SPATIAL VARIABILITY OF SELECTED SOIL PROPERTIES IN A CULTIVATED GRAVELLY LANDSCAPE IN MINNA, NIGER STATE, NIGERIA

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ABSTRACT

The spatial variability of soil properties is needed for agricultural productivity, more importantly for precision farming. This study assessed spatial variability of some soil properties in topsoil of a gravelly agricultural landscape in Minna, Niger State, Nigeria. The study site was divided along physiographic units into upper, middle and lower slopes. In each unit, soil samples were collected from 0 – 20 cm depth, from three randomly selected points for purpose of statistical evaluation. Samples were taken to the laboratory for determination of particle size distribution, bulk density, particle density, total porosity, pH and organic carbon. Results showed that topography had significant ($P < 0.05$) effect on distribution of gravels, sand and silt across the field. Distribution of clay, bulk density, particle density, total porosity, pH and organic carbon were not significantly different. Overall spatial variability in respect to sand, clay, bulk density, particle density and pH was low with coefficient of variation (CV <15 %), total porosity was moderate (CV = 18.19 %), while gravel, silt and organic carbon showed high spatial variability (CV >35 %). For precision tillage and sustainable soil organic carbon management, partitioning of the studied site into homogenous units along the spatial distribution of gravels, total porosity and organic carbon which showed high spatial variability, could be very helpful.

Keywords: Soil spatial variability, physiographic units, precision farming.

INTRODUCTION

Soil varies tremendously in physical, chemical and biological properties in vertical and horizontal directions. Whichever form variability in soil takes, major contributory factors could either be intrinsic (soil forming factors) or extrinsic (majorly soil management practices) or combination of the two (Dowling *et al.,* 1986; Cambardella and Karlen, 1999; Brejda *et al.*, 2000). Among the intrinsic factors, topography has controlling effect in spatial distribution in soil properties (Babalola *et al.*, 2007), due to its influence on other factors as well as use and management of the land.

Reports have indicated that even though spatial variability in soil properties is a gradual process (Buol *et al.*, 1997), it is capable of threatening food security (Okeyo *et al.*, 2006). This is because the effects of spatial variability are not limited to differences within field crop growth alone, but also reduction in yields (Brouwer *et al.*, 1993; Udoh *et al.*, 2010). Hence, fields identified with a high degree of spatial variability of soil properties are better managed by delineating them into relatively homogenous units (Inman *et al.*, 2005). Hence, the need for spatial variability of soil properties to be monitored and quantified for purpose of selecting appropriate agricultural use and management (Kilic *et al.*, 2012; Ojobor, 2017). Soil survey is a key to providing such important information about soil covering the landscape.

The pisolithic or gravelly forms of soil have numerous management challenges ranging from low fertility, shallow rooting depth to poor water-logging or drought prone (Diallo, 2014; WRB/IUSS Working Group, 2014). As a result of these limitations, these soils are categorized as marginal agricultural (Diallo, 2014). Incidentally, gravelly landscape is typical of Minna, Niger State, Nigeria (Ojanuga, 2006; Lawal *et al.*, 2012; Lawal *et al.*, 2014).

Demographic pressure endears farmers in Minna to encroach and intensify farming on the gravelly landscapes hitherto neglected. Being regarded as marginal lands, little attention was given in investigating the soils. Elsewhere, studies on spatial variability of soil properties on toposequences have been adequately documented (Udoh *et al.*, 2010; Malgwi and Abu, 2011; Njoku *et al.*, 2011; Tijjani and Hassan, 2017), but little or no attention is given to study on spatial variability of soil properties on gravelly landscapes in Minna. According to Amusan *et al.* (2006) and Osujieke *et al.* (2017) adequate knowledge on spatial variability of soil properties is very important, especially when land is earmarked for intensive farming. In this regard, this study was designed to assess the spatial variability of selected soil properties in an intensively cultivated gravelly toposequence and their implications on soil management in Minna, Niger State, Nigeria.

MATERIALS AND METHODS

The Study Site

The study site was a cultivated gentle sloping landscape located within Gidan Kwano campus of the Federal University of Technology, Minna; geo-referenced on latitude 9°32' 6.80" N and longitude 6°27' 27.072" E, on elevation of 222 to 226 m above mean sea level (asl). The vegetation of the area is southern Guinea savanna with mean annual rainfall of 1,284 mm, spread between 5 and 6 months. Mean daily temperature rarely fall below 22 □C, but rise to as high as 40 C, mostly during months of February-March (Adeboye *et al.*, 2011). The study site was underlain by the pre-Cambrian Basement Complex rocks which weathered deeply to form series of soils including Ferric Luvisols, Ferric Acrisols and . Ferric Cambisols (Ojanuga, 2006). The site has been continuous cultivation of arable crops such as millet, groundnut and cowpea (upper slope) to yam and rice at middle and lower slopes respectively. Burrowed pits of laterite (gravel) mines dominated part of the upper slope and the entire crest, thus taking the latter physiographic unit off agricultural activities.

