INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Int. Agrophys., 2013, 27, 57-67
doi: 10.2478/v10247-012-0068-9

Spatial variability of uncultivated soils in derived savanna

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Received February 1, 2012; accepted June 26, 2012

A b s t r a c t. The spatial variability of some physicochemical properties of topsoils/subsoils under secondary forest, grassland fallow, and bare-soil fallow of three locations was evaluated. The data were analyzed and described using classical statistical parameters. Based on the coefficient of variation, bulk density, total porosity, 60-cm-tension moisture content, and soil pH were of low variability. Coarse and fine sand were of moderate variability. Highly variable soil properties included silt, clay, macroporosity, saturated hydraulic conductivity, organic matter concentration, and cation exchange capacity. Overall, soil pH and silt varied the least and the most, respectively. Relative weighting showed that location dominantly influenced the soil variability, except for soil porosity and organic matter concentration influenced mostly by land use. Most of the soil data were normally distributed; others were positively skewed and/or kurtotic. The minimum number of samples (at 25 samples ha^{-1}) required to estimate mean values of soil properties was highly soil property-specific, ranging from 1 (topsoil pH-H_2O) to 246 (topsoil silt). Cation exchange capacity of subsoils related fairly strongly with cation exchange capacity of topsoils (R^2 = 0.63). Spatial variability data can be used to extrapolate dynamic soil properties across a derived-savanna landscape.

K e y w o r d s: spatial variability, uncultivated land uses, soil sampling intensity, normally distributed data

INTRODUCTION

A key feature of soils is the variability in their properties at different spatial scales. Compared to tropical soils, ample data exist on spatial variability of temperate soils (Adhikari *et al*., 2012; Kashiwagi, 2004; Mzuku *et al*., 2005; She *et al*., 2010; Tardaguilla *et al*., 2011;). Interest in the subject has, however, been awakened among tropical researchers, especially those in West Africa. In Nigeria, for instance, after the pioneer works of Folorunso *et al*. (1988) and Ogunkunle (1993) in northern and southern regions, respectively, many other studies sought to understand soil spatial variability (Abu and Malgwi, 2011; Oku *et al*., 2010; Tabi and Ogunkunle, 2007; Wuddivira *et al.*, 2000). For the acid Ultisols that abound in the tropics, variability is due mostly to inherent factors of soil genesis and inherited factors of land use (Dobermann *et al.*, 1995). The West African savanna is one region with limited data on soil variability across different land uses of the soil resources (Idowu *et al.*, 2003), including the more widespread Ultisols (Ghartey *et al.*, 2012). Okon and Babalola (2006) noted that soil variability could be induced even in a uniform field by erosion and runoff deposition. This suggests that soil depth could also be a factor in soil spatial variability.

Information on soil spatial variability is needed to infer the extent of reliability of soil data acquired from composite samples. Folorunso *et al*. (1988) noted that the reliability of soil data on which management decisions are based cannot be greater than the caution applied during sampling to ensure that the soils are quite representative. Other benefits of data on soil spatial variability include serving as a guide to:
– better understanding of observations on the many processes in soils,
– rational interpretation of agronomic responses to soil management, and
– further research in soils of interest.

Furthermore, studies on soil spatial variability help to identify soil properties with normally distributed data, with the aim of estimating their mean values at unsampled points at a pre-defined level of precision. Idowu *et al.* (2003) and Tabi and Ogunkunle (2007) used this approach to arrive at the minimum number of soil samples per hectare for predicting mean properties of Alfisols in southwestern Nigeria.

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The studies done so far in Nigeria differed in their consideration of the inherent and the inherited attributes of soils contributing to their spatial variability. In order to enhance the usefulness of such studies in any ecological zone, locally important factors should be factored into them. The soils in the derived savanna of southeastern Nigeria are known for their structural defects. In this environment, Igwe (2001) reported differences in soil structural development due to land-use options (native forest, oil-palm plantation, grassland fallow, and arable cropping). Oyedele and Tijani (2010) reported the spatial variability of soil moisture content in an Alfisol in southwestern Nigeria. She *et al.* (2010) and Wei *et al.* (2008) highlighted the importance of studies on soil spatial variability across various land uses in China. Recently, Phil-Eze (2010) specifically showed the role of vegetation cover in variability of soil properties in southeastern Nigeria. The study identified sand, organic matter, moisture content and cation exchange capacity (CEC) as explaining over 91% of the impact of vegetation cover on variability of soil properties (Phil-Eze, 2010).

In spite of their fragile nature, the Nigerian derived-savanna soils support intensive agricultural activities (Igwe, 2001). Thus, the focus has been placed on variations in physical properties of the soils due to cropping systems (Amana *et al.*, 2010; Asadu *et al.*, 2010; Obalum and Obi, 2010), but knowledge of their spatial variability under uncultivated conditions is limited to date. Since soil spatial variability is better manifested under uncultivated than cultivated land uses (Ogunkunle, 1993), data for uncultivated soils are preferable in deciding the permissible spatial extent of composite soil sampling. When available for both topsoils and subsoils, such data could also guide the choice of sampling depth that would better suit a specific purpose, depending on the desired level of homogeneity of soil samples. Thus, the objectives of this study were:

- to quantify the spatial variability of selected soil properties and the relative weights of location, land use and soil depth zone to such variability;
- to define the data distribution shape for the soil properties and determine the minimum number of samples required to estimate their mean values.

MATERIALS AND METHODS

The study was conducted in three locations (Nsukka, ~ 445 m a.s.l. and Obimo and Ibagwa-aka, ~ 336 m a.s.l.), lying between 06°47′ and 06°57′ N and 07°17′ and 07°27′ E, at Nsukka Agroecological Zone in southeastern Nigeria. The zone is characterized by a humid tropical climate receiving a mean annual total rainfall of about 1550 mm, with relative humidity and mean air temperatures of 55-80% and 22-31°C, respectively. The underlying geologic materials (mainly sandy deposits of false-bedded sandstones) are deeply weathered, and the soils are porous and well-drained. These soils are brownish red and have been classified as Typic Paleustults by the keys of Soil Survey Staff (2006) of the USDA. In a grassland fallow condition, the topsoil could show an average value of mean-weight diameter of aggregates of about 2.3 cm (Obalum and Obi, 2010). Within the solum, they have an ustic moisture regime and an isohyperthermic thermal regime (Soil Survey Staff, 2006). The original vegetation was rainforest but has given way to derived savanna due to massive deforestation in search of arable farmlands (Igwe, 2001).

