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VARIABILITY OF SURFACE AND SUBSURFACE PROPERTIES OF AN ULTISOL AS FUNCTION OF TOPOGRAPHY IN SANDSTONE LANDSCAPE OF SOUTH WESTERN NIGERIA.

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ABSTRACT

Productivity of soils is influenced by soil properties; it is, therefore, of interest to characterize their distribution for the purpose of intensified soil management practices in variable landscape. Soil properties (soil colour, texture, bulk density, volumetric moisture content and ECEC) were studied in 5 intensively sampled transects in a gently rolling sandstone landscape near Abeokuta, Ogun State, Nigeria. Using a landform description model, the study site was delineated into upper, middle and lower Landform Element Complexes (LEC). The programme used a digital elevation model created from relative elevation data collected on a 10-metre grid. Landform element complexes (LEC) were ranked lower >mid>upper with respect to convergent character. Across the LECs silt content (CV:93%) and colour hue (CV: 94%) were the most variable properties at the Ap horizon. At the B-horizon, clay content (CV; 83%), bulk density (CV: 82%) and silt (79%) were the most variable properties. Within individual LEC, colour hue (CV: 38%) and colour value (CV: 28%) were the most variable properties at the Ap horizon within the upper and middle LECs, while clay (CV 23%) and bulk density (CV 22%) were the most variable properties within the lower LEC. Total variance of these properties was highly significant across LECs but not significant within individual LEC. Colour, silt and clay were related to indices of convergence. In general, soil texture (e.g. clay and silt) and color are better correlated to the terrain attributes. There was substantial variability of soil properties measured in response to gradients and pedogeomorphological processes over the landscape

KEYWORDS: Variability, Ultisol, Sandstone, Topography, Land Element Complexes.

INTRODUCTION

The soil is a product of the interactions among topography, climate, vegetation (living organisms) and parent materials over time. The relative impact of these factors on soil characteristics varies from one environment to another. Soil characteristics and soil-slope interactions occur in rolling sandstone landscape of southwestern Nigerian as a result of the effect of topography on pedogenesis. At the landscape scale, soils develop that are taxonomically and functionally distinct mainly due to varying intensity of accumulation and net downward influx of water, controlled by convergent and divergent landscape characters. As a result of this, soil properties may be predictable as a function of topography, through mathematical models (Troeh, 1964) or characterized within discrete, three dimensional hill-slope elements or complexes (Pennock et al. 1987, 1994).

Studies in the West African sub-region, especially in the *southern rainforest* of Nigeria (Smyth and Montgometry, 1962; Moorman 1981, Okusami et al., 1986, Ogunkunle 1986) have confirmed the interrelationship between profile characteristics and topography. This approach to understanding soil variation by the existence of different taxonomic pedons along a toposequence can only be useful for broad land us planning.

The distribution of soil physical and chemical properties along the toposequence is of interest because of their direct and indirect influences on productivity, which have implications for site-specific fertility management.

Soil fertility includes plant available sources of inorganic, residual nutrients (CEC) in the profile, and organic nutrients, which are potentially mineralizable in the growing season. Explanation of systematic differences in cation exchange capacity and pH as a function of landscape requires integration of soil properties, previous management and cropping effects (Fiez et al. 1994).

In a pedogenic context, moisture, colour, textural characteristics and cation exchange capacity are relatively dynamic in the sense that they are not stable spatially or temporally. However, their distribution is influenced by systematic variation of relatively more static and predictable soil-landscape attributes. Soil genetic data provide a history of hydrologic conditions, and therefore historical productive potential, which maybe useful to predict the utility of added fertilizer at any given location

Due to the systematic, quantitatively, predictable influences of the landscape on pedogenic development, broadly applicable landform segmentation procedure provides a useful means of capturing pedogenic variability in the soil-landscape relationship. Landform segmentation has been developed by Pennock et al (1987) and MacMillan and Pettapiece (1997) who used topographic derivatives from digital elevation data for the description of terrain orientation, shape and scale. Discrete land elevation complexes (LECs) of similar convergent or divergent character are delineated, with consideration given to the landscape context in which they occur

These LECs have not previously been evaluated for their utility in capturing variability of soil properties in soil-landscape in Nigeria. The purpose of this study was to assess the influences of surface geometry on spatial distribution of soil properties using landform discretion model

