Tropical Grasslands (1995) Volume 29, 40–46

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

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Abstract

Samples of topsoil (0–30 cm) and dry season herbage from 135 sites in the Mt Elgon region of Kenya were classified according to farm (n = 84), site altitude, underlying soil bedrock (6 types) and botanical composition (6 classes). Effects on pasture concentrations of Ca, P, Mg and S were determined using a mixed model for unbalanced data sets and the Wald (W) statistic to assess the significance of fixed effects. Associated effects on pH, plus extractable Ca and P concentrations in the topsoils were also evaluated.

Soil bedrock influenced herbage concentrations of S ($P < 0.001$) but not those of Ca, P or Mg. Mean herbage S concentrations were lowest on volcanic and metamorphic gneiss associations (1.2 g/kg DM) but only extreme values would be inadequate for grazing livestock. Altitude appeared to affect the concentration of P ($P < 0.01$) and not those of Ca, Mg and S in herbage but the effect on P was dependent on soil P. Geological and topographical maps cannot be used to predict macro-mineral disorders in livestock in the Mt Elgon region.

Herbage species differed markedly in their concentrations of S ($P < 0.001$), Ca ($P < 0.001$) and Mg ($P < 0.05$) but not P. Ca deficiency may arise on setaria, S deficiency on some napier grass pastures and P deficiency on some dry season pastures irrespective of botanical composition.

Low herbage P concentrations may reflect advanced maturity rather than low soil P status (mean value 20 mgP/kg DM). The correlation between soil P and herbage P was significant ($r = 0.595$), and similar in slope and intercept for all herbage classes but not strong enough to predict deficient herbages. Herbage Ca was not correlated with soil Ca.

Introduction

Few attempts have been made to map the likely incidence of mineral deficiencies in grazing livestock in tropical countries (Appleton 1992). Since geological and soil series maps are generally available and unlikely to change, the ability to predict disorder from such maps would be a distinct advantage. However, some workers have concluded that such approaches are unlikely to succeed because correlations between soil and pasture mineral composition in the tropics are poor (Conrad *et al.* 1980; McDowell *et al.* 1984). Before dismissing the predictive value of information on soil type and mineral composition, attempts should be made to identify those factors which influence the relationship between mineral composition of soil and pasture. There is a lack of information about the mineral composition of typical agricultural pastures and soils of Kenya in relation to the underlying geology. The reports of Hudson (1944), Howard (1970) and Maskall and Thornton (1989; 1991) either considered only a few elements or were based in areas where farming was limited. The varied geology in the Mt Elgon region of Kenya (e.g. Sanders 1963) makes it an ideal area to study the effects of soil:plant relationships on mineral composition.

There is also considerable variation in the botanical composition of local pastures.

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Differences between temperate pasture species in macro- (Minson 1990) and trace element (Mitchell 1974; Burridge *et al.* 1983) composition have been reported but less is known about tropical species. They generally have lower concentrations of Ca and P but higher Mg concentrations than temperate grasses (Minson 1990), and differences amongst tropical species have been reported from Uganda (Long *et al.* 1970). Since a substantial proportion of the grass samples taken from the Mt Elgon region were deficient in a large number of macro-elements (Jumba *et al.* 1994), it was decided to examine the effect of geology, soil composition, altitude and herbage species on the prevalence of deficient, sufficient or potentially antagonistic mineral concentrations in pasture for grazing ruminants. This paper reports on the major elements Ca, P, Mg and S, while a subsequent paper will deal with 7 trace elements (Jumba *et al.* 1995).

Materials and methods

Geology and altitude

The program of soil sample collection is described by Jumba *et al.* (1994). The 135 topsoil samples were taken to a depth of 30 cm, came from drift-free areas and represented soils derived from a range of parent materials. The parent bedrock underlying individual farms was determined from 1:125 000 geological maps of the area published by the Geological Survey of Kenya (Gibson 1954; Miller 1956; Sanders 1963). A circle 5 km in diameter delineated an area centred on the farmhouse, and the principal soil bedrock of the area as well as its altitude were recorded. Altitude varied from 1340–2340 m above sea level. The position of sampled areas in relation to the solid geology of the region was illustrated by Jumba (1989). Most of the sampling sites overlay metamorphic gneisses (44%) but 5 other classes were well represented (n > 9; Table 1).

