duplicate. Differences between the two subgroups of samples could thus be identified and examined.

After the samples had been thoroughly grouped and mixed, exactly 1 g of liver sample with 2 mℓ of 200-g/ℓ magnesium nitrate was digested over low heat (40 °C) for approximately 4 d. After removal of all remaining digestible OM by heating at 100 °C, samples were ashed to a white ash at 500 °C (3–4 d). Cooled samples were dissolved in 2 mℓ of 200-g/ℓ hydrochloric acid over a steam bath, and diluted to 50 mℓ with deionized, distilled water. Diluted samples were read against standards on an atomic-absorption spectrophotometer (Varian Techtron 1979).

Because of the costs involved, liver samples for Co determination were pooled for each farm, one value representing all samples collected over the period of 6 years. This value represented a minimum of ten animals and a maximum of 40. Dried, mixed liver samples were analysed by means of neutron-activation analysis by the Atomic Energy Corporation of the RSA. Two hundred mg of each sample were ultrasonically

closed in a polythene tube, and radiated for 10 h with thermal neutrons. Samples were left for 6 months to eliminate interfering nucleides before the cobalt concentration was determined over a 1-h period on a multichannel analyser.

IODINE

Milk samples were directly analysed for I by a potentiometer (Orion) according to Wheeler, Fell, Fleet & Ashley (1980).

Quality control

For purposes of quality control, three control samples were also analysed every time samples were processed. The coefficient of variation of the concentration of the minerals for these control samples was always less than 10% in 50 separate series of analyses.

Statistical analyses

Classifications represented by more than five pooled samples (representing at least 50 animals at different ages and stages of production from different farms) were compared statistically. For statistical comparison of Co concentrations, only classifications where analyses from more than three farms per classification were available, were used.

To determine statistical differences in mineral concentrations classified according to soil, vegetation, geology and month, one-way analyses of variance were performed. Because of repeated testing of the same mineral-analysis values in different classifications, adjustment had to be made to the significance level according to Bonferroni's principle, which in some cases meant a nine-times adjustment (Zar 1984).

Results of individual samples were used in the statistical tests for determination of differences in I concentration in different classifications systems. Only areas represented by 20 or more samples were compared. Values of these individual samples were not normally distributed, therefore differences between classifications were determined by use of the Kruskall-Wallis non-parametric test (Zar 1984).

RESULTS

Mineral concentrations in general

Concentrations of Ca, Co, Fe, Mn and Zn never reached very low levels. On certain farms in the north, marginal concentrations of Cu in liver below 78 mg/kg of DM (McDowell 1976) and I in milk below 75 µg/ℓ (Wheeler *et al.* 1980) were recorded. Critically low faecal P concentrations of below 2,0 g/kg of OM (Moir 1966) were recorded in samples from the eastern part of the country.

Mineral concentrations according to classification system

Only some classification systems proved useful in demarcating areas with significantly different trace-mineral concentrations, whereas all systems could effectively indicate differences in Ca and P. Differences in Co and Zn concentrations were not marked and were therefore not indicated by any system. The null hypothesis was therefore rejected for most minerals, as areas of low mineral concentrations could be identified by the use of specific classification systems.

Geology

When mineral concentrations in animal tissue were grouped according to geological classification, significant differences were found in Ca, P, I and Mn (Table 1).

Phosphorus was lowest in samples from farms on the basalt and minor sandstone from the Kalkrand formation of the Karoo system (J in Fig. 1) and highest in samples from farms on calcareous and dolomite-rich geological formations of the Damara sequence (Nsc, Nc, and Nt in Fig.1). Faecal Ca concentrations were highest in samples from farms on the dolomite- and limestone-rich Tsumeb group of the Damara sequence (Nt in Fig. 1), and lowest in samples from farms on eolian sandstone of the Karoo sequence (Je in Fig. 1).

The highest Mn concentrations were recorded in liver samples from cattle grazing on the granite and dolorite intrusions of the Damara sequence (Egs in Fig. 1). Manganese concentrations were lowest in samples from cattle on farms on metamorphosed calcareous deposits, and on granite intrusions of the Damara sequence. Samples from cattle grazing on the red mudstone and sandstone of the Omingonde formation of the Karoo sequence were equally low in Mn (Egs, Nsc and T20 in Fig.1).

Milk samples from cows grazing on the Otavi facies of the Damara system had the lowest I concentrations (Nt in Fig .1), while the Kalahari sand (Tk in Fig. 1) had the highest.