MATERIAL AND METHOD

Site Characteristics

The study site, representative of a broad region of *moderately medium texture sandstone landscapes*, was located near Abeokuta, south west of Nigeria. The surface form of the landscape was rolling with slope gradient not exceeding 5°. Prior to 1990, the site was in a bush rotation with small, farmland dotting the landscape under minimum tillage methods. Subsequently, the site was bulldozed and was cropped continuously under the conventional tillage

1:10,000 soil survey was conducted on the entire site by the staff of soil survey unit of the Institute of Agricultural Research and Training, Ibadan, resulting in the differentiation of soils into series of the Benin fasc. Typical subgroups were identified and related to defined soil series (Ojo-Atere, 1996). The soils in the site were classified as *Ultisols*. Soils in the upper and mid portions of the landscape were predominantly well drained

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Rhodic Kanhapludult, described by the Alagba series. There were also occurrences of slightly eroded Orthic soils Imperfectly drained soils in the lower slope position were of a typical higher moisture regime. Characterized by more strongly leached and eluviated horizons, these profiles were classified as Aquic Kanhapludult (Owode series).

Mean annual rainfall at the site is 1235mm, with rainy season occurring between April and November, while the mean annual temperature is 28°C.

Sampling Design

The site consisted of 5 parallel adjacent transects 1240m in length that were separated by 10m (Figure 1) These transects crossed a variable landscape with 62 sampling points in each transect. The site encompassed classic crest, midslope and valley toposequence components.

Sampling Activities

Topographic characterization was performed on the site and surrounding area on a 10 – m grid The X and Y coordinates were chained in and marked so that elevation (Z coordinate) could be determined A rod and level were utilized within the site boundaries and at each of the 310 sampling points. The information was then used to create a digital elevation model.

Minipits were dug at each of the 310 points, to the minimum depth of 75cm Each minipit was characterized according to criteria outlined by the Expert Committee on Soil Survey (1983). Samples were taken at 0-20cm and 20 – 40cm depth at each sampling point.

Colour (hue, value and chroma) was determined at sampling using the Munsell soil colour chart The samples were air-dried, ground, and sieved to separate fine fraction