Herbage species

Pasture samples were collected during the dry season (January–March) at the hay stage. Of the 14 pasture types sampled from the 135 different sites, the dominant species were napier grass (*Pennisetum purpureum*) and rhodes grass (*Chloris gayana*) which constituted 64.4% of the total. Kikuyu grass (*Pennisetum clandestinum*) and setaria (*Setaria sphacelata*) provided a further 13.4% (Table 2). The rest of the samples

Table 1. Distribution of samples in relation to geology.

Soil bedrock type	System classification	Symbol	No. of farms	No. of samples	% Class frequency
Soft volcanic	Tertiary volcanic	TV	12	20	14.8
Igneous	Granitic (basement)	IG	13	17	12.6
Metamorphic	Gneisses (basement)	MG	36	60	44.0
Metamorphosed sedimentary	Schists-quartz (basement and intrusives)	MS	5	10	7.4
Sedimentary	Sandstones and grits (Kavirondian)	SSG	6	9	6.7
Local drift/deposits/peat	Alluvium/black valley and sandy soils	AD	12	19	14.1

Table 2. Distribution of samples in relation to botanical composition.

Herbage species	Pasture classification	Symbol	No. of sites sampled	% of total samples
Napier (*P. purpureum*)	Fodder	Pp	39	28.9
Rhodes (*C. gayana*)	Ley pasture	Cg	48	35.5
Setaria (*S. sphacelata*)	Ley pasture	Ss	9	6.7
Setaria + rhodes mixture (50:50)	Ley pasture	Ss/Cg	13	9.6
Kikuyu (*P. clandestinum*)	Ley pasture	Pc	9	6.7
Natural grasses	Mixed pasture	Mng	14	10.4
Assorted single species	Ley pasture	—	3	2.2

comprised sown or natural grass mixtures (20%) and assorted single species growing on large areas; the latter were excluded from the statistical analysis. Details of the sampling procedures are given by Jumba *et al.* (1994).

Chemical analysis

Soils were analysed for extractable Ca (1 M NH_4Ac at pH 7; Weir and Sommer 1948), P (0.1M HCl in 0.0125 M H_2SO_4; Nelson *et al.* 1953) and soil pH (Hesse 1971) while the herbages were analysed for Ca, P, Mg and S as total concentrations using standard methods (Jumba 1989; Jumba *et al.* 1994).

Statistical analysis

The 135 samples (units of data) arose from 84 farms. Samples from the same farm share a similar micro-climate and management system and are likely to be from the same soil bedrock type and be at approximately the same altitude. Consequently, they are particularly useful for estimating the effects of botanical composition. However, the effects of geology and also of altitude must be largely estimated between farms, multiple samples from the same farm adding little precision to these estimates. In order to utilise the structure of the data and thus produce good estimates of mean effects and standard errors, a mixed model was fitted to the data using the Residual Maximum Likelihood (REML) method of estimation (Patterson and Thompson 1971). For a scholarly discussion of methods of fitting this model see Harville (1977), and for examples of its use see Robinson (1987). All calculations were carried out using the Genstat 5.3 program (copyright 1994, Lawes Agricultural Trust, Rothamsted Experimental Station). The method is also available in SAS and in BMDP. Fixed effects were fitted for geology, altitude (herbage only) and for botanical composition and random effects for farm and for sample within farm. Soil calcium and phosphorus data were transformed by taking logarithms to the base 10 because their distributions were skewed. The overall statistical significance of each factor was determined using the Wald statistic, which is asymptotically distributed as a Chi-square. For the herbage phosphorus, an augmented model including soil phosphorus and pH as covariates was fitted to the data.

Results

Effects of geology

The effects of geology on soil pH and both soil and herbage mineral concentrations are shown in Table 3. Significant differences in soil pH were observed between the 6 bedrock formations, values being highest in soils derived from soft volcanic bedrock and lowest in those from overlying metamorphosed sedimentary and

Table 3. Effects of soil bedrock associations on the pH and mean mineral concentrations in herbage (H, g/kg DM) and soil (S, mg/kg DM) at 135 sites in Kenya. Minimum and maximum standard errors of the differences between means (s.e.d.m.) and Wald statistics (W) for group comparisons are also presented.