Delineation of the Site and Soil Sample Collection

Rapid reconnaissance survey was conducted purposefully to select an appropriate landscape used for the study. The studied site was divided into three topographic units, namely: the upper, middle and lower slopes (Figure 1). Stratified random sampling technique as described by Wilding and Drees (1985) was adopted for soil sample collection. In each topographic unit, core-samples for bulk density study, were carefully collected from topsoil, 0-20 cm, from three randomly selected points. From the same positions and soil depth, 500 g of soil samples were collected and sent to the laboratory for soil physical and chemical analysis.

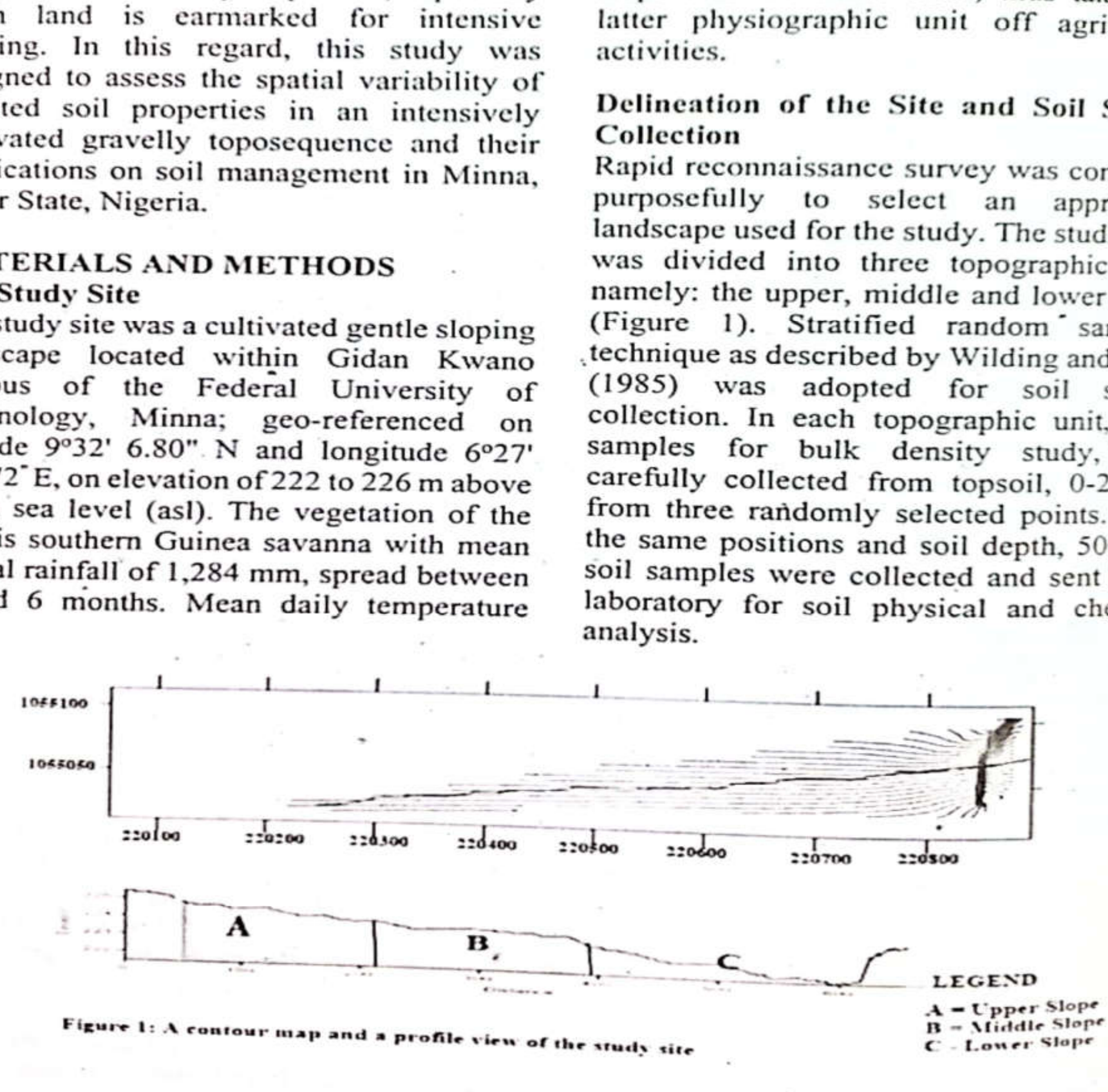

Figure 1: A contour map and a profile view of the study site

Laboratory Analysis

Soil samples for routine analysis were air-dried for a week and gravels separated using 2 mm sieve. The gravels were then weighed and expressed in percentage. Core samples were oven dried for 24 hours at 105 C for determination of bulk density (Blake and Hartge, 1986; Chen *et al.*, 2010). The 2 mm sieved soils were analyzed for particle density using pycnometer method as described in Blake and Hartge (1986) and Flint and Flint (2002). Particle size distribution was determined using Bouyocous hydrometer method as explained in Gee and Or (2002). The textural classes of the soils were determined using IUSS soil Textural Triangle. Total porosity was calculated as a function of the total volume not occupied by soil solids, using the equation: TP = [1 - (Bd /Pd)] x 100, where TP = total porosity, Bd=bulk density and Pd= particle (Danielson and Sutherland, 1986). Soil pH was measured potentiometrically in 1:2.5 soil-water ratio (Hendershot *et al.*, 1993). Organic carbon was determined following the Walkley-Black procedure as described by Nelson and Sommers (1996).

