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Variation of some soil physical properties within land use types along a toposequence on the basement complex of south western Nigeria

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Abstract

Spatial variability of three soil physical properties (Bulk density, Hydraulic conductivity and Gravimetric moisture content) along a toposequence on the Basement Complex of south western Nigeria under three land use types was investigated. Representative soil samples were taken at 0-15, 15-30, 30-60, 60-90, 90-120 cm depths at 20 m intervals from the crest down to the valley bottom of the toposequence. The three land use types occur at different locations on the toposequence. Bulk density was the least variable (C.V= 2.94 – 9.92%) of all the parameters investigated irrespective of the land use type, location and depth. The variability of the two other properties was moderate (C.V = 15 – 35 %) under all the land use types, although hydraulic conductivity showed few high CV values. Semivariogram for hydraulic conductivity showed a uniform range of spatial dependence (40 m) for all the depths. The nugget variance was small (less than 2), indicating that sampling interval was adequate to show variability. The variability study gives an indication for plot layout, farm planning and good management strategy for profitable agricultural venture.

Key words: Variability; Land use; Soil properties; Semivariogram.

Introduction

Soil properties change markedly across small distances within a few hectares of farmland or even within a mapping unit (Dahiya *et al.* 1984). At very large scale, variability is primarily the result of climatic and vegetation patterns and secondarily related to parent material differences. However, spatial heterogeneity of soil properties is a fact we have to deal with. It is caused by a number of factors and processes acting at different spatial and temporal scales. Thus, proper agricultural land management practices require adequate knowledge of soil properties spatial variability and understanding of the relationships between them (Buchter *et al.*, 1991; Diwu *et al.*, 1998). Certainly, no soil property can act completely independent, standing by itself. There exists an interrelationship between soil and other properties that we can describe statistically. Geostatistical methods are useful in quantifying spatial variability of soil properties (Warrick and Nielsen 1980; Dahiya *et al.*, 1984). Precision agriculture or site-specific management is based precisely on the analysis of spatial distribution and the interactions between the properties. Ogunkunle (1993) reported that for decisions on special purpose land use (like irrigation, choice of fertilizer, choice of which portion goes for which of two arable crops, e.t.c), mere knowledge of the soil classes may be inadequate. This may require more specific understanding of the point-to-point variations of some properties on the landscape. Xuewen *et al.*, 2001 investigated spatial variability of soil properties along the transect of Conservation Reserve Programme Land (CRP) and continuously cropped land in Kansas state, U.S.A. They found out that soil total carbon exhibited a periodic behaviour along the transect depending mainly on field topographic position and less on land use. Buchter *et al.* (1991) measured soil properties including soil-water-characteristics curve, particle size, saturated hydraulic conductivity

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and bulk density along two parallel 100 m transects separated by 60 cm and found that the parameters had a strong periodic behaviour with a main cycle of 50 m.

The objective of this study is to evaluate the spatial variability and patterns of some soil physical properties under three land use types along a toposequence on the basement complex parent material with the aid of geostatistics.

Materials and Methods

Field Description and Data Collection

The study was conducted on a major toposequence at the National Horticultural Research Institute (NIHORT), Idi-Ishin, Ibadan in Nigeria. The soils are derived from the meta-morphic banded gneiss of the basement complex as reported by Smyth and Montgomery (1962) and Jaiyeola (1974). The land uses on the toposequence are Arable land (cassava, maize, etc), forested fallow and citrus orchard. 156 soil samples were collected from minipits (75x75x75 cm) dug at 20 m interval from the crest to the valley bottom. The soils were collected from 0-15 cm, 15-30 cm, and 30-60 cm depths. Bulk density was determined using the core method (Blake, 1964). Gravimetric moisture content was determined by oven drying the soil at 105°c to a constant weight. The mass of dry soil was then subtracted from the mass of wet soil to get the mass of moisture (Veihmeyer and Hendrickson, 1949). Unsaturated conductivity was carried out using a constant head permeameter and Darcy's equation was used to calculate hydraulic conductivity (Anderson and Ingram, 1993).