Soil

The association of P intake and soil type is well recognized and animals grazing on sandy soils often suffer from P deficiencies (Du Toit *et al.* 1940; Van der Merwe 1957). This proved to be the case in all soil classifications examined (Tables 2 and 3).

The lowest faecal P concentration was found in samples from animals grazing on the Denhere soil type of the Macvicar classification (Table 2) and the sandy cambic arenosol (Qc38-1a in Fig. 2) of the FAO

TABLE 1 Mineral concentrations found for different geological classifications

Geological* class	Mn g/kg DM (liver)	*n*	I** µg/mℓ (milk)	*n***	P g/kg OM (faeces)	Ca g/kg OM (faeces)	*n*
EGS	$9,5^{ac}$	25			$2,98^{a}$	$19,2^{ABc}$	13
J	$10,0^{a}$	17	90,4	62	$2,51^{a}$		
Je					$2,74^{a}$	$12,8^{a}$	16
NC	$10,7^{Ab}$	17			$3,68^{AB}$	$15,4^{b}$	22
ND	$10,1^{a}$	67			3,42	$15,0^{b}$	96
NK	$10,7^{Ab}$	66			$3,22^{b}$	$15,5^{AB}$	64
NKA	$11,6^{AB}$	38			$2,6^{a}$	$13,5^{a}$	31
NN		12			$2,61^{a}$	$19,1^{AB}$	20
NSC	$9,6^{ac}$	29			$3,69^{AB}$	$15,1^{b}$	27
NT	$10,1^{bD}$	24	$76,5^{a}$	40	3,42	$23,3^{ABC}$	33
T20	$9,5^{cd}$	11			$2,65^{a}$		17
TK	$10,2^{bC}$	154	$106,5^{A}$	193	$2,82^{a}$	$13,9^{a}$	163

Superscripts: Upper case (e.g. A) always higher and differs significantly from lower case (e.g. a) within each column ($P < 0,05$)

* For explanation please refer to Fig. 1

** Non-parametric tests employed here without multiple comparison between groups

*n**** = No of samples tested

n = No of groups of samples tested

TABLE 2 Mineral concentrations in different soil types classified according to the Macvicar system

Macvicar classification	Cu mg/kg DM (liver)	Mn mg/kg DM (liver)	*n*	Ca g/kg OM (faeces)	P g/kg OM (faeces)	*n*
Denhere	$175,3^{A}$	$10,8^{B}$	14	$11,3^{a}$	$2,51^{a}$	17
Gaudam	$172,6^{A}$	$11,7^{A}$	19	$12,4^{a}$	$2,45^{a}$	15
Mispah	$135,4^{ab}$	$10,61^{B}$	61	$14,8^{b}$	$3,66^{AB}$	78
Muden	150,7	$9,1^{ab}$	13	$22,1^{AB}$	$3,71^{AB}$	32
Rock	$164,6^{B}$	$9,9^{B}$	10			
Shorrcks	$159,1^{B}$	$9,7^{ab}$	51	$15,6^{b}$	$3,55^{A}$	73
Zwartfontein	$146,4^{a}$	$10,6^{B}$	33	$13,9^{b}$	$2,75^{b}$	66

Superscripts: Upper case (e.g. A) always higher and differs significantly from lower case (e.g. a) within each column ($P < 0,05$)

n = No of groups of samples tested

TABLE 3 Mineral concentrations in samples from different FAO soil-classification zones

F.A.O. class	Mn mg/kg DM (liver)	*n*	I* µg/ℓ (milk)	*n***	P g/kg OM (faeces)	Ca g/kg OM (faeces)	*n*
1-x-c	$9,7^{Ab}$	34			$3,27^{A}$	$12,45^{a}$	30
BV14-2/3b	$8,1^{a}$	13	$70,2^{a}$	20	$2,94^{b}$	$17,5^{A}$	60
Q19-1a	$9,7^{A}$	143	95,7	58	$3,01^{b}$	$14,12^{a}$	359
Qc38-1a	$10,2^{AB}$	114	$115,8^{A}$	36	$2,68^{b}$	$15,3^{b}$	138
VP55-3bc	$9,8^{A}$	12	73,7	48	$2,71^{a}$	$19,69^{AB}$	25
XK24-2ab	$10,6^{A}$	53	99,5	36	$3,45^{AB}$	$15,93^{Ab}$	94