At each of the three locations, secondary forest, grassland fallow, and bare-soil fallow were identified. The soils had been under these land-use types for over 15 years, except for the grassland fallow at Ibagwa-aka, which was cultivated in the last four years without inorganic fertilization. This uncultivated condition ensured that farming activities did not confound the variability in the soil properties (Ogunkunle, 1993). In all the locations, the prevailing slope was gentle, averaging about 1%. Sampling was done from the topsoil (0-30 cm) and subsoil (30-60 cm) layers in triplicates while maintaining a distance of 30-50 m between any two adjoining land uses. At each point, undisturbed soil samples were collected using cylindrical (5×5 cm) cores, followed by disturbed samples. Eighteen each of undisturbed and disturbed soil samples were collected from each location, giving 54 samples altogether. The samples, grouped the way they were collected in triplicates, have been described in Table 1.

Soil samples were analyzed using standard procedures for physical properties (Dane and Topp, 2002) and chemical properties (Sparks, 1996).Undisturbed samples in soil cores were saturated and, using the constant head permeameter method, the steady state volume of outflow from the soil column/core was measured and used to calculate the saturated hydraulic conductivity (K_s) by the transposed Darcy's equation. Other soil hydrophysical properties determined on the undisturbed samples included moisture content at 60-cm-water tension, total porosity, macroporosity (taking pores draining at 60-cm-water tension as macropores, with equivalent radius ≥25 μm) and bulk density. Oven-drying of samples was done at 105°C for 24 h. Soil properties determined on the undisturbed samples after air-drying and passing through a 2-mm sieve included particle-size fractions, pH (measured electrometrically in deionized H_2O/0.1N KCl in the liquid-soil ratio of 1:2.5), soil organic matter (SOM) concentration and cation exchange capacity (CEC).

Standard deviation was used to represent the variability within the three replicate samples, as well as within each of the locations, land uses, and soil depth zones. The coefficient of variation (CV %) which is known to normalize variability was also presented to enable comparison of the soil physicochemical properties regarding the extent of variability. Using the classification scheme proposed by Wilding (1985), we rated the variability of soil properties

Table 1. Notation and description of the soil samples

Sample No.	Location	Land cover	Depth zone*
1	Nsukka	Secondary forest	Topsoil
2		Secondary forest	Subsoil
3		Grassland fallow	Topsoil
4		Grassland fallow	Subsoil
5		Bare-soil fallow	Topsoil
6		Bare-soil fallow	Subsoil
7	Obimo	Secondary forest	Topsoil
8		Secondary forest	Subsoil
9		Grassland fallow	Topsoil
10		Grassland fallow	Subsoil
11		Bare-soil fallow	Topsoil
12		Bare-soil fallow	Subsoil
13	Ibagwa-aka	Secondary forest	Topsoil
14		Secondary forest	Subsoil
15		Grassland fallow	Topsoil
16		Grassland fallow	Subsoil
17		Bare-soil fallow	Topsoil
18		Bare-soil fallow	Subsoil

*Soil depth: 0-30 cm for topsoil and 30-60 cm for subsoil.

with a range of CV values of 0-15, 16-35 and > 36% as low, moderate, and high, respectively. The relative weights of the factors (location, land use and depth zone) in the spatial variability of the soil properties were calculated thus:

$$RW = \frac{CV_c \text{ due to a given factor}}{(\text{Sum } CV_c \text{ due to the three location})} 100\%, \quad (1)$$

where: RW is relative weight and CV_c is the corrected value of % CV obtained by multiplying the % CV by the ratio of the number of variables in a given factor to the sum of the number of variables in all the three factors. This correction was done to take care of the imbalance in the number of variables in the contributing factors. Location, land use and soil depth zone have 3, 3 and 2 variables, respectively, such that their correction factors are 0.375, 0.375 and 0.250, respectively.

The coefficients and standard errors (SE) of skewness and kurtosis of the data were used as a measure of symmetry of the population. Where the skewness or the kurtosis coefficient fell outside the range -2 SE to +2 SE, the distribution was regarded as significantly skewed or kurtotic, respectively. The shape of the data distribution was described for each of the measured soil properties. For a given soil property, the data were deemed normally distributed only when the skewness and the kurtosis were simultaneously not significant. The minimum number of soil samples required to estimate the mean value of soil properties was computed using the equation (Starr *et al*., 1992):

$$N = (t_\alpha CV\varepsilon^{-1})^2, \quad (2)$$

where: N is the minimum number of required samples; t_α is the value of a normal variate at p = 0.05, corresponding to 1.96 in the Student *t*-table; CV is the % coefficient of variation when the soil samples were considered discretely; ε is the pre-defined degree of precision, the allowable uncertainty of the exact value of the mean (10% here). In essence, the above implies that 95% of the time, sampling at a chosen intensity would yield a mean value that is 90-110% of the exact mean. Since arithmetic means give good estimates of central tendency only for normally distributed data, normality was first achieved in skewed and/or kurtotic data by log-transformation before deriving the CV. Considering the small size of the data, these classical statistics were adequate to fully quantify the variability and so there was no further application of geostatistics (Okon and Babalola, 2006).

