SOIL VARIABILITY WITHIN LAND FACETS UNDER A SAVANNA CLIMATE, NORTHERN NIGERIA

Variabilité des sols pour divers faciès sous un climat de savane, Nigéria septentrional

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RESUME

Les différentes propriétés du sol ont été étudiées sur les trois facettes des versants - sommet, partie intermédiaire, base - d'une plaine mollement ondulée dans une région de savane du Nigéria septentrional. Au sein des facettes ainsi distinguées, il existe une grande variabilité: CV = 20 à 50 % pour la texture, la teneur en matière organique et en azote; 10 à 25 % pour le pH du sol et le pourcentage de BS ; 50 à 80 % pour la teneur en bases échangeables et la capacité d'échange.

A la profondeur de 5-15 cm, il existe une différence significative (au niveau 0,05) entre les différentes facettes pour presque tous les caractères à l'exception de la teneur en argile, la densité apparente et le K échangeable. Toutefois à la profondeur de 20-30 cm, seules la teneur en cailloux, en Na et Mg échangeables ainsi que la capacité d'échange sont encore significativement différentes.

Les facteurs et les implications d'une telle variabilité sont discutées.

ABSTRACT

Studies are made to compare some properties of soils from the summit, middle and lower slope facets of broad interfluves amid a gently undulating plain in the savanna zone of northern Nigeria. Within each facet there is considerable variability as shown by coefficient of variation of 20-50 % for the textural fractions, organic matter and nitrogen contents, 10-25 % for the soil pH and % BS and 50-80 % for exchangeable bases and CEC.

In the 5-15 cm depth, each of the properties reveals significant differences between the land facets at the 0.05 probability level, except silt content, bulk-density value and exchangeable K. But in the 20-30 cm depth only the gravel content, Na, Mg and CEC are significantly different. The potential contributions of a number of factors to the observed variations and the implications of such variability for soil sampling and mapping are discussed.

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INTRODUCTION

In field soil survey, there is the pratical limit to the number and detail of soil profiles examination that can be made on the landscape. Once the relationships between soil profile characteristics and surface features are established however, the soil can be mapped fairly cheaply and with speed and accuracy, according to its surface expression, with as much direct observations of profiles as is required by the scale of mapping and the complexity of the soil pattern (DENT & YOUNG, 1982).

Land facets are areas within which for most pratical purposes environmental conditions are uniform. This attribute, coupled with the economies of delineating boundaries on air photographs, has made land facets a very attractive operational unit in soil mapping, at least at the reconnaissance scale (AMEYAN, 1983; AREOLA, 1974, 1982; DENT & YOUNG, 1982).

Although land facets are of great pratical value in field soil survey, their effectiveness could be increased with an understanding of the range of values of soil properties which may be expected within the facets (COLLINS & FENTON, 1984; KHAN & NORTCLIFF, 1982; BLYTH & MACLEOD, 1978). The investigations described in this paper were initiated with this end in view. The degree of uniformity exhibited by selected soil properties within three major land facets and the differences between the facets have been investigated.

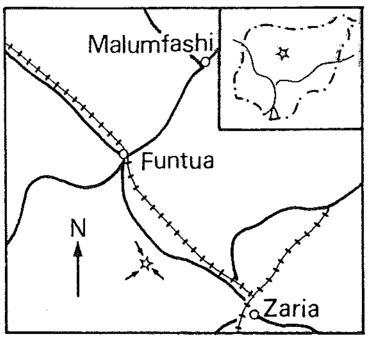

Fig. 1 : Location map.

The study area lie in an area of gently undulating plain in the savanna zone of Nigeria. Natural variations within apparently uniform areas have been found to be suprisingly large for a wide range of soil properties. BECKETT and WEBSTER (1971) in their review quote median coefficient of variation of 35 % and 58 % for organic matter and exchangeable cations, respectively, within topsoils of a given soil series. Their data refer to temperate area but their is no reason to suppose that soil distribution patterns are any less complex in the tropical area (YOUNG, 1973, 1979).

STUDY AREA

The study area is located some 55 km north-west of the northern Nigerian old city of Zaria (fig. 1). The area experiences dry sub-humid tropical continental climate (HORE, 1970) with average annual rainfall of about 1100 mm, concentrated almost entirely into 5-months period. Air temperatures are high throughout the year with April temperatures averaging about 28° C and January 22° C. The vegetation is northern guinea savanna in which *Isoberlinia doka* (s) and *I. tomentosa* are the dominant tree species. Below the trees, there are tufted grasses and both trees and grass are often mixed with shrubs undergrowth.