Please refer to Fig. 2 for explanation of codes

Superscripts: Upper case (e.g. A) always higher and differs significantly from lower case (e.g. a) within each column ($P < 0,05$)

* Non-parametric tests employed here without multiple comparison between groups, but overall difference indicates a significant difference between zones ($P < 0,0001$)

*n*** = No of samples tested

n = No of groups of samples tested

TABLE 4 Concentrations of copper in liver samples and phosphorus in faecal samples from farms in different Loxton soil types

LOXTON classification	Cu mg/kg DM	*n*	P mg/kg OM	*n*
Very shallow and stony non-calcareous red soils	$127,5^{abcdef}$	36	$3,7^{A}$	50
Deep, red, loamy coarse sand with 8% clay	$130,7^{abcdef}$	21	2,88	46
Shallow gravelly loamy sands	$136,7^{abcdef}$	14	$3,75^{A}$	17
Lithosols on calcrete	$138,8^{abcdef}$	13	$2,62^{a}$	28
Yellow coarse sandy loam with 12% clay in upper subsoil	$141,8^{abcde}$	17	$2,69^{a}$	72
Shallow dark sandy loam soils on calcrete	$145,1^{abcde}$	20	2,75	20
Shallow stony black lithosols on calcrete	$146,5^{abcd}$	10		
Reddish loamy sands with 7% clay in upper subsoil	$150,9^{abc}$	14	$2,41^{a}$	19
Sandy clay on calcrete	$155,4^{ab}$	23	3,35	33
Shallow stony red clay loams	$161,2^{abF}$	14	$3,64^{A}$	25
Deep red sandy loams	163^{aF}	11		
Shallow sandy-clay loams overlying calcrete	$163,4^{aEF}$	8		
Deep red sand containing 6% clay	166^{aDEF}	21	2,94	43
Rocks and lithosols with some deep sandy-loam patches	$166,7^{aDEF}$	19	3,39	16
Deep red sand containing 6% clay with light-textured yellow sands	$168,3^{aDEF}$	11		
Rock/lithosol	174^{aCDEF}	8		
Loose deep grey and yellow sands	$181,3^{aBCDEF}$	14		
Dunes of brown sands and sandy loams.	$201,6^{ABCDEF}$	18	$2,52^{a}$	40
Deep red-brown loamy sands with calcrete 90 cm from surface			$2,31^{a}$	22
Deep brown coarse sandy loam with 12% clay in upper soil			$2,69^{A}$	72

Superscripts: Upper case (e.g. A) always higher and differs significantly from lower case (e.g. a) within each column ($P < 0,05$)

TABLE 5 Mineral concentrations in different vegetation-classification zones

Vegetation zone	Mn mg/kg DM (liver)	Fe mg/kg DM (liver)	*n*	I* µg/ℓ (milk)	*n***	P g/kg OM (faeces)	Ca g/kg OM (faeces)	*n*
Southern Kalahari	$9,4^{a}$	$278,0^{A}$	159			$3,00^{b}$	$15,9^{b}$	22
Central Kalahari	$11,0^{A}$	$223,8^{ab}$	105			$2,70^{a}$	$15,0^{a}$	129
Northern Kalahari	$9,4^{a}$	$224,9^{aC}$	52	85,5	148	$2,68^{a}$	$14,2^{a}$	35
Highland savanna	$10,8^{A}$	$239,8^{B}$	117			$3,49^{AB}$	$13,1^{a}$	50
Mopane savanna		$203,1^{abc}$	50			$3,12^{Ab}$	$17,9^{Ab}$	47
Mountain savanna	$9,7^{a}$	$223,0^{ab}$	35	83,8	58	$3,58^{AB}$	$22,0^{AB}$	38
Thornbush savanna	$9,7^{a}$	$243,7^{B}$	42	96,3	47	$3,19^{Ab}$	$16,3^{b}$	133

Superscripts: Upper case (e.g. A) always higher and differs significantly from lower case (e.g. a) within each column ($P < 0,05$)

* Non-parametric tests employed here without multiple comparison between groups, but overall difference indicates a significant difference between zones ($P < 0,0001$)

*n*** = No of samples tested

n = No of groups of samples tested

classification (Table 3). The more arid, shallower, calcrete-rich soils of the calcic xerosol (XK24-2ab in Fig. 2) supported animals with the highest P concentrations.