RESULTS AND DISCUSSION

Table 2 shows the spatial variability in the mechanical composition of the soils. The coarse sand and silt contents exhibited the lowest and highest variability, respectively. These results agree with other studies done elsewhere in southern Nigeria (Okon and Babalola, 2006; Oku *et al*., 2010; Phil-Eze, 2010). Although the soils are underlain by similar parent materials, the variability in their particle-size fractions was due more to location than to land use and soil depth zone. Because the soils are genetically similar, the most plausible reason for the results is the differences in altitude of the locations (Ogunkunle, 1993). Research has shown that topsoils usually show a higher sand content than subsoils (Nartey *et al*., 1997; Usowicz *et al*., 2004), and the present results suggest that this is due mainly to coarse sand and not fine sand (Table 2). The silt content showed no appreciable change with depth, and this agrees with other reports from the area (Igwe, 2005; Asadu *et al*., 2010). For the clay content, the soil depth zone ranked closely next to location. This is possibly due to pronounced clay illuviation in these Ultisols, especially with their coarse texture. Asadu *et al.* (2010) reported a similar observation in cultivated plots in the Nsukka site of the present study. It appears thus that sampling at a soil-depth interval of 30 cm could permit the expression of clay eluviation/illuviation phenomenon in these soils. Generally, the topsoils were more similar in clay content (but not in the other particle-size fractions) than the subsoils, as evident from the standard deviations. Furthermore, plots under grassland fallow contained more silt than those under secondary forest and bare fallow. This is attributed to the tendency of the grass cover to impede runoff

T a b l e 2. Spatial variability in textural composition of the soils (± SD)

Factor	Sample No.	Coarse sand (2.0-0.2 mm)	Fine sand (0.2-0.02 mm)	Silt (0.02-0.002 mm)	Clay (<0.002 mm)	Textural class
All samples	1	45.4 ± 4.7	43.9 ± 5.5	3.2 ± 0.0	7.5 ± 1.2	Sand
	2	41.2 ± 1.3	42.7 ± 0.4	3.9 ± 1.2	12.2 ± 0.0	Loamy sand
	3	42.3 ± 3.1	42.3 ± 3.1	4.5 ± 2.3	10.9 ± 1.2	Loamy sand
	4	36.1 ± 1.8	44.5 ± 4.0	3.9 ± 1.2	15.5 ± 4.2	Sandy loam
	5	38.9 ± 1.9	45.0 ± 0.7	3.2 ± 0.0	12.9 ± 1.2	Loamy sand
	6	31.4 ± 3.6	45.2 ± 3.3	3.9 ± 1.2	19.5 ± 3.1	Sandy loam
	7	61.2 ± 4.2	17.9 ± 5.2	13.8 ± 1.2	7.1 ± 2.0	Loamy sand
	8	60.0 ± 6.9	22.3 ± 8.3	10.0 ± 5.3	7.7 ± 3.1	Sandy loam
	9	65.5 ± 4.4	16.3 ± 4.4	13.1 ± 0.0	5.1 ± 0.0	Loamy sand
	10	62.2 ± 1.5	18.3 ± 2.7	13.1 ± 0.0	6.4 ± 1.2	Loamy sand
	11	65.9 ± 6.4	19.2 ± 2.4	8.4 ± 6.4	6.4 ± 1.2	Loamy sand
	12	49.9 ± 9.1	31.9 ± 9.9	10.4 ± 5.7	7.8 ± 2.3	Loamy sand
	13	52.5 ± 4.7	38.0 ± 1.7	2.1 ± 1.2	7.4 ± 2.0	Loamy sand
	14	51.7 ± 1.5	34.2 ± 2.9	1.4 ± 0.0	12.7 ± 2.3	Sand
	15	48.7 ± 6.1	39.2 ± 3.8	2.7 ± 1.2	9.4 ± 2.0	Sand
	16	43.9 ± 0.7	33.3 ± 6.4	8.7 ± 6.4	14.1 ± 1.2	Sandy loam
	17	56.0 ± 5.4	33.9 ± 6.0	2.7 ± 1.2	7.4 ± 0.0	Loamy sand
	18	52.5 ± 9.8	27.4 ± 10.4	6.1 ± 3.1	14.1 ± 1.2	Sandy loam
	CV (%)	20.3	31.5	65.1	38.4	
Location	Nsukka	39.2 ± 5.3	43.9 ± 3.0	3.8 ± 1.1	13.1 ± 4.3	Loamy sand
	Obimo	59.4 ± 8.2	22.1 ± 8.0	10.9 ± 4.3	7.5 ± 2.9	Loamy sand
	Ibagwa-aka	50.9 ± 6.1	34.3 ± 6.3	4.0 ± 3.7	10.8 ± 3.3	Loamy sand
	CV (%)	20.3	32.7	65.4	26.6	
	RW (%)	73.4	87.3	72.6	49.1	
Land use	Forest	50.6 ± 7.4	34.3 ± 10.0	5.2 ± 4.8	9.9 ± 3.1	Loamy sand
	Grass	49.8 ± 11.3	32.3 ± 12.0	7.7 ± 5.0	10.2 ± 4.2	Loamy sand
	Bare	49.1 ± 12.8	33.8 ± 11.0	5.4 ± 3.9	11.3 ± 5.0	Loamy sand
	CV (%)	1.5	3.1	22.6	7.2	
	RW (%)	5.4	8.3	25.1	13.3	
Depth zone	Topsoil	52.9 ± 10.3	32.9 ± 11.8	6.0 ± 4.9	8.2 ± 2.6	Loamy sand
	Subsoil	46.7 ± 10.1	34.0 ± 10.0	6.2 ± 4.5	12.8 ± 4.2	Sandy loam
	CV (%)	8.8	2.5	3.1	30.5	
	RW (%)	21.2	4.4	2.3	37.6	

RW – relative weights of location, land use, and depth zone in the soil variability.

speed, thereby allowing ample time for siltation. Based on the relative weight of land use to the variability in mechanical composition of the soils, composite sampling across the three land uses may be advisable for the determination of coarse sand and fine sand fractions but not silt and clay fractions in the study area.