The general relief consist of gently undulating dissected lands traversed by shallowly incised intermittent streams and broken by occasional granite inselbergs and isolated lateritic ironstone capped plateaux. It is thus a very characteristics type of landscape on the shield area of Africa (AREOLA, 1982).

The soils belong to Tropical Ferruginous Soils. They are deeply weathered and except on very steep slopes rocks rarely outcrop at the surface. Textures are sandy loam at the surface and clay loam at the lower horizons and the structure is normally weak angular or fine blocky. The colour may be red, yellowish red or reddish yellow and apart from the brownish organic topsoil, it remains constant down to the C horizons. In the C horizon white and red weathering mottles are common.

METHODOLOGY

3.1. Soil Sampling

Soil samples were collected in three separate locations. The locations are 2.4 km, 2.9 km and 3.2 km apart and are underlain by porphyroblastic biotite gneiss and experience the same climatological conditions (fig. 1). The lands have not been affected by agriculture for many years, being under government Forest Reserve. The geomorphological characteristics is also the same. This consists of a belt of relatively steep slope between broad gently slopping convex interfluves and short foot slope that is either planner or concave in form and grading into a narrow valley floor (fig. 2). The landscape is dominated however, by the broad interfluves and it is over this portion of the landscape that this study is based. Broadly similar type of landscape was described in the federal capital territory further south by AREOLA (1982) but while the latter could identifie on air photo only two major land facets over the broad interluve, three facets are discerneable in the present study area.

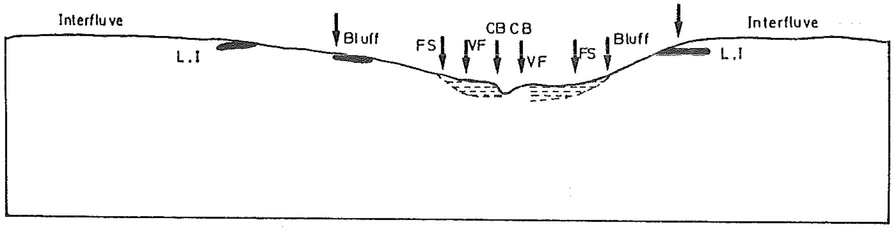

Fig. 2 : Model of valley orm on plains over the study area showing slope elements : LI = laterite ironstone; A = alluvium; FS = foot slope; VF = valley flor; CB channel bank.

Seventy two sampling points all together, eight each over the three land facets in the three locations were selected. The points were located at 10 m interval and divisible equally along two transects. The transects are also 10 m apart and perpendicular to a line from the crest to the valley bottom. Soil samples were taken at two standard depths : 5-15 cm and 20-30 cm. These have been referred to in later discussions as topsoil and subsoil, respectively.

3.2. Measurement of soil properties

The soil properties analysed are given in Table I. The particle size distribution was measured by the pipette and sieving methods, bulk density by core method, organic matter by Walkley and Black oxidation method and total nitrogen by kjoeldahl digestion method. The soil pH was determined by the use of the pH meter in soil water ratio of 1:25, exchangeable Ca, K and Na by flame photometry and exchangeable Mg by atomic absorption spectrophotometry. Both the CEC and % BS were obtained by the summation method (FAO, 1970).

4. RESULTS AND DISCUSSION

4.1. Soil variability within land facet.

The results of the soil measurements is shown in Table I. In this study variability was assessed by the coefficient of variation (CV)[1].

4.1.1. Texture and bulk-density value

The three land facets are fairly homogenous with respect to gravel content, with coefficient of variation ranging between 21 % and 32 %. In all the facets, the gravel content is consistently greater and more uniform at the topsoil than at the subsoil.

Like the gravel content, the sand content is greater and more uniform at the top than at the subsoil over the three facets. In the upper facet, the coefficient of variation is 25 % at the topsoil and 31 % at the subsoil. At the middle facet, the values are 30 % and 41 % and the lower facet they are 34 % and 64 %. When split into coarse sand (2000 - 200 microns) and fine sand (50-200 microns) subfractions, fine sand predominate in all the facets and with consistently greater coefficient of variation, except in the topsoil of the upper facet.

Unlike the sand fraction, the silt and clay contents are lower but more variable in the top- than in the subsoil. Like the sand however, the two fractions show an increase of variability downslope, except silt at the topsoil of the upper land facet. On the whole, the land facets exhibit comparatively lower variability in silt content (29 - 48 %) than clay content (39 - 56 %).