Data Analysis

The mean $(\overline{X})$, standard deviation (SD) and coefficient of variation (CV), for each property was determined. The variability of each property was measured by the coefficient of variation (CV).

$$CV = \frac{SD}{X} x100$$

Group	CV (%)
Low	<15
Moderate	15-35
High	>35

(According to Wilding and Drees, 1983)

Geostatistical Analysis

Spatial variations are described with the aid of a semivariogram (Warrick and Nielsen 1980). In geostatistics, the concept of variance from classical statistics is extended to semivariance. Considering a transect with equally spaced samples and measurements of soil property Z, a set of values $Z(x_1)$, $Z(x_2)$ … $Z(x_n)$ at locations X_1, X_2, … Xn were obtained. The semi-variance Y(h) is estimated as.

$$Y(h) = \frac{1}{2N(h)} \sum_{i+1}^{N(h)} [z(x_i) - z(x_i + h)]$$

Where

N (h) = Number of pairs separated by lag distance h.

$Z(x_i)$ = Measured sample value at point i

$Z(x_i + h)$ = Measured sample value point i + h

A semivariogram which is the graphs the semivariance between spatially separate data points as a function of the distance was used to illustrate spatial relationship of soil properties (Warrick *et al.* 1986; Buchter *et al.*, 1991). Spherical models were used to describe the semivariogram. In these models, parameters Co, Co+C and Ao are the nugget variance, sill and range respectively. The spherical model is a modified quadratic function for which some distance Ao pairs of points will no longer be correlated and the semivariogram reaches an asymptote. Usually the semivariances increase with distance between sample locations rising to a more or less constant value (the sill, Co+C) at a given separation distance called the range of spatial dependence (Ao). Samples separated by distances closer than the range are spatially related and those separated by distances greater than the range are not spatially related. Ideally, semivariogram should pass through the origin when the distance of sample separation is zero. However, many soil properties have non-zero semivariance as h tends to zero. This non-zero semivariance is called nugget variance and it represents unexplained or random variance often caused by measurement error or microvariability of the property which cannot be detected at the scale of sampling (Journel and Huijberts, 1978).

The data was normalized by taking the natural logarithm transformations in order to meet the requirement for geostatistical analysis.

Results

Statistical parameters of soil property data

Descriptive statistics for the soil properties at 0-15 cm, 15-30 cm and 30-60 cm depths are shown in tables 1, 2 and 3.

Table 1: Descriptive statistics for soil properties (0-15 cm depth)

	Mean	SD	Skewness coefficient	Kurtosis	CV (%)	VG
Land use 1 (Arable land)						
Bd	1.56	0.11	0.05	-0.94	7.04	Low
G	32.99	4.44	0.71	-0.93	13.46	Low
K	5.03	1.44	-0.60	-1.18	28.66	Moderate
Land use 2 (Forested fallow)						
Bd	1.43	0.14	-1.54	2.73	9.92	Low
G	31.75	4.14	2.31	6.24	13.04	Low
K	4.09	1.24	0.09	-0.79	30.20	Moderate
Land use 3 (Citrus orchard)						
Bd	1.58	0.05	-1.44	0.00	2.94	Low
G	33.13	1.73	-0.96	-0.68	5.23	Low
K	3.83	1.38	0.44	0.54	36.17	High

Bd = Bulk density
K = Hydraulic conductivity
CV = Coefficient of variation

G = Gravimetric moisture content
SD = Standard deviation
VG = Variability group

Group	CV (%)
Low	<15
Moderate	15-35
High	>35

(According to Wilding and Drees 1983)

Table 2: Descriptive statistics for soil properties (15-30 cm depth)

Kurtosis	Mean		SD	Skewness coefficient	CV (%)	VG
Land use 1 (Arable land)						
Bd	1.56	0.13	0.41	0.58	8.34	Low
G	27.69	5.28	-0.06	-1.75	19.06	Moderate

