

Variability in Soil Properties Along an Udalf Toposequence in the Humid Forest Zone of Nigeria

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ABSTRACT

Uniform soil management without any knowledge of the variability of soil properties could result in some parts of an agricultural field receiving insufficient inputs, while other parts receive an excess. Profile soil samples were collected and analyzed for some physico-chemical properties along an Udalf toposequence and their variability assessed. Soil pH was consistently least variable along the toposequence and at all depths. Highly variable properties on the upper slope (crest) included Ca, Mg, Na, K, and P; on the middle slope (hill slope) they were K, organic C, N, silt and clay; and on the foot slope (valley floor) they were Mg, organic C, available P, EA, silt and clay. Moderately variable properties were: C, electrical conductivity (EC), effective cation exchange capacity (ECEC), bulk density, clay, gravimetric moisture, volume wetness and degree of saturation on the upper slope; Mg, Na, EC, and ECEC, base saturation, sand, bulk density, gravimetric moisture and volume wetness on the middle slope; and on the foot slope Ca, N, EC, ECEC, base saturation, bulk density, gravimetric moisture, volume wetness and degree of saturation were moderately variable. The use of bulk samples randomly collected to determine soil properties should be minimized. Large soil sample sizes are needed for soil property studies along the toposequence, as most properties varied from highly to moderately variable. Uniform soil management along the toposequence should be avoided.

Keywords: spatial variability, Udalf, precision agriculture, soil chemical properties, soil physical properties

INTRODUCTION

Both horizontal and vertical properties of the soil have been extensively studied (Beckett and Webster, 1971; Wilding and Drees, 1983; Dahiya *et al.*, 1984; Wilding, 1985). According to Lark and Wheeler (2000), variation in soil properties has long been known and has been the subject of much research. It was in recognition of

this that Sir Ronald Fisher, then at Rothamsted, developed a formidable array of statistical methods. Ogunkunle (1993), working on the variability of some soil properties along quartzite schist and banded gneiss toposequences in southwestern Nigeria, noted there was relatively little work and literature on the variability of tropical soils, particularly for the forest zone of Nigeria, compared to the vast work and readily

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available literature on the variability of physical and chemical properties of temperate soils. A key feature of the soil is the variation in soil properties (Mulla and McBratney, 2001). Lark and Wheeler (2000) reported that farmers and scientists were asking whether the response of a crop to an input may vary significantly within fields. Since the answer is yes, the researchers' reported that under uniform application, some parts of the field may not be receiving sufficient inputs, such as fertilizer, to enable the crops or plants to meet their potential. Accordingly, horizons may differ in organic matter content, structure, texture, pH, base saturation, cation exchange capacity (CEC), bulk density and water holding capacity, as well as many other soil physical and chemical properties. According to Mulla and McBratney (2001), variability in soil properties at the series level is often caused by small changes in topography that affect the transport and storage of water across and within the soil profile.

Limited studies have investigated vertical soil variability compared to horizontal variability, as evident in the review of Dahiya *et al.* (1984). Cassel (1983), observed that different nutrients and water uptake are not always the same at different depths or in different soils. Hunter *et al.* (1982) and Yost *et al.* (1982) reported that soil-forming factors affect different properties differently at different depths. Variability of soil pH, for example, increases with depth (Ogunkunle and Ataga, 1985). Ogunkunle (1993), working on the Alfisols of southwestern Nigeria, observed that soil pH was the least variable (low variability) property, irrespective of depth. The variability of properties like organic matter, available phosphorus, total nitrogen and CEC, increases with depth. Properties, such as soil pH and porosity are among the least variable, while those pertaining to water or solute transport are among the most variable. Percentage sand ranges from low to moderate variability. Organic matter and % clay range from moderate to high variability. Available

phosphorus and potassium were observed to be highly variable (Jury, 1986; Jury *et al.*, 1987; Beven *et al.*, 1993; Wollenhaupt *et al.*, 1997). Therefore the aim of this study was to assess the degree of variability of some soil physical and chemical properties along an Udalf (Bulktrade, 1989) toposequence, because the more variable these properties, the more variable the crop growth and yield. Understanding soil variability is essential in applying location-specific (precision agriculture) management strategies.