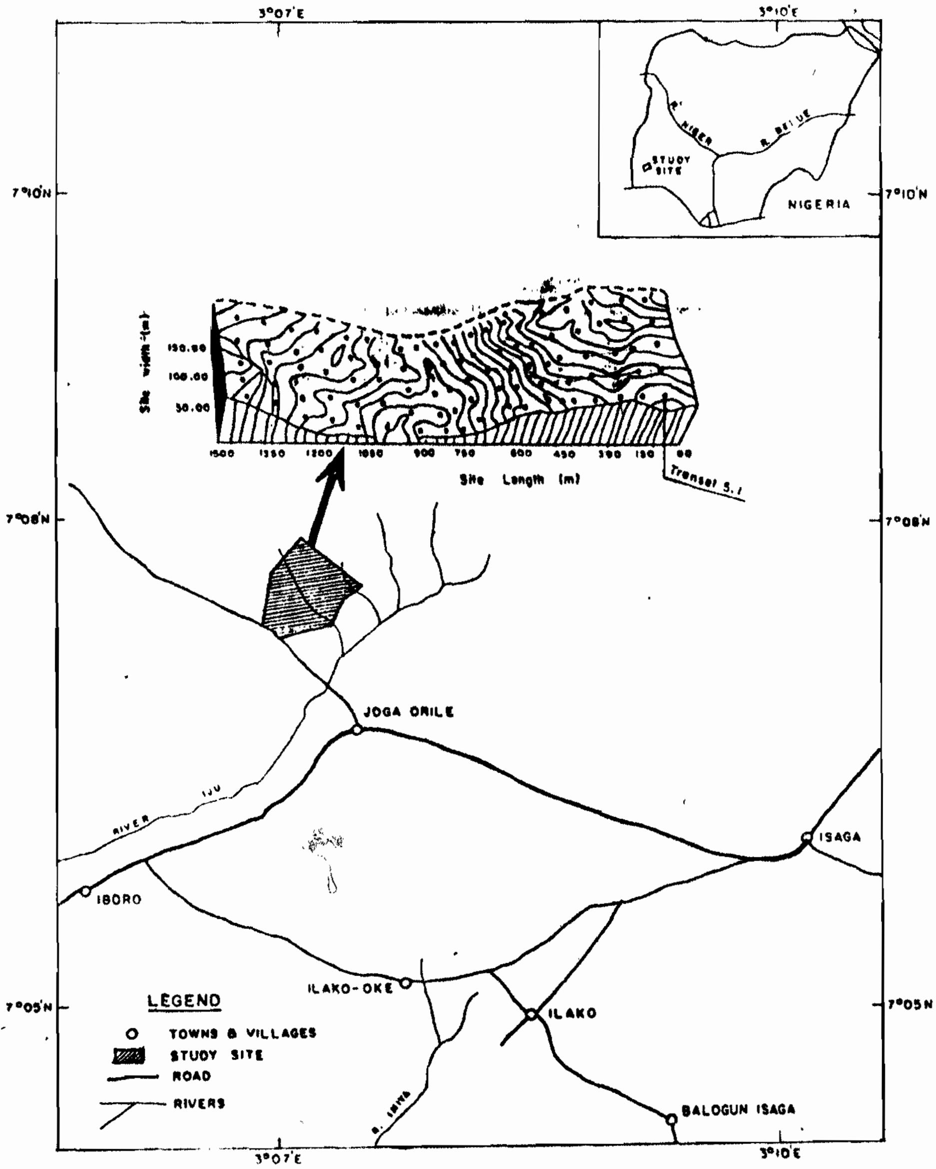

Fig. 1: Study site location, surface morphology and sampling points.
SCALE:- 1:50000

(<2mm) from coarse fragments. Particle size was determined by the hydrometer method (Day, 1965) the sand fraction was further separated into coarse sand (200-2000μm) and fine sand (20 - 200μm). Soil pH was determined volumetrically (Topp, 1993). Bulk density was determined using cylindrical soil cores at about 50 mm in height and 50mm in diameter (Blake, 1965). Exchangeable cations were extracted by 1N NH_4 OAc, Na and K were determined by flame photometry with a detection limit of 10ppm (ASSW 26: 178; APHA 3500-K D; Ashworth and Mrazek (1995), while Ca and Mg were determined by Atomic Absorption Spectrophotometry with detection limit of IDPM. Effective CEC was calculated as the summation of the exchangeable bases and exchangeable acidity (Chapman, 1965).

Organic matter content was not determined because its variation at the topsoil will be confounded with the various past farming activities along the landscape (Ogunkunle, 1993) For this reason, variation in ECEC was examined and taken as reflecting variation in native soil fertility.

Landform Segmentation

The Landform Description programme from Landmapper Environmental Solution (MacMillan and Pettapiece, 1997; MacMillan et al. 2000) was used to delineate four discrete landform elevation complexes (LEC) using the site elevation data, corresponding to upper, middle and lower LEC. These LECs were superimposed on the existing maps, and sampling points were assigned accordingly. There were 54, 216 and 40 sampling points in the upper, middle and lower LEC respectively. Topographic descriptors, including relative elevation (E), plan and profile curvature (Kh and Kv), slope gradients (G) and global and local catchments (Cg and Cl) were calculated for each of the sampling points using algorithms presented by Pennock et al (1987). Relative elevation is the elevation of a given point relative to the lowest point in the site. Gradient is the maximum change of elevation at each grid point in degrees. Plan curvature is the rate of change of aspect along the contour line in metre, where aspect is the azimuthal bearing of the gradient. Profile curvature is the rate of change of gradient in metre.

Statistical Analysis

For ease of computation, color hue was coded thus: R = 0, 2.5YR = 1, 5YR = 2, 7.5YR = 3, 10YR = 4, All the other sets of data were analysed statistically without coding. Coefficient of Variation (CV) was calculated for each property across LECs and within LECs as in equation 1

$$CV - \frac{100s}{X} \quad \text{--------------------------------}(1)$$

s: sample standard deviation

X: Sample mean

The variability was further classified after Wilding and Drees (1978) as follows:

CV < 15%: least variable

CV = 15 – 35%: moderately variable

CV > 35%: Highly variable

Spearman correlations were calculated between landform descriptors and soil properties.

Two-way ANOVA procedures were performed in SAS following the unbalanced random model (Model II) (Milliken and Johnson, 1984).