K	3.55	2.49	1.04	0.21	70.04	High
Land use 2 (Forested fallow)						
Bd	1.53	0.13	0.99	1.22	8.18	Low
G	29.81	3.16	-0.30	0.91	10.61	Low
K	2.65	0.63	0.18	-1.60	23.95	Moderate
Land use 3 (Citrus orchard)						
Bd	1.53	0.10	-1.68	3.14	6.79	Low
G	31.70	4.88	1.95	4.36	15.38	Moderate
K	3.46	1.46	-1.20	0.71	42.28	High

Bd = Bulk density
K = Hydraulic conductivity
CV = Coefficient of variation
G = Gravimetric moisture content
SD = Standard deviation
VG = Variability group

Group	CV (%)
Low	<15
Moderate	15-35
High	>35

(According to Wilding and Drees. 1983)

Table 3: Descriptive statistics for soil properties (30-60 cm depth)

SD	Mean		Skewness coefficient	Kurtosis	CV (%)	VG
Land use 1 (Arable land)						
Bd	1.68	0.14	-0.27	-2.21	8.29	Low
G	29.34	4.67	0.77	-0.42	15.92	Moderate
K	2.08	1.19	0.68	-0.29	57.18	Moderate
Land use 2 (Forested fallow)						
Bd	1.52	0.10	-1.24	0.95	6.79	Low
G	37.77	6.01	-1.14	1.48	15.90	Moderate
K	3.05	1.17	1.56	4.37	38.31	High
Land use 3 (Citrus orchard)						
Bd	1.48	0.10	-0.39	-0.45	7.02	Low
G	35.94	6.40	0.21	0.39	17.82	Moderate
K	3.35	1.20	0.59	1.00	35.93	High

Bd = Bulk density
K = Hydraulic conductivity
CV = Coefficient of variation
G = Gravimetric moisture content
SD = Standard deviation
VG = Variability group

Group	CV (%)
Low	<15
Moderate	15-35
High	>35

(According to Wilding and Dress 1983)

Tables 1, 2 and 3 show that the soil properties differ in their degrees of variability with depth. Hydraulic conductivity was consistently the most variable and was highly variable irrespective of the depth or land use type except for land use type 1 at 0-15 cm depth and land use 2 at 15-30 cm depth where it varied moderately. Bulk density (Bd) was also consistently the least variable, showing low variability irrespective of depth and land use. The CV value for Bd ranged from 2.94 to 9.92%. Gravimetric moisture content on the other hand was has low variability (13.46, 13.04, 5.23) at the different land use types at depth 0-15 cm while at 15-30 cm depth, it was least variable (10.61) in land use 2, and the other parameters were moderately variable (15 - 35%). For better fitting, the data was compared with normal distribution. The skewness and kurtosis coefficient were used to describe the shape of the data as presented in Tables 2 and 3. At an absolute value if the coefficient is greater than 2, the distribution is considered either skewed or kurtotic. A significant positive skewness coefficient indicates a long right tail while a negative value indicates a long left tail. A significant positive kurtosis coefficient shows a peaked distribution while a negative coefficient shows a flat distribution.

Geostatistical Analysis Interpretation

Figures 1, 2, and 3 show the semivariogram of hydraulic conductivity of the soils at different depths. They all have non-zero variance, also called nugget variance, of 1.65, 0.05 and 0.02 values respectively. The range of spatial dependence (40 m) was uniform for all the depths while sill varied. Depth of 0-15 cm had the largest sill value of 2.60 followed by 15-30 cm depth (0.06) and then for 30-60 cm depth (0.03). The data at different depths were best fitted with a spherical model