Soil bedrock[1]	TV	IG	MS	MG	SSG	AD	s.e.d.m.		W	Signif.[4] of diff.
No. of sites	20	17	10	60	9	19	min (60)	max (9)		
H Ca	1.24	1.46	1.56	1.33	1.40	1.38	0.130	0.243	2.9	ns
H P[2]	1.28	1.59	1.81	1.27	1.69	1.32	0.178	0.378	8.5	ns
H Mg	1.71	1.71	1.51	1.61	1.85	1.50	0.125	0.231	6.6	ns
H S	1.29	1.66	1.79	1.23	1.93	1.52	0.126	0.234	28.6	***
S pH	5.7	5.2	4.9	5.2	5.0	5.2	0.16	0.30	13.2	*
S Ca[3]	1272	349	510	590	986	450	0.155	0.288	12.9	*
S P[3]	26.7	19.6	22.4	20.9	23.9	19.6	0.068	0.126	3.9	ns

[1] TV — soft volcanics; IG — igneous; MG — metamorphic; MS — metamorphosed sedimentary; SSG — sedimentary sandstones and grits; AD — alluvial deposits.

[2] REML model included altitude, pH and soil P; removing them did not affect statistical significance of bedrock effect.

[3] Extractable soil Ca and P were analysed after $\log_{10}$ transformation; back-transformed means are given but the s.e.d.m. is the $\log_{10}$ value.

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

sedimentary sandstones and grits. The soils also showed a nearly 4-fold variation in extractable Ca with higher values in soils of volcanic origin than in those derived from igneous or alluvial deposits. Soil P concentrations were highest in soils of volcanic origin and lowest in igneous and alluvial deposits but not significantly so. Herbage Ca, P and Mg concentrations were not influenced by bedrock formations but S was strongly affected with values about 30% lower in pastures overlying volcanic and metamorphic gneiss associations than in those overlying sedimentary sandstones and grits and metamorphosed sedimentary formations ($P < 0.001$).

Effects of herbage species

Table 4 gives the mean macro-mineral concentrations in the botanical groups and the extractable Ca and P concentrations and pH of soils associated with each group. Botanical composition generally had a greater effect on mineral concentrations in herbage than soil origin with S the most ($P < 0.001$) and P the least ($P > 0.05$) affected element. Rhodes grass and kikiyu were relatively rich in S whereas napier grass was poor. Mean herbage Ca concentrations were lowest in setaria and highest in rhodes grass, whereas extractable Ca levels in the soils did not vary between species sites. Mg concentrations were lowest in setaria and rhodes grass and highest in kikuyu ($P < 0.05$). The mixed natural grasses were generally intermediate in their macro-mineral composition. Soil Mg and S concentrations were not measured and the possibility of confounding effects of site differences in soil composition cannot be ruled out. There were no marked correlations between herbage mineral concentrations (Table 5), the strongest association — that between P and S — accounting for only 5.6% of variation.

Effects of soil composition

The most significant effects of soil composition were those on herbage P which was positively correlated with extractable soil P, Ca and soil pH (Table 5). Extractable P concentrations ranged from the deficient (4 mg/kg DM) to the abundant (107 mg/kg DM) with a derived mean value of 20 mg/kg DM. There were no significant differences in the slopes of the P relationships between species and in the complete REML model, pasture P increased by 0.032 ± 0.0067 g/kg DM for every mg of P extracted from the soil. Extractable concentrations of Fe (Jumba *et al.* 1995) and P were negatively correlated ($r = -0.313$) in soils which were mostly acidic (mean pH 5.2; sd = 0.15).

Effects of altitude

There were few effects of altitude on the macro-mineral composition of the Mt Elgon forages. P alone was affected, concentrations rising by 0.37

Table 4. Effects of botanical composition on the mean macro-mineral concentrations in herbage (H, g/kg DM) and associated extractable Ca and P concentrations (mg/kg DM) and pH in the soils (S) associated with a given botanical group. Minimum and maximum standard errors of differences between means (s.e.d.m.) and Wald statistics (W) are also given.