Table 3 shows the spatial variability in the selected structural properties of the soils. Whereas the variability was low for bulk density, total porosity and 60-cm moisture content, it was high for macroporosity and very high for K_S. Similar results for bulk density have been severally reported across various landscapes in the West-African savanna (Abu and Malgwi, 2011; Folorunso *et al*., 1988; Ghartey *et al*., 2012; Idowu *et al*., 2003; Okon and Babalola, 2006) and the United States (Adhikari *et al*., 2012). The soil moisture content has also been reported to exhibit low spatial variability (Ogunkunle, 1993). In the present study where bulk density was of low variability, similar observation for the moisture content was expected because of the direct proportional relationship between the variances of these two soil properties (Janik, 2008). The high variability of macroporosity and K_S supports Koszinski *et al.* (1995) that these two structural properties are highly variable. Notably, both soil properties are related to water flow in soils. Location affected the variability in bulk density more than land use and depth zone, the reverse was true for macroporosity. The higher bulk density at Nsukka/Obimo than Ibagwa-aka suggests a smaller concentration of nodules in Ibagwa-aka soil (Nartey *et al*., 1997). The trend of bulk density in the land uses (secondary forest < grassland< bare soil) reflects the relative extent of traffic-induced compaction and structural degradation of the soils (Igwe, 2001; 2005). Bulk densities were lower under the grassland fallow compared to the bare-soil fallow, as also found by Okon and Babalola (2006) and Amana *et al.* (2010). Also, the secondary forest showed higher values of macroporosity than the grassland and bare-soil fallows, suggesting better aeration under secondary forest in the absence of anthropogenic activities. Igwe (2001) similarly reported no differences in total porosity and low-tension moisture content between native forest and grassland fallow in the area. The bulk density and macroposity data in the topsoils and subsoils reflect the overbearing influence of the former over the latter. Increased bulk density of the subsoils compared to the topsoils may also be associated with the tendency for an increase in soil strength with depth (Sharifi and Mohsenimanesh, 2012), more so with the illuviated clay and lower SOM concentration in the subsoils.

The low variability of the 60-cm moisture content, coupled with the more or less equal contributions of location, land use and depth zone to the variability, suggests that composite soil sampling across the landscape may give reliable data for this soil moisture content. In this derived savanna, the higher SOM concentration in the topsoils than the subsoils would be expected to cause higher moisture content in the former than the latter (Igwe, 2001). Therefore, the comparable moisture content at 60-cm tension in both depth zones was probably due to mutual cancellation of the positive effects of the higher SOM in the topsoils and the higher clay content of the subsoils. The three factors under consideration differed in their relative weights in the variability in K_S thus: location > depth zone > land use. The K_S was higher under grassland fallow than under bare-soil fallow, as also reported by Amana *et al*. (2010) from the Nsukka location of the present study. As with macroporosity, K_S was higher in the topsoils than the subsoils. This is attributed to the lower bulk density of the topsoils than the subsoils, clay accumulation in subsoils and the attendant reduction in proportion of macropores (Table 3), as well as to greater concentration of plants roots and faunal activities in the topsoils than the subsoils. Eneje *et al*. (2005) also reported decreases in K_S with depth in a sandy-loam soil elsewhere in southeastern Nigeria. Notably, land use had the least influence on the spatial variability of 60-cm moisture content and K_S, suggesting that these soil hydraulic properties may be rather insensitive to land use.

The spatial variability in soil pH was low compared with that in the SOM concentration and CEC of the soils (Table 4). The negligible differences in soil pH among the locations could be due to the similarity in the parent material and rainfall amount (Jaiyeoba, 1996). Again, the similarity in pH among the land uses suggests that the soils are of high buffering capacity. Ghartey *et al.* (2012) also reported low variability in pH of an Ultisol across different land uses in a Ghanaian savanna. The topsoils and subsoils showed comparable pH values, implying that 30 cm is perhaps too small a depth interval for studying changes in soil reaction in this environment. Of all the soil properties of the present study, the soil pH varied the least, an observation supporting similar studies (Adhikari *et al*., 2012; Ogunkunle, 1993; Tabi and Ogunkunle, 2007; Oku *et al*., 2010). The effect of land use on the SOM concentration was more pronounced than those of location and depth zone. The SOM trend among the land uses was expected because of the intense litter recycling in forest and grassland soils compared to bare soils, where the rate of SOM mineralization is usually high due to the exposure of soil surface to high temperature (Igwe, 2001; Okon and Babalola, 2006).

The factors contributed to the variability in the soil CEC in the order location > land use > depth zone. The CEC differed among the locations, with higher values at Nsukka on a higher altitude than at Obimo and Ibagwa-aka on lower altitudes, probably due to local lithological modifications arising primarily from the small differences in altitude (Jaiyeoba, 1996). The CEC was higher under the secondary forest than under the grassland and bare-soil fallows for which values were similar, thus suggesting that maintenance of grassland fallow does not improve soil fertility over bare-soil fallow. Notably, in spite of the higher SOM concentration in topsoils than subsoils, the CEC was slightly lower in the former than the latter. This reflects high-

T a b l e 3. Spatial variability in selected structural properties of the soils (± SD)