Nugget variance = 1.65
Sill = 2.60
Range = 40 m

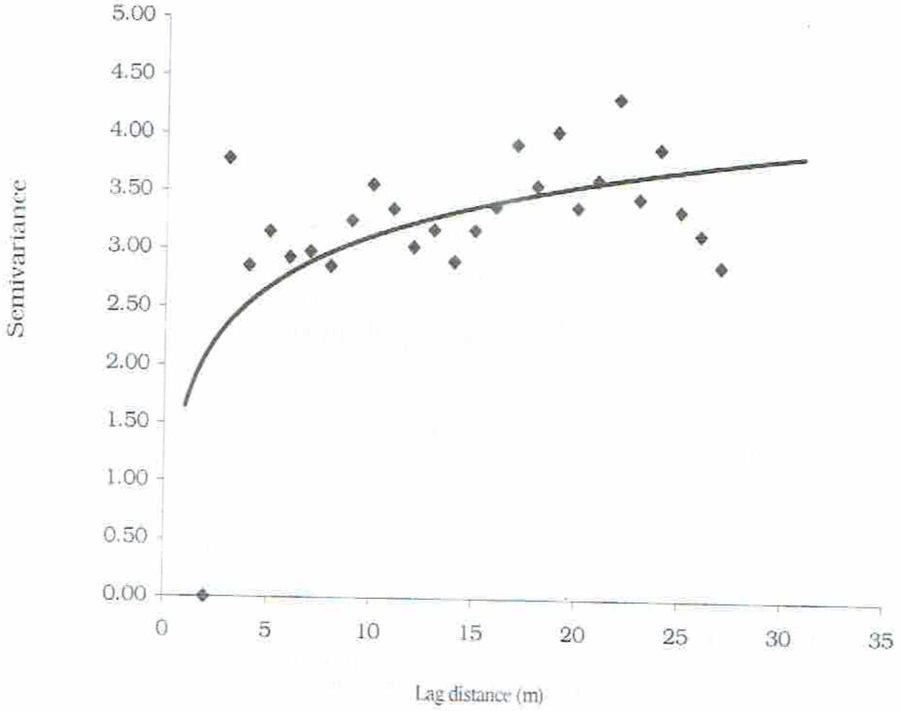


Fig 1: **Semivariogram for hydraulic conductivity of soil at 0-15cm depth**

Nugget variance = 0.05

Sill = 0.06
Range = 40 m

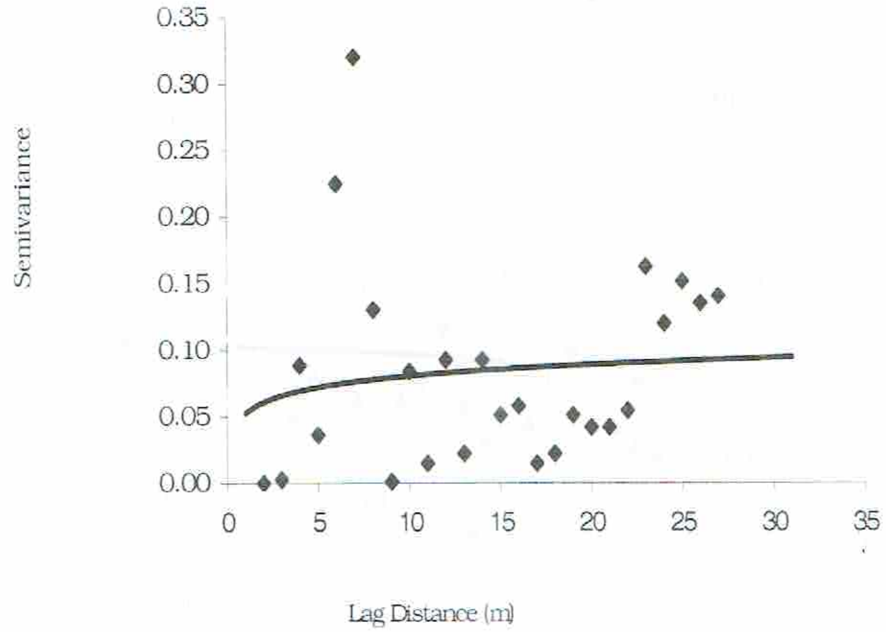
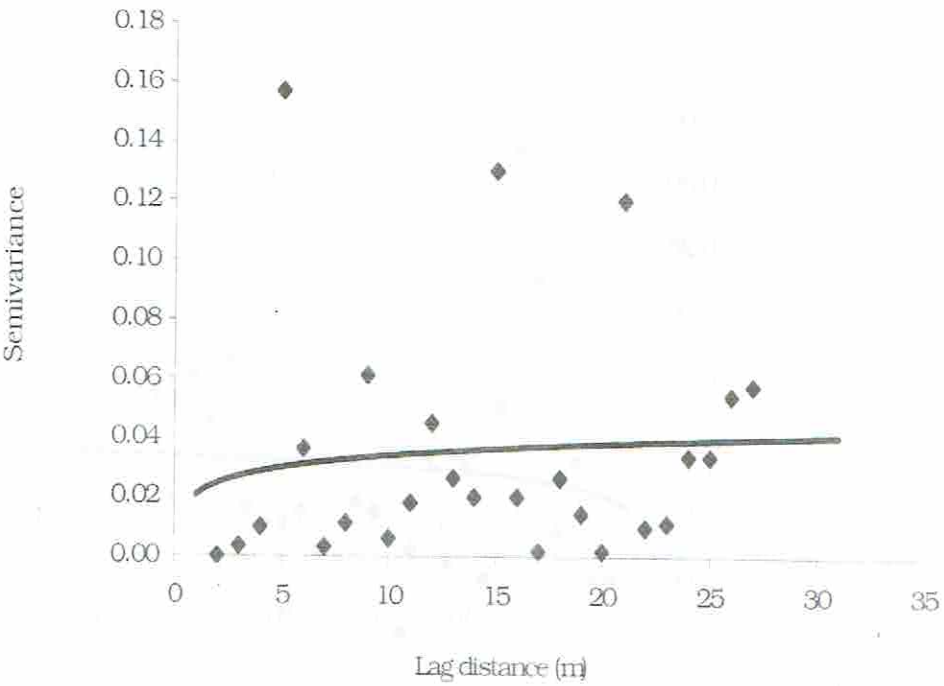