According to the detailed Loxton classification, the same relationship was apparent; again the sandy-soil associations with very little clay, supported the lowest faecal P concentrations, whereas the shallow gravel and stony soils supported animals with the highest faecal P concentrations (Table 4).

Significant differences in Cu concentration were found when mineral concentrations were grouped according to the refined soil classification of Loxton (Table 4), and the classification according to the Macvicar system was used (Table 2). The lowest Cu concentrations were found in samples from animals grazing on very shallow, stony or sandy soils (Mispah of Macvicar, and very shallow and stony, non-calcareous red soils of Loxton) some of these reaching marginally low levels (Tables 2 and 4). Samples collected from animals grazing on deep sandy soils in the Kalahari area had the highest Cu concentrations (Table 4).

Concentrations of minerals grouped according to soil type were significant between groups for Mn, I and Ca (Table 3). The lowest Mn and I concentrations were found in samples from cattle grazing on the clay soils of the vertic cambisol (BV14-2/3b in Fig. 2) of the FAO classification, while Mn was also low in the Muden series of the Macvicar classification (Table 2). Faecal samples from farms on vertic cambisol (BV14-

TABLE 6 Mineral concentrations with significant overall variance in areas classified according to production zones

Production zone*	Mn g/kg DM (liver)	*n*	I** µg/ℓ (milk)	*n***	Ca g/kg OM (faeces)	P g/kg OM (faeces)	*n*
1	$9,6^{a}$	38	92,2	94	$15,9^{c}$	$2,79^{a}$	33
3	$9,3^{a}$	22	82,2	132	$22,0^{ABCDE}$	$2,84^{a}$	47
4	$9,5^{a}$	11			$19,2^{ABCDe}$	$3,84^{ABCD}$	20
6	$9,4^{a}$	8			$13,1^{a}$	$3,74^{ABCD}$	36
7					$18,0^{ABCe}$	$2,94^{b}$	25
9					$15,2^{c}$	$3,22^{Ad}$	21
11	$9,8^{a}$	11			$19,5^{ABCD}$	$3,18^{c}$	21
12	$10,1^{b}$	56	175	41	$14,8^{c}$	$2,9^{b}$	64
13					$16,5^{ABe}$	$4,14^{ABCD}$	12
14	$9,5^{a}$	10	93,3	28	$19,2^{ABCDe}$	$3,74^{ABCD}$	13
18	$0,6^{A}$	21	107	35	$12,2^{a}$	$3,04^{b}$	58
19	$12,0^{AB}$	23			$12,5^{a}$	$2,59^{a}$	23
20	$10,8^{A}$	25			16^{ABd}	$2,66^{a}$	20
21	$10,6^{A}$	18			$14,7^{c}$	$2,28^{a}$	13
22	$10,7^{AB}$	55	99,5	36	$14,3^{b}$	$3,50^{AB}$	71
23	9,6	12			$12,9^{a}$	$2,95^{b}$	140

* Please refer to Fig. 4 for explanation of codes

Superscripts: Upper case (e.g. A) always higher and differs significantly from lower case (e.g. a) within each column ($P < 0,05$)

** Non-parametric tests employed here without multiple comparison between groups, but overall difference indicates a significant difference between zones ($P < 0,0001$)