RESULTS AND DISCUSSION

Topographic Descriptors

The site was gently undulating with a maximum of 3.6cm of relief and slope gradient that did not exceed 6% (Table 1). With the exception of slope gradient (G), topographic descriptors indicated that convergent landscape character increased in the order upper <mid<lower. This result followed that of Manning et al (2001) in a Manitoba landscape, (Canada). Slope gradient (G) was inversely related to convergent character. In all, slope gradients were low, but

Table 1 Descriptive statistic of Topographic descriptors summarized across all sampling points and stratified landform element complex

	E(m)	G(o)	Kv (o/m)	Kh (o/m)	Cg (m2x100)	Cl (m2x100)
			Overall (n = 310)			
Mean	2.9	1.2	0.0	-0.2	12.3	10.2
Std. Dev.	1.3	0.3	0.1	6.8	32.5	29.8
Minimum	0.2	0.0	-0.3	-96.8	0.0	0.0
Maximum	4.3	2.3	0.3	23.6	298.0	214.0
Median	2.1	1.0	0.0	0.2	2.0	2.0
			Upper (n = 541)			
Mean	3.4	0.7	0.0	0.6	1.6	1.2
Std. Dev.	0.2	0.4	0.1	7.1	3.9	2.4
Minimum	2.1	0.1	0.1	32.4	0.0	0.0
Maximum	4.3	2.1	0.3	11.9	21.0	14.0
Median	3.2	1.4	0.1	3.2	0.0	0.0
			Middle (n = 216)			
Mean	1.9	0.6	0.0	0.4	4.2	3.7
Std. Dev.	0.6	0.4	0.0	3.2	14.2	11.2
Minimum	0.4	0.0	-0.1	-7.9	0.0	0.0
Maximum	3.6	2.3	0.1	21.6	86.0	87.6
Median	1.8	1.0	0.1	0.3	1.1	1.1
			Lower (n = 40)			
Mean	0.8	0.4	0.0	-2.3	-1.2	36.1
Std. Dev.	0.5	0.3	0.1	14.8	60.5	52.4
Minimum	0.1	0.0	0.2	-96.8	0.0	0.0
Maximum	2.2	0.9	0.1	11.5	98.0	214.0
Median	0.6	0.4	0.0	-1.2	0.9	3.9

E- Relative elevation, G = slope gradient; Kv = profile curvature, Kh = Plan Curvature, Cg = global catchments; Cl = local Catchments were greatest in the middle LEC. The upper and lower LECs were comprised of more level topography. Negative values for profile covertures (Kv) and plan curvature (Kh) indicated convergence of flow. With respect to Kh, the upper was most divergent (+3.2), the mid was slightly divergent, but more linear in character (+0.3), and the lower was most convergent (-1.2). The rank of convergent character with respect to both global catchment (Cg) and local chatchments (Cl) indices was lower>mid>upper. This result also agreed with the finding of Manning et al (2001). These results were not unexpected since these topographic descriptors were used in part to derive them.

Variability of Soil Properties

Textural Properties

Figure 2 shows the complexity of soil properties with the studied landscape. Thus, at 0-30cm (Ap horizon) total sand fraction (2µm - 2000µm) had medium variability across LECs. The CV ranged between 15% and 90%. A medium CV was reported by Ogunkunle (1993) for the Basement Complex toposequence in southwestern Nigeria. Separating the total sand into coarse (200 – 2000µm) and fine sand (20-200µm) fractions, presented varying results under LEC (Figure 2). The variability of coarse sand across LECs was moderate (CV:36%). In upper and middle LECs however, the variability of coarse sand was low (CV: 13%). At the lower LEC, coarse sand had medium variability (CV:17%). Fine sand on the other hand had low variability across the LECs, while upper and middle LECs had moderate variability. The variabilities of silt and clay were high (CV $\geq$ 70%) across the LECs. These results have shown that at the LECs large sized particles (coarse and fine sand) were less variable compared to smaller sized particles (silt and clay). The high variability of small sized particles at the Ap-horizon may be related to the selected removal of small sized particles from the soil by run-off. Since the distribution of concentrated flow during a rainfall event is highly variable (Luk and Morgan 1981), the removal of these small sized particles will not be uniform across the LECs. Furthermore, large fractions were less variable across LECs within upper and middle LECs compared to lower LEC. This maybe due to divergent of flow at these LECs compared to convergent of flow at the lower LEC.

At the B-horizon (40-60cm) the results showed more variability in textural fractions than the Ap horizon (0-30) cm. The variability was higher at the upper and middle LECs, probably because of eluviations of clay particles to the B-horizon.