Factor	Sample No.	Bulk density (g cm^{-3})	Total porosity (%)	Macroporosity* (%)	Moisture content (vol. vol^{-1}%)	K_s (cm h^{-1})
All samples	1	1.43 ± 0.10	54.1 ± 5.8	16.4 ± 7.7	37.6 ± 5.5	36.1 ± 21.3
	2	1.49 ± 0.03	52.4 ± 4.9	6.3 ± 1.4	46.1 ± 6.2	26.0 ± 14.0
	3	1.59 ± 0.07	44.4 ± 3.4	7.0 ± 4.3	37.4 ± 4.3	39.7 ± 28.0
	4	1.81 ± 0.14	42.8 ± 5.6	4.4 ± 0.2	38.4 ± 5.5	1.7 ± 2.1
	5	1.83 ± 0.10	50.7 ± 2.2	5.9 ± 1.9	44.9 ± 2.6	31.8 ± 21.2
	6	1.71 ± 0.15	56.3 ± 3.2	5.0 ± 2.4	51.3 ± 5.5	18.6 ± 25.5
	7	1.58 ± 0.22	52.0 ± 4.4	6.7 ± 3.1	45.3 ± 1.4	32.3 ± 23.1
	8	1.69 ± 0.05	48.6 ± 1.5	5.3 ± 2.9	43.3 ± 3.7	8.8 ± 4.1
	9	1.58 ± 0.02	52.0 ± 2.3	5.2 ± 1.2	46.8 ± 2.8	58.4 ± 32.4
	10	1.64 ± 0.05	53.5 ± 8.3	8.1 ± 4.3	45.4 ± 4.0	44.3 ± 12.3
	11	1.71 ± 0.06	46.0 ± 6.1	6.8 ± 1.4	39.3 ± 5.7	28.3 ± 24.8
	12	1.71 ± 0.09	42.8 ± 3.5	6.3 ± 2.7	36.5 ± 1.8	17.8 ± 6.0
	13	1.30 ± 0.08	50.9 ± 3.8	11.1 ± 0.4	39.8 ± 4.1	8.6 ± 3.8
	14	1.59 ± 0.09	46.4 ± 0.9	6.4 ± 2.3	40.1 ± 3.1	12.8 ± 12.3
	15	1.41 ± 0.09	54.2 ± 3.2	9.2 ± 0.8	45.0 ± 2.4	3.5 ± 1.0
	16	1.47 ± 0.08	45.1 ± 2.4	2.8 ± 1.9	42.3 ± 1.0	7.5 ± 2.1
	17	1.39 ± 0.06	48.4 ± 4.5	6.2 ± 4.1	42.2 ± 0.8	5.1 ± 0.7
	18	1.48 ± 0.03	49.0 ± 1.3	6.4 ± 1.1	42.6 ± 1.5	13.4 ± 0.6
	CV (%)	9.4	8.3	42.5	9.3	73.2
Location	Nsukka	1.64 ± 0.17	50.1 ± 5.4	7.5 ± 4.5	42.6 ± 5.7	25.7 ± 13.9
	Obimo	1.65 ± 0.06	49.2 ± 4.1	6.4 ± 1.1	42.8 ± 4.0	31.7 ± 17.9
	Ibagwa-aka	1.44 ± 0.10	49.0 ± 3.3	7.0 ± 2.9	42.0 ± 1.9	8.5 ± 4.0
	CV (%)	7.5	1.2	7.9	1.0	54.8
	RW (%)	53.4	23.2	16.8	35.3	59.0
Land use	Forest	1.51 ± 0.14	50.7 ± 2.8	8.7 ± 4.3	42.0 ± 3.4	20.8 ± 12.3
	Grass	1.58 ± 0.14	48.7 ± 5.1	6.1 ± 2.4	42.6 ± 3.9	25.9 ± 24.5
	Bare	1.64 ± 0.17	48.9 ± 4.6	6.1 ± 0.6	42.8 ± 5.1	19.2 ± 9.8
	CV (%)	4.0	2.3	21.5	0.9	15.9
	RW (%)	28.5	44.5	45.7	31.8	17.1
Depth zone	Topsoil	1.54 ± 0.17	50.3 ± 3.4	8.3 ± 3.5	42.0 ± 3.6	27.1 ± 18.2
	Subsoil	1.62 ± 0.12	48.5 ± 4.8	5.7 ± 1.5	42.9 ± 4.4	16.8 ± 12.5
	CV (%)	3.8	2.5	26.5	1.4	33.3
	RW (%)	18.1	32.3	37.5	32.9	23.9

*Comprising pores of equivalent radius – 25 µm, moisture content at 60-cm – water tension, K_s – saturated hydraulic conductivity, RW – relative weights of location, land use, and depth zone in the soil variability.

T a b l e 4. Spatial variability in selected chemical properties of the soils (± SD)

Factor	Sample No.	pH_{H_2O}	pH_{KCl}	SOM (%)	CEC (cmol kg^{-1})
All samples	1	4.8 ± 0.5	4.4 ± 0.5	1.90 ± 0.9	8.0 ± 2.4
	2	4.8 ± 0.6	4.4 ± 0.6	1.22 ± 0.16	6.3 ± 0.6
	3	4.4 ± 0.3	3.9 ± 0.1	1.42 ± 0.08	5.5 ± 0.2
	4	4.4 ± 0.2	3.8 ± 0.1	1.05 ± 0.18	6.7 ± 1.2
	5	4.0 ± 0.1	3.7 ± 0.1	1.05 ± 0.04	5.5 ± 0.2
	6	4.2 ± 0.2	3.8 ± 0.1	0.82 ± 0.12	6.8 ± 1.1
	7	4.0 ± 0.1	3.6 ± 0.1	1.67 ± 0.29	5.3 ± 0.2
	8	4.3 ± 0.2	3.9 ± 0.1	0.66 ± 0.39	4.7 ± 0.2
	9	4.4 ± 0.1	4.0 ± 0.1	0.63 ± 0.07	1.2 ± 0.4
	10	4.3 ± 0.1	3.9 ± 0.1	0.92 ± 0.17	2.3 ± 0.9
	11	4.4 ± 0.1	3.9 ± 0.1	0.18 ± 0.07	1.5 ± 0.6
	12	4.4 ± 0.2	4.0 ± 0.1	0.43 ± 0.15	1.7 ± 0.5
	13	4.5 ± 0.1	3.8 ± 0.1	1.97 ± 1.03	5.1 ± 0.6
	14	4.3 ± 0.1	3.9 ± 0.1	1.44 ± 0.97	4.8 ± 0.8
	15	4.5 ± 0.2	3.9 ± 0.1	0.96 ± 0.54	3.6 ± 0.7
	16	4.4 ± 0.1	3.9 ± 0.0	0.69 ± 0.12	4.7 ± 0.2
	17	4.5 ± 0.2	3.9 ± 0.1	0.87 ± 0.03	4.0 ± 0.8
	18	4.5 ± 0.2	3.9 ± 0.1	0.76 ± 0.21	4.3 ± 0.6
	CV (%)	4.9	5.5	47.2	42.1
Location	Nsukka	4.5 ± 0.4	4.0 ± 0.4	1.24 ± 0.38	6.5 ± 0.9
	Obimo	4.3 ± 0.2	3.8 ± 0.2	0.75 ± 0.52	2.8 ± 1.8
	Ibagwa-aka	4.5 ± 0.1	3.9 ± 0.1	1.12 ± 0.50	4.4 ± 0.6
	CV (%)	2.1	1.9	24.8	40.5
	RW (%)	100	54.3	32.1	62.0
Land use	Forest	4.4 ± 0.4	4.0 ± 0.4	1.48 ± 0.49	5.7 ± 1.3
	Grass	4.4 ± 0.1	3.9 ± 0.1	0.95 ± 0.28	4.0 ± 2.0
	Bare	4.4 ± 0.2	3.8 ± 0.1	0.69 ± 0.32	4.0 ± 2.1
	CV (%)	0.0	1.6	39.0	21.8
	RW (%)	0.0	45.7	50.5	33.4
Depth zone	Topsoil	4.4 ± 0.3	3.9 ± 0.3	1.18 ± 0.60	4.4 ± 2.1
	Subsoil	4.4 ± 0.3	3.9 ± 0.3	0.89 ± 0.31	4.7 ± 1.8
	CV (%)	0.0	0.0	20.2	4.5
	RW (%)	0.0	0.0	17.4	4.6