*n**** = No of samples tested

n = No of groups of samples tested

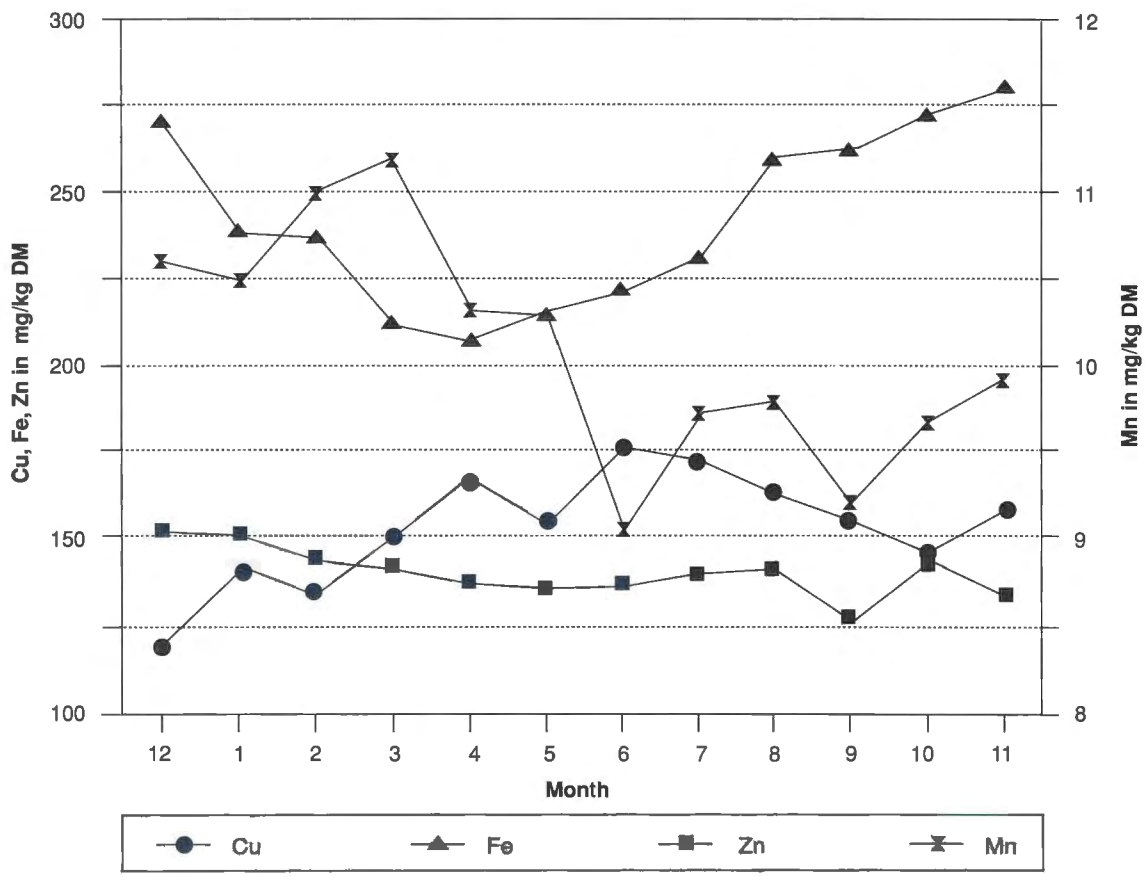

FIG. 5 Monthly variation in liver samples of the trace minerals Cu, Fe, Zn and Mn