Volumetric Moisture Content

Variability of moisture content is very important due to its effects on crop growth and yield. Moisture content at the Ap horizon (0-30cm) was highly variable (CV > 35%) across the LECs. However, the variability was moderate (CV < 35%) within individual LEC. The high variability recorded across the LECs may be attribute to convergent flow within individual LEC and divergent flow across the LECs. Distribution of soil moisture in the landscape may be largely due to variation of surface curvature (Sinai et al., 1981). As a result, soil moisture is generally greater at topographic position with more strongly convergent character (Hanna et al., 1982). Such landscape differences in moisture content may be accentuated or attenuated with differential distribution of textural characteristics, evapotranspiration demand and the amount, type and timming of precipitation (Manning et al, 2001). The variability of soil moisture content at the B-horizon was not different from the Ap horizon.

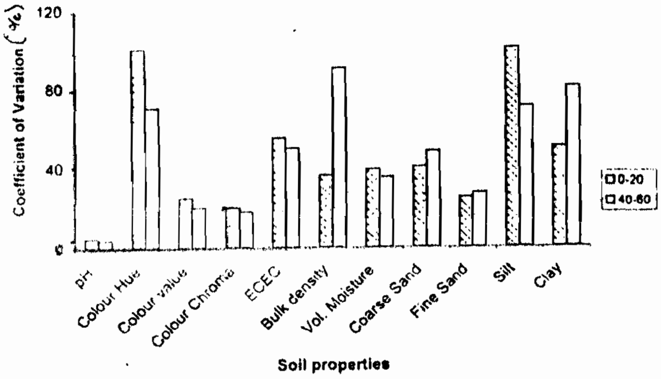

Figure 2a: Coefficient of Variation (C.V.) of soil properties across landform element complexes (Overall)

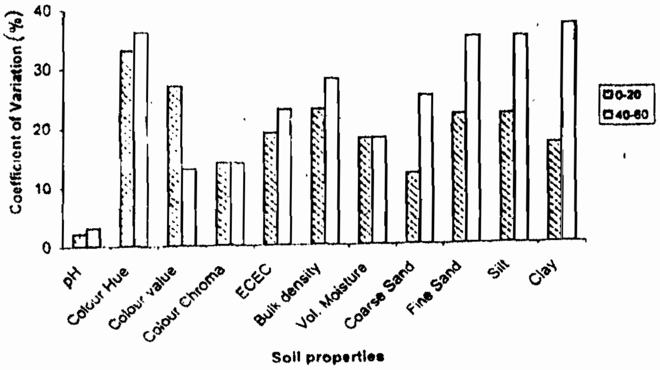

Figure 2b: Coefficient of Variation (C.V.) of soil properties within upper landform element complexes (Overall)

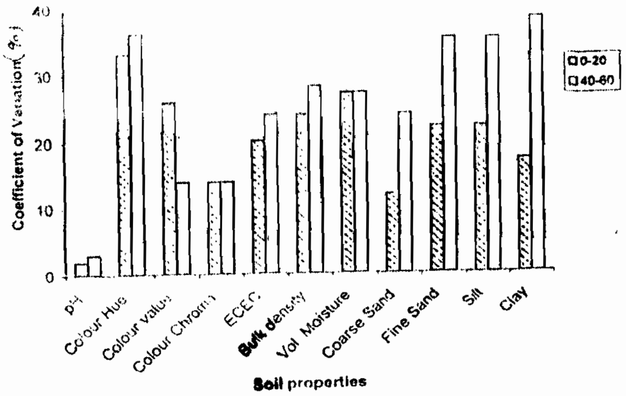

Figure 2c. Coefficient of Variation (C.V.) of soil properties within middle landform element complexes

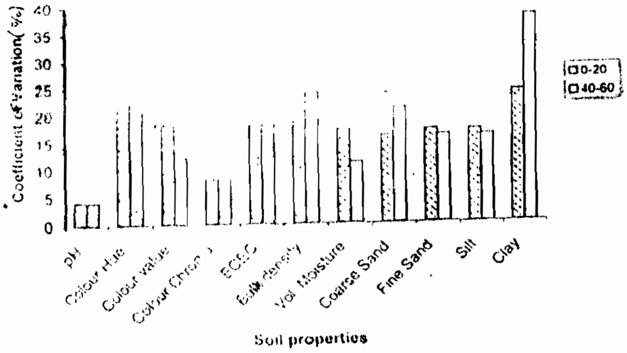

Figure 2d: Coefficient of Variation (C.V.) of soil properties within lower landform element complexes

Bulk Density

The variability of bulk density at the Ap horizon was moderate across LECs and high within individual LEC, with CV ranging between 23% and 28%. At the B-horizon, the variability was high (CV 94%) across LECs but moderate (CV 35%) within individual LEC (Figure 1). The high to moderate variability recorded may be due to compaction of the soil as a result of land clearing, which was done using heavy equipment as well as tillage effects. This indicated that this property might pose problems in terms of variability in the toposequence.