MATERIALS AND METHODS

The study was conducted along an Udalf toposequence sustaining *Gmelina arborea* in Southern Nigeria (4° 53' N and 8° 02' E) with annual rainfall in the area ranging from 2,500 to 3,000 mm. The mean temperature is 28°C and relative humidity 70-80% (CRADP, 1992). The dominant vegetation is *Gmelina arborea*. The peripheral vegetation outside the plantation is humid rain forest. The geology of the area is a basement complex underlain by gneiss, which is associated with quartzite and cut by pegmatite. Major soil forming minerals found in the area are quartz, plagioclase and biotite (Ekwueme, 2003). Three profiles pits were dug along the toposequence at the upper slope (crest), middle slope (hillslope) and valley floor (flood plain). Core samples were collected in the center of each horizon for soil bulk density, particle size distribution and chemical analysis. Samples were air dried, ground and passed through a 2-mm sieve.

Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986), bulk density as described by Blake and Hartge (1986), while porosity was calculated as a function of the total volume not occupied by soil solids, assuming a particle density of 2.65 Mg m³ (Danielson and Sutherland, 1986). Bulk density and moisture content were determined by the core method (Burke *et al.*, 1986; Cresswell and

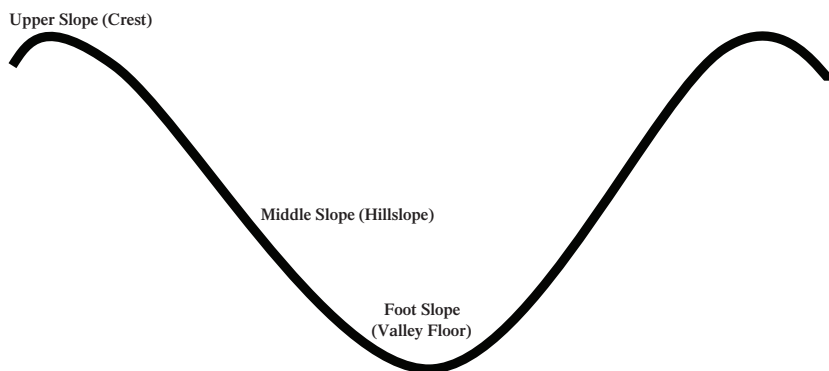


Figure 1 Sketch of the toposequence sampled from crest to valley floor.

Hamilton, 2002). Soil pH was determined using 1:2.5 soil water suspension (adequate to wet the electrode) using a pH meter (IITA, 1982). Organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1982). Total nitrogen was determined using the Micro-Kjeldal method (Bremner and Mulvaney, 1982), while available phosphorous was assayed by the Bray P-I method (Olsen and Sommers, 1982) since the soils were not calcareous. Exchangeable bases (Ca, Mg, Na, and K) were extracted with 1 N NH_4OAc buffered at pH 7.0 (Thomas, 1982). Exchangeable acidity (EA) was determined by titration with 0.05 N NaOH, while effective CEC was taken as the summation of exchangeable bases and total exchangeable acidity (IITA, 1982).

Soil variability was estimated using discrete sampling. This involved collecting soil samples at predetermined locations (crest, hillslope and valley floor) and depths (soil profile horizons) along the toposequence (Mulla and McBratney, 2001). Measures of spread about the mean used the range and coefficient of variation. The range is the difference between the maximum and minimum values. The coefficient of variation (CV) gives a normalized measure of spread about the mean and was estimated using Equation 1:

$$\text{CV} = \frac{S}{Z} \times 100\% \quad (1)$$

where;

S = standard deviation, which is the square root of the sample variance.

Z = is the number of measured values.

Properties with larger CV values are more variable than those with smaller CV values. Wilding (1985) described a classification scheme for identifying the extent of variability for soil properties based on their CV values, in which CV values of 0-15, 16-35 and > 36% indicate low (least), moderate and high variability, respectively.