SOM – soil organic matter; CEC – cation exchange capacity. Explanations as in Table 2.

intensity leaching, which is a major agronomic problem in the zone (Igwe, 2001). From the illuviation perspective, the results also point to the role of clay in the CEC of the soils. In general, the soils, having intensively weathered, were of low CEC. The relative weight of land use in the variability of soil chemical properties suggests that composite soil sampling across the landscape, irrespective of land use, may be ideal for determination of soil pH.

Table 5 shows the coefficients of skewness and kurtosis, as well as the median and mean values of the soil properties. The SE of skewness and kurtosis are given as footnotes to the table. The extent of spatial variability of the soil properties, alongside the parameters for describing the shape of the data distribution, is summarized in Table 6. Soil properties with positively skewed data had the greater proportion of the distribution within the low range, with some few extreme values in the population. That was the reason for the higher median than mean values for such soil properties (Table 5). Conversely, positively kurtotic data imply that the distribution of these soil properties is peaked. Some of the soil properties showed data that were both positively skewed and positively kurtotic. This meant that, although most of the values were observed at the lower end of the range, the data spanned a broad range. A good example here is the SOM concentration in the subsoil (30-60 cm), as also found by Tabi and Ogunkunle (2007) in another derived-savanna environment.

Notably, all the particle-size fractions exhibited normality in data distribution regardless of soil depth zone; the only exception was clay when considering the entire samples, a situation attributable to irregularity in composition occasioned by the aforementioned eluviation/illuviation processes. Soil properties with high variability showed the greatest number of skewed and kurtotic data. The data-distribution shape may however not be inferred solely from the extent of variability of the soil data, as both the depth zone and nature of the soil properties tended to influence the shape as well. For instance, K_s and CEC were highly variable but consistently showed contrasting shapes. Conversely, soil bulk density was among the least variable soil properties but was consistently normally distributed. Soil pH in H_2O was also of low variability but showed contrasting shapes in both depth zones. This suggests that the assumption that static soil properties are normally distributed may not always apply in this environment.

The minimum numbers of samples required to estimate the mean values of the soil properties are shown (Table 7). It is evident from the data shown that these estimated numbers depended largely on the soil property and depth zone considered. Also, transforming skewed data to achieve normality in distribution tended to have a reducing effect on the estimate. These results reflect the spatial variability of the soil properties, as the estimated values show an overall tendency of increasing with an increase in percent CV. Soil pH and silt consistently showed the lowest and highest values, respectively. The mean sampling spacing of about 40×10 m (or 400 m^2) used in this study translates into 25 samples per hectare. For subsoil pH, the estimated value of 1 denotes that in a hectare, the pH of 25 subsoils sampled at the above spacing would be so similar that one sample would be representative. For the topsoil silt content, the estimated value of 246 implies either sampling about 10 ha at 40×10 m or sampling one hectare at about 10 times the above sampling intensity.

The CEC was the only dynamic soil property with highly variable (CV > 35%) and normally distributed data in the topsoils and subsoils (Table 6). Most of the plots we studied were devoid of such anthropogenic activities as farming for over 15 years; one was cultivated in the last four years but without inorganic fertilizers. Under such situations, the variability in the CEC could be taken as reflecting variation in the native fertility of the soils (Ogunkunle, 1993). We consider all this as rendering the soil CEC a good candidate for taking advantage of spatial variability in soil properties to delineate the relationship between topsoil and subsoils properties. A regression of the subsoil CEC on the topsoil CEC thus showed a fairly strong relationship:

$$\text{Subsoil CEC} = 1.760 + 0.664 \text{ topsoil CEC} \quad (R^2 = 0.63;\ p = 0.001), \tag{3}$$

Because of easier sampling of topsoils compared to subsoils, the above relationship (Eq. (3)) may be used for quick prediction purposes for soils with pH range of 4.0-4.8, more so with the relatively large number of samples required to estimate the mean value of subsoil CEC (194 samples, second only to the silt content). However, large-scale research will be needed to validate the relationship.

CONCLUSIONS

1. The variability in particle-size fractions of the soils tends to increase with a decrease in their size classes. Across the landscape, uniformity in soil pH but certainly not in the SOM concentration and CEC may be expected.

2. Structural properties of the soils related to compactness, eg bulk density and 60-cm moisture content, exhibit little variability whereas those related to water flow in soils, *eg* macroporosity, are highly variable.