Nutrient Retention

Percentage effective cation exchange capacity (ECEC), showed high CV across LECs at the Ap horizon as well as in B-horizon. The high CV may be due to variation of clay content. Measures of clay content increased with convergent character in the landscape. Relative rank of the LEC was upper < mid < lower (Fig. 1). The high variability of ECEC across LECs may be due to accumulation of fine materials eroded from the upper LEC to the lower LEC. This accumulation in the surface soil and their vertical illuviation may be responsible for high CV of ECEC both at the Ap and B-horizons. The Observed differences among LECs may as well have implication for productivity. It is reasonable that the lower LEC where most materials are deposited and accumulated would be the most productive for Crop deficient in moisture (Stoop, 1985).

Surface soil pH CV ranged between 3% and 4% across LECs, a range that was not limiting to crop production. The subsurface pH also exhibited low variability across LECs and within individual LEC. This confirms earlier work by Ogunkunle and Ataga (1985) in which a CV of 3-5% was observed for pH in some Nigerian sandstone soils.

Soil Colour

Colour hue at the Ap horizon was highly variable (CV 70%) across LECs. This result was in contrast to what obtained at the quartzite landscape of southwestern Nigeria (Ogunkunle 1993) that showed that colour hue was moderately variable. Nevertheless, colour hue was moderately variable within individual LEC. At the B-horizon, however, color hue was highly variable at the upper and middle LECs, while variability was moderate at the lower LEC.

Colour value and chroma were moderately variable across LECs and lower LEC but highly variable at the upper and middle LECs. Colour value was more variable at the Ap horizon than B horizon within individual LEC. This might be due to mixing that took place at the Ap horizon during tillage. Also, hydrologic processes may be largely responsible for the observed variability in colour; although other formative controllers may mask them. Hydrologic influences themselves are predictable by surface morphology. However, the occurrence of mottles at the B-horizon of the lower LEC was as a result of convergence flow as well as ground water table fluctuations.

Table 2 showed that at the Ap horizon, colour hue, ECEC, bulk density, silt and clay contents were significantly (P ≤ 0.05) different across LECs. Within individual LEC, however, none of the properties was significantly different. Furthermore, at the B-horizon, colour hue; ECEC, bulk density and clay contents were highly significant (P < 0.01) across LECs. Within LECs, colour hue, ECEC and clay contents remained significantly different (P < 0.05) at the middle LEC but not significant at the upper and lower LECs. This result showed that the LECs as delineated in this landscape could be a practical management domain since variation of the properties within individual LEC was not significant.

Table 2: Analysis of variance of soil properties across landform element complexes

Soil Properties	Landform element complexes							
	Overall		Upper		Middle		Lower	
	0-20	40-60	0-20	40-60	0-20	40-60	0-20	40-60
PH	NS	NS	NS	NS	NS	NS	NS	NS
Colour hue	*	**	NS	NS	NS	*	NS	NS
Colour value	NS	NS	NS	NS	NS	NS	NS	NS
Colour chroma	NS	NS	NS	NS	NS	NS	NS	NS
ECEC	*	**	NS	NS	NS	*	NS	NS
Bulk density	*	**	NS	NS	NS	NS	NS	NS
Volumetric moisture	NS	NS	NS	NS	NS	NS	NS	NS
Coarse sand	NS	NS	NS	NS	NS	NS	NS	NS
Fine sand	NS	NS	NS	NS	NS	NS	NS	NS
Silt	*	*	NS	NS	NS	NS	NS	NS
Clay	*	**	NS	NS	NS	*	NS	NS

** = Significant at 0.05*

*** = Significant at 0.01*

NS = Not Significant

Soil properties in Relation to Landform Element Complexes

The data in Table 3a revealed the complexity of soil properties as described by landform descriptors across and within LECs. At the Ap horizon, clay content was inversely correlated with elevation (E), slope gradient (G), profile curvature (Kv), and plan curvature (Kh) across LECs, while silt content was only correlated with plan curvature and global catchments (Cg). Coarse sand, and fine sand particles were not significantly correlated with all the topographic descriptors. Within individual LEC, clay content was inversely correlated with slope gradient, profile curvature, plan curvature and global catchments at the upper LEC; while silt content was positively correlated with slope gradient, plan curvature and global catchments. None of the textural particles was significantly correlated with landform descriptors at the middle and lower LECs However, clay content was inversely correlated with slope gradient and local catchments (Cl).