Botanical composition[1] No. of samples	Pp 39	Ss 9	Cg 48	Pc 9	Ss/Cg 13	Mng 14	s.e.d.m.		W	Signif.[4] of diff.
							min (48)	max (9)		
H Ca	1.33	1.07	1.73	1.38	1.43	1.43	0.100	0.213	26.2	***
H P[2]	1.39	1.32	1.40	1.59	1.68	1.60	0.135	0.301	4.0	ns
H Mg	1.70	1.39	1.50	1.95	1.63	1.73	0.102	0.215	11.4	*
H S	1.12	1.40	2.00	1.72	1.64	1.54	0.098	0.214	82.6	***
S pH	5.2	5.1	5.1	5.4	5.2	5.2	0.07	0.16	9.4	ns
S Ca[3]	576	514	586	784	639	543	0.065[3]	0.145[3]	3.5	ns
S P[3]	20.3	25.6	21.6	27.3	19.6	19.1	0.034[3]	0.075[3]	0.2	ns

[1] Pp — napier grass; Ss— setaria; Cg — rhodes grass; Pc — kikuyu; Ss/Cg — setaria/rhodes mixture; Mng — mixed natural grasses.
[2] REML model included as covariates (regression coefficients ± s.e.): soil P (0.032 ± 0.0067), soil pH (0.21 ± 0.130) and altitude (0.00016 ± 0.000136).
[3] Extractable soil Ca and P were analysed after $\log_{10}$ transformation; — back-transformed means are given but the s.e.d.m. is the $\log_{10}$ value.
[4] $P < 0.05$ = *; $P < 0.001$ = ***; $P > 0.05$ = ns.

Table 5. Correlation matrix describing relationships between the macro-mineral concentrations in herbage (H) and soil (S) and their dependence on soil pH.

H Ca	1.00						
H P	0.083	1.00					
H S	0.0203	0.236	1.00				
H Mg	0.030	0.150	0.048	1.00			
S Ca	–0.034	0.421	0.088	0.162	1.00		
S P	–0.01	0.476	0.241	0.005	0.473	1.00	
S pH	–0.01	0.259	–0.162	0.045	0.430	0.421	1.00
	H Ca	H P	H S	H Mg	S Ca	S P	S pH

± 0.159 (s.e.) g/kg DM for every 305 m increase in height above sea level over the range encountered (1340–2340 m).

Discussion

The results indicate that consideration of the effects of altitude, geology, soil composition and herbage species on herbage macro-mineral concentrations will be of limited value in delineating deficiency problems in livestock in the Mt Elgon region during the dry season. This is in contrast to the position with regard to trace elements (Jumba *et al.* 1995).

Geology

The effects of soil origin on the macro-mineral composition of the forages were small and significant only for S, despite the 3–4-fold variations in extractable soil Ca. There are probably 3 major reasons for the weak geological influence. Firstly, plants have buffering mechanisms which nullify differences in soil composition. Secondly, the use of P and Ca fertilisers may have masked geological differences; effects of geology were significant for S and most of the trace elements (Jumba *et al.* 1995) which are rarely used as fertilisers in Kenya. Thirdly, hydromorphic processes involving leaching and erosion are particularly influential in tropical environments and affect soil mineral dispersion (Butt 1987; Roquin *et al.* 1990). The mapping of soil mineral status by stream sediment analysis provides an alternative assessment of geological influences (cf. Appleton 1992) which involves hydromorphic processes, but its value in predicting herbage mineral concentrations under tropical conditions is largely untested. In general, geological maps would appear to be of little use in predicting the incidence of forages deficient in macro-minerals. The exception is for S deficiency which may occur principally in areas with volcanic and metamorphic gneiss associations, the most prevalent in the Mt Elgon region.

Soil composition

The analysis of soils for Ca and pH did not improve the prediction of macro-mineral deficiencies in dry season herbage at the farm level, confirming the findings of Long *et al.* (1970) in Uganda. With 3 outliers removed, variation in soil P accounted for only 25% of the variation in herbage P and showed no sign of improvement at low concentrations. Though stronger (r = 0.64) the corresponding relationship found by Long *et al.* (1970) also lacked predictive merit. The generally low P status of the forages (Jumba *et al.* 1994) may reflect their advanced maturity at the time of sampling (Minson 1990) rather than a general deficit in available soil P, which for the most part was adequate (cf. Kerridge *et al.* 1990). The predictive value of soil analysis may be greater for wet season forages. The poor relationship between soil and herbage P cannot be attributed to the soil extraction method chosen as it was found to give the highest correlation with herbage P when compared with 3 other common extraction methods (Jumba 1989).