RESULTS AND DISCUSSION

The data in Tables 1 and 2 reveal the complexity of soil property variability along the toposequence at all depths. The pH was consistently least variable along the toposequence at all depths (Ogunkunle, 1993; Mulla and McBratney, 2001). Variability of the sand fraction was least at the upper slope (CV = 7%) and the valley floor (foot slope) (CV = 14%), while it was moderately (medium) variable at the middle slope (CV = 25%). Silt fraction variability was low, very high and high with CV values of 11, 88 and 69%, respectively, for the upper, middle and foot slopes, respectively. Variability in clay fraction was medium, very high and high (CV = 17, 87 and 58%) for the upper, middle and foot slopes,

Table 2 Variability in soil chemical properties along the toposequence.

Soil chemical properties	Upper slope (crest)			Middle slope (hillslope)			Foot slope (valley floor)					
	Range	X	SD	CV (%)	Range	X	SD	CV (%)	Range	X	SD	CV (%)
Ca (C mol kg-1)	1.92 - 5.44	3.88	1.71	60	2.24 - 4.48	3.28	1.21	36	1.92 - 3.20	2.56	0.64	25
Mg(C mol kg-1)	1.00 - 2.24	1.36	0.59	4	1.10 - 2.24	1.66	0.55	33	0.09 - 1.80	1.50	0.52	35
Na (C mol kg-1)	0.01 - 0.09	0.06	0.04	64	0.09 - 0.14	0.12	0.02	14	0.10 - 0.13	0.12	0.02	13
K (C mol kg-1)	0.09 - 0.24	0.014	0.07	49	0.10 - 0.48	0.28	0.16	56	0.09 - 0.10	0.09	0.01	11
Organic carbon (%)	1.05 - 1.99	1.67	0.54	32	0.93 - 2.48	1.87	0.67	36	1.43 - 2.95	2.02	0.81	40
Total nitrogen (%)	0.08 - 0.09	0.09	0.01	7	0.04 - 0.12	0.09	0.03	39	0.08 - 0.14	0.10	0.03	3
Avail P (mg kg-1)	1.33 - 8.66	5.58	3.14	56	1.26 - 5.99	5.31	3.67	69	3.66 - 9.99	7.10	3.02	45
pH	5.93 - 6.11	6.0	0.08	1	5.99 - 6.16	6.04	0.10	2	6.02 - 6.23	6.15	0.12	2
EC (ds/m)	0.05 - 0.07	0.06	0.01	16	0.04 - 0.06	0.05	0.01	13	0.05 - 0.07	0.06	0.01	20
EA (C mol kg-1)	3.36 - 5.28	4.41	0.80	18	3.04 - 4.8	3.96	0.72	18	2.24 - 5.76	3.47	1.99	57
ECEC (C mol kg-1)	6.47 - 12.26	8.87	2.46	28	7.72 - 12.14	9.29	2.08	22	5.25 - 9.65	7.50	2.20	29
Base saturation (%)	41.26 - 64.43	48.50	11.14	23	48.18 - 68.20	56.31	0.79	17	41.31 - 68.42	55.69	13.63	25

X = mean, SD = standard deviation.

CV = Coefficient of variability, where 15% = least variable; 15-35% = moderately variable > 35% = highly variable.

respectively. Bulk density variability was medium throughout the toposequence (from crest to valley floor). Variability of gravimetric moisture content, volume wetness and degree of saturation was medium along the toposequence. These results reflect the integrated effect of geology, slope (length, gradient and sequence) and to lesser extent, management. Ogunkunle (1993) observed that in a landscape such as the one in the study, where the topography and geology were so closely related, it was most difficult to separate the effects from one another.

Ca, Mg, Na, K, and available P were highly variable on the upper slope (CV > 35%). Electrical conductivity (EC), exchangeable acidity (EA) effective cation exchange capacity (ECEC) and base saturation were moderately (medium) variable (CV between 15 and 35%) at the upper slope site. Total nitrogen and pH were least variable on the upper slope. For the middle slope, calcium, potassium, organic carbon, total nitrogen and available P were highly variable (CV > 35%), sodium and exchangeable acidity were moderately (medium) variable, while electrical conductivity was least (low) variable (CV < 15%). Calcium, total nitrogen, EC and ECEC were moderately (medium) variable, while Na, K and pH were least (low) variable. These results agreed with those reported by previous workers (Ogunkunle, 1993; Ogunkunle and Ataga, 1995).