Colour hue and value were inversely correlated with elevation, slope gradients, profile curvature and plan curvature but positively correlated with global and local catchments across the LECs. Colour chroma was inversely correlated with slope gradients and global catchments Colour hue, value and chroma were not significantly correlated with all descriptors at the upper LEC while colour hue and chroma were correlated with the descriptors at the middle LEC The correlations with the descriptors were inconsistent at the lower LEC

At the B-horizon (Table 3b), silt and clay contents were inversely correlated with all descriptors (except *Cg and Cl*) across LECs, while silt content consistently correlated with the descriptors at middle LEC, but inconsistently correlated with the descriptors at the upper and lower LECs Colour hue, value and chroma were consistently correlated with the descriptors across LECs but inconsistently correlated with Kv, Kh and Cg descriptors at the middle and lower LECs The correlation with the descriptors at the upper LEC was not significant. Volumetric moisture content was not significant with the descriptors both at the Ap and B-horizons However, ECEC, pH, and bulk density were inconsistently correlated with E, G and Kv descriptors across LECs.

Correlation with individual landform descriptors supported the premise that pedogenic development was proportional to the extent of convergent landscape character (Manning *et al* 200

Table 3a: Spearman correlations among topographic descriptors and soil attributes stratified by landform element complexes (P < 0 05)

	E	G	Kv	Kh	<u>Cg</u>	Cl
			Overall (n = 310) 0-20cm			
Coarse sand	NS	NS	NS	NS	NS	NS
Fine sand	NS	NS	NS	NS	NS	NS
Silt	NS	NS	NS	-0 27	0 29	NS
Clay	-0.36	0 59	-0.51	-0 34	NS	NS
BD	0.38	0 38	NS	0 57	-0 38	-0 63
Vm	NS	NS	NS	NS	NS	NS
PH	0 31	NS	0 29	0 71	-0 74	-0 72
ECEC	NS	NS	0 27	NS	NS	NS
Colour hue	-0.54	-0 43	-0 45	-0 80	0 77	0 69
Colour value	-0.57	-0 50	-0 51	-0 68	0.54	0 53
Colour chroma	0 29	-0 43	0 40	0 37	-0 53	NS
			Upper (n = 54)			
Coarse sand	NS	NS	NS	NS	NS	NS
Fine sand	NS	NS	NS	-0 47	NS	NS
Silt	NS	-0 64	NS	0 58	.0 59	NS
Clay	NS	-0 68	-0 49	-0 60	-0 60	NS
BD	NS	-0 48	NS	NS	NS	NS
Vm	NS	NS	NS	NS	NS	NS
pH	NS	NS	NS	0 52	NS	0 53
ECEC	NS	NS	NS	NS	NS	NS
Colour hue	NS	NS	NS	NS	NS	NS
Colour value	NS	NS	NS	NS	NS	NS
Colour chroma	NS	NS	NS	NS	NS	NS
			Middle (n = 216)			
Coarse sand	NS	NS	NS	NS	NS	NS
Fine sand	NS	NS	NS	NS	NS	NS
Silt	NS	NS	NS	NS	NS	NS
Clay	NS	NS	NS	NS	NS	NS
BD	-0 37	NS	-0 45	-0 48	0 45	NS
Vm	NS	NS	NS	NS	NS	NS
pH	NS	NS	NS	NS	NS	NS
ECEC	NS	NS	NS	NS	NS	NS
Colour hue	-0.55	NS	-0 47	-0 60	0 66	-0 38
Colour value	NS	NS	NS	NS	NS	NS
Colour chroma	0 45	0 69	0 49	0 54	-0 55	0 67
			Lower (n = 40)			
Coarse sand	NS	NS	NS	NS	NS	NS
Fine sand	NS	NS	NS	NS	NS	NS
Silt	NS	NS	NS	NS	NS	NS
Clay	NS	-0 73	NS	NS	NS	-0 63
BD	0 67	NS	-0 66	NS	NS	NS
Vm	NS	NS	NS	NS	NS	NS
pH	NS	NS	NS	NS	NS	NS
ECEC	NS	-0 71	NS	NS	NS	NS
Colour hue	NS	-0 81	NS	NS	NS	NS
Colour value	NS	NS	0 66	NS	NS	NS
Colour chroma	NS	NS	NS	NS	.NS	NS

Table 3b **Spearman correlations among topographic descriptors and soil attributes stratified by landform element complexes (P < 0.05)**