Herbage species

There have been no comparisons of species differences in mineral concentrations in which the influence of soil origin and composition were taken into account (cf. Minson 1990). Individual species were apparently more important than soil characteristics in determining mineral concentrations in the dry season forages of Kenya. Species differences in herbage S were the most pronounced and their relevance to animal production is enhanced by the fact that the species with least S (napier grass) was commonly used (Table 2) and may alone be marginally inadequate on occasions. The high S concentration in rhodes grass compared with napier grass and setaria agrees with the data of Long *et al.* (1970) for rainy season samples in Uganda, except that the difference between species was smaller (0.9 vs 1.4 g S/kg DM). Concentrations of Ca and P were both low in napier grass and setaria with Ca values 35–45% below the minimum TCORN (1991) dietary allowance (2.0 g Ca/kg DM) for cattle and sheep. Furthermore, they constituted 64% of the samples collected. In the Long *et al.* (1970) study, napier grass contained less Ca than setaria and rhodes grass but still an adequate level of Ca (3.2 g/kg DM). Comparisons with other studies confirm the relatively low Ca content of setaria and the higher value for kikuyu but not the high ranking for rhodes grass (Minson 1990). The lack of difference between species in P concentration agrees with the literature on tropical grasses (Long *et al.* 1970; Minson 1990).

With regard to Mg, Hill and Guss (1976) and Hacker (1982) reported wide variations in the Mg content of various species and concluded that plant breeding had considerable potential for increasing the mineral composition in a number of forage species. As with a previous study (Long *et al.* 1970), species differences in Mg concentration were not marked but setaria and rhodes grass (found on 42% of the sampled sites) contained 1.50 gMg/kg DM or less and would not meet Mg requirements, especially for pregnant and lactating cattle and sheep which need 1.4–2.1 g Mg/kg DM (ARC 1980; Suttle 1983). Although kikuyu grass had an Mg concentration which was closest to the requirement, the lusher foliage may contain Mg of lower availability than the other species.

Species differences in mineral concentration may be associated with morphological or physiological traits because minerals are unevenly distributed within the plant and across seasons. The leaves of tropical grasses contain twice as much Ca as the stem (Minson 1990) and the species studied differ in their rates of maturity (Bogdan 1977). In setaria and rhodes grasses, the rapid increase in stem:leaf ratio (S:L) at the flowering stage occurs 7–14 days earlier than in napier grass and both species have higher S:L ratios than kikuyu grass. However, the species differences in concentrations of Ca cannot be explained simply in terms of S:L ratio. With P, there is little difference in the composition of leaf and stem but P concentrations in the whole plant decrease with maturity at rates varying from 0.017–0.050 g P/kg DM/d in tropical grasses (Minson 1990). Mg concentrations are also lower in stemmy, mature plants (Minson 1990). The results obtained for all minerals will therefore partly reflect the chosen sampling time (January–March; dry season) and comparable studies on wet season pastures are warranted.

The priority given to exploiting herbage species differences in the control of mineral deficiencies will be influenced by the severity of deficiency, the availability and cost of alternative treatments, antinutritional factors in the mineral-rich species and miscellaneous limitations such as the commercial availability of seed. While Ca deficiency can be produced easily in young growing animals and lactating dairy cows fed native low-Ca forages supplemented with concentrates, it has not been reported in grazing beef cattle even during lactation (Loosli 1978). Furthermore, Ca can be supplied cheaply by liming. By contrast, attempts to correct P deficiency by fertiliser application can be expensive if the basic problem is one of non-availability through P fixation as is suggested by the negative effects of soil Fe and acid soil conditions on soil P status. Application of expensive P can merely add to the pool of non-available P in the soil at great cost. It is unfortunate that species differences for P were not wide enough to suggest control of deficiency by choice of botanical species. The wider use of kikuyu — with 13–55% more S than species other than rhodes grass — could, however, contribute to the control of S deficiencies while raising the intakes of most other minerals (cf. Table 4 and Jumba *et al.* 1995) in the Mt Elgon region.

This study did not address the matter of differences in mineral availability between species but these could be important for Ca. In western Kenya (Bogdan 1977; I. O. Jumba, unpublished data) and in other parts of the world (Seawright *et al.* 1970; Barry and Blaney 1987), higher oxalate concentrations have been found in setaria (6–10% DM) than in kikuyu grass (0.5–4% DM). In Australia, acute oxalate poisoning in cattle and horses grazing setaria has been attributed to low availability of Ca (McKenzie and Schultz 1983). Kikuyu grass may therefore be a better source of available as well as total Ca than setaria.

Acknowledgements

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

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