One possible explanation for the variability of the different particle size fractions is random spatial variations in the composition of the parent rock which on weathering would cause variations in several of the soil properties, including the soil texture. Another possibility is the presence of large stones and/or tussocky vegetation which often result in re-organization of surface runoff into anastomosing rills with a consequent re-organization of the slope materials (SMITH *et al.*, 1978; LEOW *et al.* *1981).* Variation in slope angle might also induce considerable variability. The slope angle of the sites from which soil samples were collected ranged between zero and two degrees. Such slight variations may have a significant effect on the movement and

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[1] Coefficient of variation is defined as s/x. 100 %, where s is standard deviation of sample and x is sample mean.

Soil properties		5-15 cm soil depth Upper facet	Middle facet	Lower diff.	Sig.	20-30 cm soil depth Upper facet	Middle facet	Lower diff.	Sig.
Gravel	x	53.5	21.4	10.0	S	33.8	16.5	9.4	S
	o	12.3	4.7	1.5		8.7	3.6	1.9	
	cv	23	22	15		26	22	21	
Sand	x	70.3	63.5	60.1	S	60.8	55.1	54.2	NS
	o	17.5	19.1	20.4		18.8	12.7	24.9	
	cv	25	30	34		31	23	46	
Coarse sand	x	25.7	21.8	19.2	S	20.2	18.3	17.0	NS
		8.3	6.1	5.8		5.9	6.6	8.0	
	cv	32	28	30		29	36	47	
Fine sand	x	44.6	41.4	40.9	S	40.6	36.9	37.2	NS
	o	13.4	12.8	16.8		17.0	17.3	18.9	
	cv	30	31	41		42	47	51	
Silt	x	17.3	17.9	19.6	NS	18.1	20.8	21.2	NS
	o	7.9	7.2	9.4		5.2	6.2	7.0	
	cv	45	40	48		29	30	33	
Clay	x	12.4	15.5	20.3	S	21.0	23.9	24.6	NS
	o	4.8	7.3	17.4		8.6	10.3	17.3	
	cv	39	47	56		41	43	46	
Bulk density	x	1.40	1.37	1.35	NS	1.43	1.40	1.41	NS
	o	0.22	0.25	0.23		0.29	0.21	0.35	
	cv	16	18	17		20	15	25	
Organic matter %	x	1.83	2.40	2.93	S	1.04	1.10	1.41	NS
	o	1.06	1.10	1.14		0.42	0.36	0.39	
	cv	58	46	39		40	33	28	
Nitrogen %	x	0.30	0.48	0.63	S	0.19	0.15	0.20	NS
	o	0.14	0.20	0.23		0.07	0.05	0.05	
	cv	45	41	37		39	32	27	
pH	x	6.84	6.08	5.57	S	6.85	6.33	6.42	NS
	o	0.82	1.15	0.56		0.82	0.70	1.09	
	cv	12	19	10		12	11	17	
CEC me/100g	x	6.34	10.06	18.33	S	5.25	9.44	15.28	S
	o	3.80	8.34	10.6		2.89	6.14	9.47	
	cv	60	83	58		55	65	62	
Exch.K me/100g	x	0.35	0.74	0.73	NS	0.45	0.53	0.41	NS
	o	0.23	0.52	0.55		0.11	0.33	0.36	
	cv	67	70	75		25	63	89	
Exch.Na me/100g	x	0.45	0.87	1.26	S	0.55	0.74	1.07	S
	o	0.34	0.67	1.01		0.55	0.28	0.80	
	cv	75	77	80		100	38	75	
Exch.Ca me/100g	x	5.45	7.55	12.02	S	5.27	10.06	10.32	NS
	o	3.05	4.61	8.05		5.06	6.54	7.22	
	cv	56	61	67		96	65	70	
Exch.Mg me.100g	x	1.03	3.70	4.66	S	1.65	2.05	4.29	S
	o	0.93	2.52	2.61		1.24	1.50	2.57	
	cv	90	68	56		75	73	60	
% BS	x	76.5	71.0	57.6	S	84.6	83.0	75.0	NS
	o	19.1	16.3	9.8		15.2	17.4	18.0	
	cv	25	23	17		18	21	24	

S or NS = differences between facets significant or non-significant at the 0.05 probability level

Table I : Variation in measured soil properties with slope facet.

deposition of materials, silt and clay in particular, downslope. There is also the possibility of a limited aeolian addition of coarse silt and very fine sand to the soils. All three sampling areas lie within the area mapped by LAWES (1962) as a loess plain soil unit. This soil is an easily recognized fine sand drift of up to 4 m thickness with a disjunction distribution. Whilst efforts were made to avoid the drift itself, the possibility remains that some of it may have once overlain or been reworked into soil that were sampled.