	E	G	Kv	Kh	Cg	Cl
			Overall (n = 310) 20 40cm			
Coarse sand	0 27	0 34	NS	NS	NS	NS
Fine sand	NS	NS	NS	NS	NS	NS
Silt	-0 42	-0 38	-0 34	-0 39	0 38	NS
Clay	-0 41	-0 58	-0 50	0 34	0 26	NS
BD	0 47	0 50	0 36	0 62	0 62	-0 54
Vm	NS	NS	NS	NS	NS	NS
pH	0 31	NS	0 29	0 79	0 68	0 77
ECEC	0 28	0 29	0 31	NS	NS	NS
Colour hue	-0 47	-0 38	-0 30	-0 75	0 59	0 68
Colour value	-0 62	-0 60	-0 58	-0 75	0 59	0 57
Colour chroma	-0 38	0 34	-0 26	-0 51	0 45	0 41
			Upper (n = 50)			
Coarse sand	NS	NS	NS	NS	NS	NS
Fine sand	NS	NS	NS	0 47	NS	NS
Silt	NS	0 45	0 45	0 49	-0 47	NS
Clay	NS	-0 59	-0 59	-0 49	-0 47	NS
BD	NS	NS	NS	NS	NS	NS
Vm	NS	NS	NS	NS	NS	NS
pH	-0 56	NS	NS	0 52	NS	0 53
ECEC	NS	NS	NS	NS	NS	NS
Colour hue	NS	NS	NS	NS	NS	NS
Colour value	NS	NS	NS	NS	NS	NS
Colour chroma	NS	NS	NS	NS	NS	NS
			Middle (n = 216)			
Coarse sand	NS	0 42	0 38	NS	NS	0 43
Fine sand	NS	NS	NS	NS	NS	NS
Silt	-0 60	-0 50	-0 60	-0 63	0 59	-0 60
Clay	NS	NS	NS	NS	NS	NS
BD	NS	NS	NS	-0 38	NS	NS
Vm	NS	NS	NS	NS	NS	NS
pH	NS	NS	NS	NS	NS	NS
ECEC	NS	NS	NS	NS	NS	NS
Colour hue	NS	NS	-0 47	-0 43	0 48	NS
Colour value	NS	NS	-0 38	-0 40	0 44	NS
Colour chroma	NS	NS	NS	NS	NS	NS
			Lower (n = 40)			
Coarse sand	NS	0 69	-0 61	NS	NS	NS
Fine sand	NS	NS	NS	NS	NS	NS
Silt	NS	-0 63	NS	NS	NS	NS
Clay	NS	-0 73	NS	NS	NS	NS
BD	0 63	NS	NS	NS	NS	NS
Vm	NS	NS	NS	NS	NS	NS
pH	NS	NS	NS	0 85	NS	-0 62
ECEC	NS	-0 71	NS	NS	NS	NS
Colour hue	NS	-0 81	NS	-0 65	0 64	0 75
Colour value	NS	NS	0 70	NS	NS	0 68
Colour chroma	NS	NS	NS	NS	NS	0 61

1). This is typical of regional recharge landscape where net downward migration of local water over time within convergent portions of the landscape facilitates soil development processes that favour soil colour development Across the LECs and within individual LEC, color and textural particles at both Ap and B-horizons were inversely related to the landform descriptors This implied that the soil properties at both depths were predictable from terrain information because pedogeomorphological processes are clearly controlled by horizonation and slope form The dominant contemporary slope process on the study landscape is through flow Active through flow processes result in spatial differentiation of soil properties that have a high correlation with terrain attributes. Some soil properties (e g colour and texture) show a remarkably varied spatial distribution according to their differential involvement in pedological processes

CONCLUSION

Variability of soil properties in this landscape was complex Differences in convergent and divergent character were apparent among LECs described using digital terrain model Nevertheless, these LECs were useful in accounting for gross variability in various pedogenic properties Across LECs, colour (hue, value and chroma) and texture (silt and clay contents) were related to indices of convergence Within middle and lower LECs, bulk density was inversely related to certain indices of convergence. Given the relatively uniform spatial distribution of vegetation and parent materials over the landscape, the analysis showed how individual soil properties responded differently to specific environmental gradients and pedogeomorphological processes over the landscape The division of the site to LEC provided a practical means of capturing gross variability in the soil attributes measured Overriding practical considerations include scale of measurement, the influence of pedogenic controls other than water fluxes controlled by land surface, and land management practices

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