3. Differences in location can explain most of the variability in the soil properties, except for the SOM concentration and soil porosity which are highly responsive to land use/management.

4. Generally, the smaller the degree of variability in the soil data, the greater the tendency to attain normality in the data distribution, except for static soil properties such as pH.

T a b l e 5. Assumption of normality test in the data distribution on the measured properties of the soils

Depth zone	Coarse sand	Fine sand	Silt	Clay	Bulk density	Total porosity	Macro-porosity	Moist. content	K_s	pH_{H_2O}	pH_{KCl}	SOM	CEC
						Skewness coefficients*							
All samples	0.08	-0.43	0.64	0.70	0.17	0.15	1.77	0.12	1.32	1.26	2.86	1.35	0.13
Topsoil	0.07	-0.41	0.72	0.59	0.34	-0.27	1.48	-0.66	1.02	0.74	2.54	0.83	0.40
Subsoil	0.12	-0.38	0.57	0.19	0.57	0.54	0.83	0.54	1.15	2.06	3.20	1.98	-0.25
						Kurtosis coefficients**							
All samples	-0.81	-1.13	-1.27	0.13	-0.35	0.17	4.24	0.18	1.34	3.24	8.82	1.98	0.55
Topsoil	-0.96	-1.24	-1.20	-0.54	-0.73	0.11	2.19	-0.34	0.24	1.44	7.08	0.36	1.06
Subsoil	-0.93	-1.15	-1.35	-0.06	0.19	0.48	1.28	0.03	0.35	5.93	10.64	6.01	-0.52
						Median							
All samples	51.3	36.5	3.4	9.8	1.59	49.4	6.1	42.6	13.3	4.4	3.9	0.89	4.8
Topsoil	52.8	36.6	3.4	7.4	1.52	49.7	7.7	42.6	16.4	4.4	3.9	1.03	5.2
Subsoil	44.6	35.2	5.1	13.1	1.61	47.5	5.4	42.6	11.6	4.4	3.9	0.89	4.8
						Mean							
All samples	50.1	33.2	6.3	10.5	1.57	49.4	7.0	42.5	21.9	4.4	3.9	1.04	4.5
Topsoil	53.4	32.3	6.1	8.2	1.53	50.3	8.3	42.0	27.1	4.4	3.9	1.19	4.4
Subsoil	46.7	34.0	6.5	12.8	1.62	48.6	5.7	42.9	16.8	4.4	3.9	0.88	4.7

*SE = 0.3246 (All samples), 0.4479 (Topsoil and subsoil), **SE = 0.6389 (All samples), 0.8721 (Topsoil and subsoil). Other explanations as in Tables 3 and 4.

T a b l e 6. Summary of the extent of spatial variability and distribution shape of the soil properties

Depth zone	Variability category		
	Low (CV < 15%)	Moderate (CV 15-35%)	High (CV > 35%)
All samples	bulk density (N) total porosity (N) moisture content (N) pH_{H_2O} (+S, +K) pH_{KCl} (+S, +K)	coarse sand (N) fine sand (N)	silt (N) clay (+S) macroporosity (+S, +K) K_s (+S, +K) SOM (+S, +K) CEC (N)
Topsoils	bulk density (N) total porosity (N) moisture content (N) pH_{H_2O} (N) pH_{KCl} (+S, +K)	coarse sand (N) fine sand (N) clay (N)	silt (N) macroporosity (+S, +K) K_s (+S) SOM (N) CEC (N)
Subsoils	bulk density (N) total porosity (N) moisture content (N) pH_{H_2O} (N) pH_{KCl} (+S, +K)	coarse sand (N) fine sand (N) clay (N) SOM (+S, +K) macroporosity (N)	silt (N) K_s (+S) CEC (N)

N – normally distributed, +S – positively skewed, +K – positively kurtotic. Other explanations as in Tables 3 and 4.

T a b l e 7. Minimum number of samples needed to estimate mean values of normally distributed soil properties

Depth zone	Coarse sand	Fine sand	Silt	Clay	Bulk density	Total porosity	Macro-porosity	Moisture content	K_s	pH_{H_2O}	SOM	CEC
Both depth zones	17	41	211	12*	4	4	31*	5	56*	1*	91*	75
Topsoils only	15	51	246	40	6	4	26*	5	56*	2	145	99
Subsoils only	19	35	194	45	3	6	76	7	69*	1*	66*	61

The mean values were estimated at the present sampling density of one sample per depth zone per 400 m^2 and with an allowance of 10% uncertainty of the exact mean, estimated at $p = 0.05$. *Computed after attaining normality in the distribution of the hitherto significantly skewed and/or kurtotic data. Other explanations as in Tables 3 and 4.

5. Though the minimum number of samples required to estimate the mean values of the soil properties is linearly related to the degree of soil data variability, such estimates seem more reliable when based on naturally normally distributed data rather than on transformed data. In savanna ecosystems with minimal anthropogenic interference, subsoil values of dynamic soil properties showing highly variable and normally distributed data can be reliably predicted from their topsoil values, especially when deeper soil sampling is impracticable.

REFERENCES

Abu S.T. and Malgwi W.B., 2011. Spatial variability of soil physico-chemical properties in Kadawa Irrigation Project in Sudan Savanna Agroecology of Nigeria. Int. J. Agric. Res., 6, 714-735.

Adhikari P., Shukla M.K., and Mexal J.G., 2012. Spatial variability of soil properties in an arid ecosystem irrigated with treated municipal and industrial wastewater. Soil Sci., 177, 458-469.

Amana S.M., Obi M.E., and Jayeoba O.J., 2010. Effects of cover management practices on physical properties in Nsukka sandy loam soil. Prod. Agric. Tech., 6, 110-121.

Asadu C.L.A., Obasi S.C., and Dixon A.G.O., 2010. Variations in soil physical properties in a cleared forestland continuously cultivated for seven years in eastern Nigeria. Comm. Soil Sci. Plant Anal., 41, 123-132.