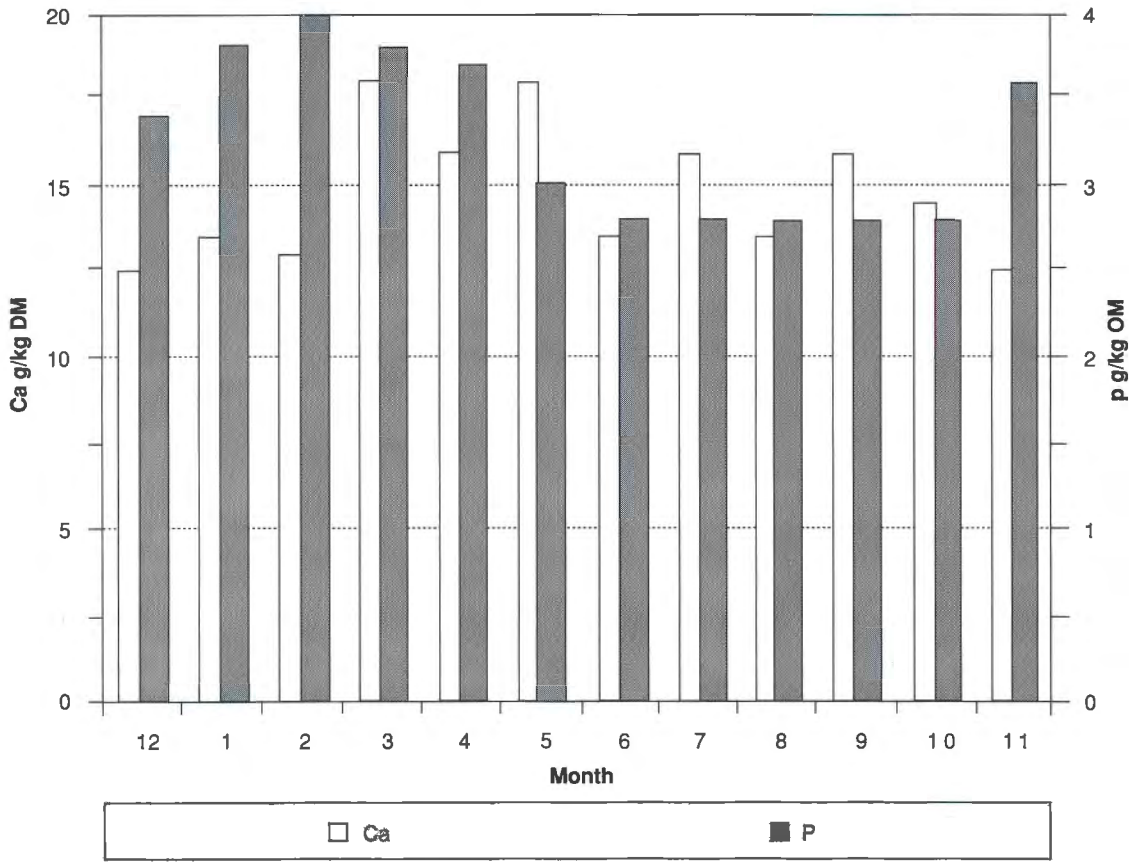

FIG. 6 Monthly variation in faecal samples of Ca and P

2/3b in Fig. 2) were high in Ca, as were samples from farms on the pellic vertisol (Vp55-3bc in Fig. 2) (Table 3).

Vegetation

When the difference in tissue concentration of minerals was examined according to the vegetation classification of Giess (1971), significant differences were found for P, Ca, Mn, Fe, and I (Table 5).

Differences in Fe concentrations were best identified with the Giess classification (Fig. 3). The lowest Fe concentrations were found in samples from farms on the alkaline clay soils of the *Mopane* Savanna. The mixed tree and shrub savanna of the southern Kalahari supported the highest Fe concentrations, but also the lowest Mn concentrations.

The more detailed production-zone classification was very useful in identifying areas of possible I deficiencies, and significant differences between classification types were also found for Mn, Ca and P (Table 6). The Shallow Turf classification in the north (three in Fig. 4) supported animals with the lowest concentrations of I in milk and Mn in liver, and the highest faecal Ca concentrations. Iodine concentrations in milk were highest in animals grazing in the *Terminalia sericea*-dominated Osire sandveld (12 in Fig. 4).

Phosphorpus concentrations again tended to be lowest in the sandveld-dominated areas, with the lowest concentrations recorded in samples from the Spatzenveld Camel-thorn savanna (21 in Fig. 4).

Monthly variation in mineral concentrations in animal samples

Mineral concentrations of Cu, Fe, Mn, Zn, P and Ca in animal tissue were significantly affected by month ($P < 0{,}005$). Copper concentrations in liver showed a trend different from the other trace minerals. The highest concentrations (177 mg/kg of DM) were recorded in livers collected in the cool dry months of June and July when vegetation was dormant, and were significantly higher ($P < 0{,}001$) than the lowest concentrations (118 mg/kg of DM) at the beginning of the hot rainy season, when the vegetation was actively growing (Fig. 5).

Iron concentrations in liver were highest (281 mg/kg of DM) towards the end of the hot dry season and were significantly higher ($P < 0{,}001$) than the lowest (208 mg/kg of DM) at the end of the rainy season.

Manganese concentrations in liver were lower (9,1 mg/kg of DM) when the vegetation was in a dormant stage during the cool dry period, concentrations rising from October onwards to reach a significantly higher ($P < 0,001$) peak (11,2 mg/kg of DM) at the end of the rainy season in March. Zinc concentrations peaked (153 mg/kg of DM) at the beginning of the rainy season, with animals grazing on actively growing vegetation, and decreasing as plants matured to reach significantly lower concentrations ($P < 0,05$) of 128 mg/kg of DM at the end of the cool dry season.

Faecal phosphorus concentrations showed a very distinct seasonal pattern (Fig. 6), following the known P-concentration variation in grass (Bisschop 1964). Phosphorus concentrations were highest (4 g/kg of OM) in the middle of the rainy period and declined steeply after the first frost at the beginning of the cool dry period, to reach a significantly lower ($P < 0,001$) minimum (2,7 g/kg of OM) at the end of that period. Faecal Ca concentrations showed almost the opposite trend (Fig. 6), with highest concentrations (18 g/kg of OM) during the cool dry period when the vegetation was dormant, and significantly lower ($P < 0,001$) concentrations (12,5 g/kg of OM) at the beginning of the rainy season, when grass was growing actively.