Fig 2: Semivariogram for hydraulic conductivity of soil at 15-30cm depth



Nugget variance = 0.02
Sill = 0.03
Range = 40 m

Fig 3: Semivariogram of hydraulic conductivity of soil at 30-60cm depth

Discussion

Bulk density and gravimetric moisture content showed minimal variations. This agrees with the observations of Dahiya *et al.* (1984) that these properties show low variability in the soils. Comparing the degree of variability of these soil physical properties among the three land use types shows that the value of each property differed across the land use types. Tables 1, 2 and 3 show the CV values for the soil properties at different depths. Only hydraulic conductivity showed high variability (>35%). Low CV values do not imply that relatively few samples give a good estimate of the mean value. Since the CV of bulk density and gravimetric moisture content were low, the semivariogram should show a lack of spatial relationship between sample values at various points.

The nugget variance for all the depths were small (less than 2) with depth having value closer to zero (0.05,0.02). This indicates that the sampling interval was adequate to reflect the variance (Nielsen, 1998). The nugget variance represents the precision of the sampling and measurement technique. The sill for 0-15 cm depth has a higher value (2.60) than the other depths (0.06; 0.03). This implies that hydraulic conductivity at the upper depth had sharp variation than the other depths even though it had lower CV value than the other depths. This agrees with the reports of Xuewen *et al.*, (2001) that even though CV value may not be very high for some soil physical properties, yet the sill value will show a sharp variation. The range was 40 m at all the depths indicating that beyond 40m along the toposequence, soil physical properties especially hydraulic conductivity will no longer be spatially related and those farther apart bear no relationship to one another. Points closer together than the range are spatially dependent and thus can be managed the same way.

Conclusion

The study examined variation of three soil physical properties on three land use types that occur along a toposequence on the Basement Complex of south western Nigeria. The soil properties showed various degrees of variability. Bulk density was consistently the least variable property irrespective of the land use types; gravimetric moisture content showed moderate degree of variability (CV <35), hydraulic conductivity showed high variability. This is a reflection of the complexity of the parent materials (basement complex) from which the soils were derived. Uniform tillage and management practices can be adopted on the land since the soil properties studied did not have excessive degree of variation. However, tillage of the land should be across the slope to forestall accelerated erosion.

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