Dane J.H. and Topp G.C. (Eds)**, 2002.** Methods of Soil Analysis. Physical Methods. SSSA Press, Inc. Madison, WI, USA.

Dobermann A., Goovaerts P., and George T., 1995. Sources of soil variation in an acid Ultisol of the Philippines. Geoderma, 68, 173-191.

Eneje R.C., Ogbenna C.V., and Nuga B.O., 2005. Saturated hydraulic conductivity, water stable aggregates and soil organic matter in a sandy loam soil in Ikwuano LGA of Abia State. Agro-Sci., 4, 34-37.

Folorunso O.A., OhuJ.O., and Adeniji F.A., 1988.The role of soil spatial variability investigation in the management of the Chad Basin vertisols of NE Nigeria. Soil Tech., 1, 149-156.

Ghartey E.O., Duwuona G.N.N., Nartey E.K., Adjadeh T.A., and Lawson I.Y.D., 2012. Assessment of variability inthe quality of an Acrisol under different land use systems in Ghana. Open J. Soil Sci., 2, 33-43.

Idowu O.J., Aduramigba V.O., and Ande E.T., 2003. Variability in surface properties of an Alfisol as function of types of land use. Comm. Soil Sci. Plant Anal., 34, 3045-3058.

Igwe C.A., 2001. Effects of land use on some structural properties of an Ultisol in south-eastern Nigeria. Int. Agrophysics, 15, 237-241.

Igwe C.A., 2005. Soil physical properties under different management systems and organic matter effects on soil moisture along soil catena in southeastern Nigeria. Trop. Subtrop. Agroecosys., 5, 57-66.

Jaiyeoba I., 1996. Variation of soil chemical properties over Nigerian Savanna. Singapore J. Trop. Geogr., 16, 141-157.

Janik G., 2008. Spatial variability of soil moisture as information on variability on selected physical properties of soil. Int. Agrophysics, 22, 35-43.

Kashiwagi J., 2004. Spatial variability analysis of soil properties in a hilly upland field (in Japanese). J. Japanese Soc. Soil Phys., 96, 71-81.

Koszinski S., Wendroth O., and Lehfeldt J., 1995. Field scale heterogeneity of soil structural properties in a moraine landscape of N-E Germany. Int. Agrophysics, 9, 201-210.

Mzuku M., Khosla R., Reich R., Inman D., Smith F., and MacDonald L., 2005. Spatial variability of measured soil properties across site-specific management zones. Soil Sci. Soc. Am. J., 69, 1572-1579.

Nartey E., Duwuona G.N., Ahenkorah Y., Mermut A.R., and TiessenH.,1997. Variability inthe properties of soils on two toposequences in northern Ghana. Ghana J. Agric. Sci., 30, 115-126.

Obalum S.E. and Obi M.E., 2010. Physical properties of a sandy loam Ultisol as affected by tillage-mulch management practices and cropping systems. Soil Till. Res., 108, 30-36.

Ogunkunle A.O., 1993. Variation of some soil properties along two toposequences on quartzite schist and banded gneiss in southwestern Nigeria. GeoJ., 30, 397-402.

Okon P.B. and Babalola O., 2006. General and spatial variability of soil under vetiver grass strips. J. Sust. Agric., 27, 93-116.

Oku E., Essoka A., and Thomas E., 2010. Variability in soil properties along an Udalf toposequence in the humid forest zone of Nigeria. Kasetsart J. (Nat. Sci.), 44, 564-573.

Oyedele D.J. and Tijani F.O., 2010. Spatial and temporal variability of soil water content. Int. Agrophys., 15, 171-176.

Phil-Eze P.O., 2010. Variability of soil properties related to vegetation cover in a tropical rainforest landscape. J. Geogr. Reg. Plan., 3, 177-184.

Sharifi A. and Mohsenimanesh A., 2012. Soil mechanical resistance measurement by an unique multi-cone tips horizontal sensor. Int. Agrophys., 26, 61-64.

She D.L., Shao M.A., Timm L.C., Pla Sentis I., Reichardt K., and Yu S.E., 2010. Impacts of land use pattern on soil water content variability in the Loess Plateau of China. Acta Agric. Scand., B-S.P., 60, 369-380.

Soil Survey Staff, **2006.** Keys to Soil Taxonomy. USDA Press, Washington, DC, USA.

Sparks D.L. (Ed.), **1996.** Methods of Soil Analysis. Chemical Methods. Soil Sci. Soc. Am. Inc. Madison, WI, USA.

Starr J.L., Parkin T.B., and Meisinger J.J., 1992. Sample size consideration in the determination of soil nitrate. Soil Sci. Soc. Am. J., 56, 1824-1830.

Tabi F.O. and Ogunkunle A.O., 2007. Spatial Variation of some soil physico-chemical properties of an Alfisol in southwestern Nigeria. Nigerian J. Soil Environ. Res., 7, 82-91.

Tardaguilla J., Baluja J., Arpon L., Balda P., and Oliveira M., 2011. Variations of soil properties affect the vegetative growth and yield components of Tempranillo grapevines. Precision Agric., 12, 762-773.

Usowicz B., Hajnos M., Sokolowska Z., Józefaciuk G., Bowanko G., and Kossowski J., 2004. Spatial variability of physical and chemical soil properties in a field and commune scale (in Polish). Acta Agrophysica, 103, 5-90.

Wei J., Xiao D., Zeng H., and Fu Y., 2008. Spatial variability of soil properties in relation to land use and topography in a typical small watershed of the black soil region, northeastern China. Environ. Geol., 53, 1663-1672.

Wilding L.P., 1985. Spatial variability: its documentation, accommodation and implication to soil surveys. In: Soil Spatial Variability (Eds D.R. Nielsen, J. Bouma). Pudoc Press, Wageningen, the Netherlands.

Wuddivira H.N., Ogunwole J.O., and Adeoye K.B., 2000. Spatial variability of soil physical properties of an Alfisol in Samaru, northern Guinea savanna, Nigeria. J. Agric. Environ., 1, 173-182.