DISCUSSION

Phosphate deficiencies are very common in rangelands (Underwood 1981), and P was also the mineral that was most frequently found to be deficient in this study. The sandy soils of the Kalahari sequence were most often associated with lower faecal P concentrations. Phosphorus is not readily available in these sandy soils and P deficiencies could therefore be expected (Reid & Horvath 1980). High permeability of these soils leads to leaching of the mineral, explaining why the higher rainfall areas support lower faecal P concentrations (Van der Merwe 1957). Where the soil drainage is impeded, as occurs in the shallower calcrete-rich soils, salts accumulate in pans or on calcrete banks (Bell 1982), and accordingly, this is where higher P concentrations were recorded.

Season significantly affected P concentration in faeces. Lowest P concentrations were found at the end of the dry season on mature pastures, when P concentrations are normally low (Underwood 1981). Phosphorus deficiencies are therefore more likely to occur in the cool dry season.

Calcium deficiencies are very unlikely to occur on arid soils (McDowell 1976); high Ca concentrations are more likely to be the problem as Ca will influence the absorption of P and certain trace minerals. Faecal Ca concentrations were high in areas with calcrete in the soil structure, with Ca:P ratios varying from 7:1 in the calcrete-rich turf areas, to 4:1 in the sand areas.

Iodine concentrations in milk were found to be low to marginal in samples collected from cows grazing on the clay soils of the dolomite-rich Damara sequence in the north and the northern Kalahari sand areas. Such areas are known to be lower in I (Reid & Horvath 1980), but as for other minerals, soil ingestion could reduce the deficiency, especially on clay soils (Thornton 1983). Factors that lead to increased soil ingestion such as short grazing due to either overstocking or low rainfall (McGrath, Poole, Flemming & Sinnott 1982) will therefore tend to affect I status as well.

The geological classification is the one single classification system that could best identify areas where mineral concentrations, apart from Cu, are lowest, and therefore more likely to have secondary deficiencies. Concentrations tended to be lower where parent rock contained low concentrations of the specific trace mineral. For example, Fe concentrations were high in samples from animals grazing on the Fe-containing mica-rich Damara system, and low in the granite and dolomite intrusions which are low in Fe-containing minerals. Mn, Fe and Cu concentrations were also relatively high in samples from farms in the Kalahari sequence. This is due to these and other trace minerals forming unleachable mineral oxides in arid sands that are available to plants and animals in high concentrations (Prof. H. Zakosek, personal communication 1988). Manganese concentrations tended to be lower in all classification systems that isolated calcrete-rich zones. This is due to the marked effect that the pH of soil has on Mn absorption. An increase of soil pH from 4,6 to 6,5 can decrease exchangeable Mn 20- to 50-fold (Reid & Horvath 1980). In the alkaline Shallow Turf area where Mn levels are already low, high Ca concentration in supplements could cause secondary Mn deficiencies.

Zinc deficiencies are unlikely to occur under normal farming conditions (Hansard 1983). The lowest zinc concentrations were found in animals grazing where the shallow calcrete-rich soils of the calcic xerosol overlie the metamorphosed calcrete deposits of the Damara sequence in the Highland Savanna.

Copper was the only trace mineral for which marginal concentrations were recorded. Possible Cu deficient areas could best be identified by a detailed soil-classification system. In this study, deep sandy soils supported the highest Cu concentrations, whereas concentrations tended to be lowest in samples from animals utilizing grazing on shallow soils. Because of mineral interactions (Little 1981), injudicious supplementation of trace minerals—especially Fe—should therefore be avoided in these areas. The same is true for S, which is often supplemented in urea licks

or used to avoid hydrocyanic-acid poisoning (Suttle 1986).

Iron levels in the liver tended to be lowest from March to May, which is also the period during which the highest burdens of internal parasites are found (Biggs & Anthonissen 1982). In the areas with low available Fe concentrations, deficiencies could be precipitated at the end of the rainy season by high burdens of blood-sucking worms.

CONCLUSIONS

From this study it is clear that P and I are the only minerals likely to be naturally deficient and which may cause production losses in Namibia. Mineral concentrations, however, show seasonal variation, and deficiencies might occur under specific climatic conditions. Areas which are more likely to suffer from deficiencies under these conditions, were identified by using different classification systems.

The geological classification system proved to be the best single classification system to use for predicting possible areas of deficiencies. Soil classification, however, proved most useful for identifying areas of possible Cu, P and I deficiencies.

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