Except at the middle facet, the soil bulk-density value is more uniform at the top than at the subsoil. Reflecting presumably the higher organic matter content, the value of the property itself is lower at the top than at the subsoil.

4.1.2. Organic matter and nitrogen contents

In all the facets, the organic matter and nitrogen contents are higher and more variable in the top than in the subsoil. This is to be expected since the topsoil interact more with the biospheric component of the ecosystem and respond more to its variation. Except at the subsoil of the lower facet however, the coefficient of variation are over 30 %.

4.1.3. Chemical properties

The soil pH is remarkably uniform troughout each facet. In the upper facet, the coefficient of variation is 12 % in both the surface and subsoil. In the middle facet, the values are 19 % and 11 % and at the lower facet they are 10 % and 17 %. The result is in general agreement with that of AREOLA (1982) in the Gwagwa plain further south of the present study area and can be attributed to the homogenous parent rock. The feature may also mean that over all the facets, leaching is or has been universally effective.

Reflecting, presumably, the considerable variability of the soil organic matter and clay contents, all the facets show a high degree of variation in CEC. At the uper facet, the CV are 60 % at the topsoil and 55 % at the subsoil. The corresponding values at the middle facet are 83 % and 65 % and at the lower facet, 58 % and 62 %.

The exchangeable bases are the most variable of the soil properties considered, the CV is of the order of 55-80 %, in a few cases over 100 %. The only exception is K at the subsoil of the upper facet and Na at the middle facet where the CV is below 40

%. In this regard, the findings of the present study are similar to those obtained by WEBSTER and BECKETT (1964), AREOLA (1982) and AWETO (1982) who also observed that exchangeable bases tend to be more variable than other soil properties.

Similar to the pH, the % BS of the soils are remarkably uniform with CV ranging between 17 % and 25 %.

4.2. Difference between facets

The general pattern of clay, silt, organic matter, nitrogen, exchangeable cations and CEC is a downslope increase whilst that of the gravel and sand contents, bulk-density value, pH and % BS is a decrease. Nevertheless, it is only at the topsoil that the differences in each of the soil properties between the land facets is significant at the 0.05 probability level, except silt, bulk density and exchangeable K. At the subsoil on the other hand, only the gravel content, CEC, exchangeable Na and Mg show statistical significant different values between the facets. The distinctive pattern of the properties with slope position, particulary at the topsoil, may be attributed to grater vegetation cover, selective transport of finer materials and/or an increasing weathering downslope. The transport of material downslope for example, would not only enrich the downslope area of such materials but also deplete those soils near the crest. Similarly, over the study area, more water is available downslope due to an accumulation of water runoff derived from the surrounding higher lying areas and/or the influence of higher water table (KOWAL OMOLOKUN, 1971). This might be expected to have some effects on both the rate and thoroughness of weathering and clay formation.

It should however be pointed out that in absolute term, soils over all the facets are acidic and low in exchangeable cations. This is understandable when one considers that the degree of acidity or basicity of a soil is often determined by the relative proportion of the ferromagnesian minerals and quartz minerals of the parent rock (GERASIMOV *et al.*, 1965). As much as 40 % of the parent rock in this study is made up of quartz, 27.5 % of microcline, 24.5 % of plagioclase feldspar and the remaining 4 % consisting mainly of biotite (WRIGHT & McCURRY, 1970). This feature might also be in part a reflection of an intensive leaching that has taken place particulary during the more pluvial periods in the Pleistocene, over the area (DE SWARDT, 1946) and/or the adsorption of acidic cations in non-exchangeable forms (BRADY, 1974).

CONCLUSION

Variation in selected soil properties both within and between land facets under a savanna climate in northern Nigeria have been examined in this paper. The statistical significant differences found is the soil properties between the land facets at the surface layers, in spite of the smooth low relative relief of the study area, confirms the traditional practice of using land facet as a soil mapping unit. As suggested by the dispersion characteristics of most of the properties however, the analytical precision with which the result of soil properties for a single "typical profile" within a facet are quoted is meaningless for the study area, as the range of variation within a facet can be substantial. Where it is desirable therefore to have a reliable estimate of the range of soil properties within a facet, a substantial programme of sampling and analysis is necessary. From the knowledge of the dispersion characteristics of the soil properties gained therefore, it is possible to estimate the sample size need to achieve a given level of precision at a particular confident level (COLLINS & FENTON, 1984).

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