Soil properties differ in their degree of variability with depth. Tables 3 and 4 show the groupings of the soil physical and chemical properties, as affected by depth. pH was consistently least variable and base saturation was consistently moderately variable. From Tables 3 and 4, sand, silt and N were least variable on the upper slope, whereas electrical conductivity was least variable. The sand fraction, Na, and K, were least variable on the foot slope. The clay content, bulk density, porosity gravimetric moisture content, volume wetness, degree of saturation, organic carbon, electrical conductivity and ECEC

were all moderately variable at the crest (upper slope). On the foot slope, the following were highly variable: sand, bulk density, porosity, gravimetric moisture content, volume wetness, degree of saturation, Mg, Na, ECEC, silt, clay, organic carbon, N, P, Ca, and K. On the foot slope, bulk density, porosity, gravimetric moisture content, volume wetness, degree of saturation, N, Ca, Mg, EC, and ECEC were moderately variable, while silt, clay, organic carbon, P and EA were highly variable on the foot slope. Similar results have been reported for temperate soils (Jury, 1986; Jury *et al.*, 1987; Beven *et al.*, 1993; Wollenhaupt *et al.*, 1997). Tables 5 and 6 show the proportion of the physical and chemical properties that were least, moderate or highly variable (Wilding and Drees, 1978).

CONCLUSION

Soil variability on the Udalf toposequence in the study area was complex. Variations in crop yield, for instance, have been often related to variations in soil moisture content. In view of the variability, there is a need to demarcate the toposequence into parcels of relatively homogenous units in order to achieve effective management. Fertilizer recommendations without prior soil testing should be avoided. Uniform soil management practices should be discouraged on the toposequence and instead, soil management should be location specific. Bulking of randomly sampled soil to obtain a composite sample should be minimized. A rigid grid sampling method should be used. Large soil sample sizes are needed for chemical properties studies along the toposequence, since most of the soil properties varied between high and moderate.

Table 3 Variability grouping of soil physical properties along the toposequence.

Group	CV (%)	Soil physical properties
Least variable	< 15	Upper slope (crest)
Moderately variable	15 - 35	Sand, silt
Highly variable	> 35	Clay, bulk density, porosity, moisture content, volume wetness, degree of saturation.
		None
		Middle slope (hillslope)
Least variable	< 15	None
Moderately variable	13 - 35	Sand, bulk density, porosity, moisture content, volume wetness, degree of saturation
Highly variable	> 35	Silt, clay,
		Foot slope (valley floor)
Least variable	< 15	Sand
Moderately variable	15 - 35	Bulk density, moisture content, volume wetness, degree of saturation
Highly variable	> 35	Silt, clay

Table 4 Variability grouping of soil chemical properties along toposequence.

	CV (%)	Soil chemical properties
Upper slope (crest)		
Least variable	<15	N, pH
Moderately variable	15-35	Org. C, EC, EA, ECEC, BS,
Highly variable	>35	Avail P, Ca, Mg, Na, K
Middle slope (hillslope)		
Least variable	<15	pH, EC,
Moderately variable	15-35	Mg, Na, ECEC, EA, BS
Highly variable	>35	Org. C, N, P, Ca, K
Foot slope (valley floor)		
Least variable	<15	Na, K, pH
Moderately variable	15-35	N, Ca, Mg, EC, ECEC, BS
Highly variable	>35	Org. C, P, EA.

Table 5 Proportion of soil chemical properties along the toposequence in variability groupings.

CV %	Upper slope (crest)	Middle slope (hillslope)	Foot slope (valley floor)
< 15 (Least variable)	2	2	3
15 - 35 (Moderately variable)	5	5	6
> 35 (Highly variable)	5	5	3

CV = coefficient of variability

Table 6 Proportion of soil physical properties along the toposequence in variability groupings.

CV %	Upper slope (crest)	Middle slope (hillslope)	Foot slope (valley floor)
< 15 (Least variable)	2	none	1
15-35 (Moderately variable)	6	6	5
> 35 (Highly variable)	none	2	2

CV = coefficient of variability.

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