Data Analysis

Data were subjected to descriptive statistics, correlation analysis and analysis of variance (ANOVA) using SPSS 20 statistical software. Significantly different means were separated using LSD at 5 % level of probability. Coefficient of variation (CV) was used for the variability analysis where CV <15 % classified as less variable, CV between 15-35 % classified as moderately variable and CV >35 % classified as highly variable (Wilding and Drees, 1985).

RESULTS AND DISCUSSION

Soil Properties in Relation to Topographic Units

Results on spatial distribution of selected soil properties in relation to three topographic units: the upper, middle and lower slopes are presented in Table 1. Topography significantly (P<0.05) affected the distribution of gravel, sand and silt in the studied soils. Gravel and sand content in the soil were significantly higher (P<0.05) in both middle and upper slopes than the lower slope while silt was significantly higher (P<0.05) at the lower slope than the other two slope units. These differences could partly be explained in terms of erosion processes which influenced sorting and lateral redistribution of soil materials along the slope gradient (Babalola *et al.*, 2007). In this regard, gravels and sand fractions were deposited at upper and middle slopes while silt and clay fractions were moved further down-slope. This corroborate with the views of Ovales and Collins (1986) and Obalum *et al.* (2011) indicating that larger particles are deposited first at upper slope, while finer materials are transported farther and subsequently deposited down-slope. Distribution of clay, bulk density, particle density, total porosity, pH and organic carbon along the slope gradient were not statistically different (P>0.05).

Table 1: Some Physical and Chemical Properties of the Soils

Topographic Unit	Gravel (%)	Sand	Silt (g kg^{-1})	Clay	BD (g cm^{-3})	PD (g cm^{-3})	TP (%)	pH	OC (g kg^{-1})
Upper Slope	42.79^a	827^a	49^b	124^a	1.59^a	2.40^a	34.77^a	6.7^a	3.51^a
Middle Slope	48.89^a	862^a	35^b	103^a	1.63^a	2.53^a	35.32^a	6.3^a	1.88^a
Lower Slope	23.33^b	696^b	196^a	108^a	1.51^a	2.37^a	37.50^a	6.6^a	3.13^a

Means on the same column with different superscripts are significantly different (p<0.05).
BD = bulk density, PD = particle density, TP = total porosity, OC = organic carbon

With exception of total porosity, other soil properties assessed revealed anon-sequential increase or decrease in the distribution of the soil properties along the slope gradient. For instance, the middle slope had the highest values of gravels (48.89 %) and sand fraction (862 g kg^{-1}), both showed a trend of middle slope > upper slope > lower slope. Bulk density and particle density showed similar pattern. Silt was also lowest in the middle slope and showed a distribution trend of lower slope > upper slope > middle slope. Distribution of clay, pH and organic carbon followed the trend of upper slope > lower > middle slope. These irregular trends suggest that the local topography of the site was not solely responsible the spatial distribution of these soil properties. Land use could partly account for high proportion of gravel and sand soil attributes in the middle slope. This could be supported by the findings of Sobieraj *et al*. (2002), stating that not all soils (or soil properties) have strong correlation with terrain attributes, especially within an agricultural field where different land use types are practiced. Also, dominance of gravel and sand fraction, particularly in the middle and upper slopes, could have effect on the overall quality of the soils more so that the organic matter content (as reflected by low organic carbon) was low. Thus, the tendency of low or poor moisture retention capacity to occur in such soils is high, especially if the soil is low in organic matter content (Tijjani and Hassan, 2017).

The distribution of clay, bulk density, particle density, total porosity, pH and organic carbon along the slope gradient were not statistically different (P>0.05), thus negating the effect of topography. Land use could be responsible for non-significant difference observed. Under continuous cultivation, Kilic *et al*. (2012) reported that chances of soil particles to homogenize exist, especially in soil that evolved from similar parent materials.

Spatial Variability of Selected Soil Properties

The coefficient of variation (CV) of selected soil properties for the three topographic units and the overall are presented in Table 3. The use of the CV values is a common procedure to assess, spatial variability in soil properties, because it gives room for comparison among properties with different units of measurement (Haruna and Nkongolo, 2013). Irrespective of physiographic units, the overall evaluation revealed low spatial variability in sand, bulk density, particle density and pH with CV values less than 15 %.Total porosity had moderate variability with CV of 18.19 %, while gravels, silt and organic carbon showed high spatial variability having CV values ranged from 38.03 to 96.67 %.

Spatial variability of clay and total porosity was low (CV, <15 %) in upper slope, and moderate (CV, 15-25 %) in middle and lower slopes. Overall ranking for the study site showed silt, gravels and organic carbon being highly variable (CV, 38.03 - 96.67 %), total porosity was moderate (CV, 18.19 %), while sand, clay, bulk density, particle density and pH had low spatial variability (CV, < 15 %). In terms of agricultural productivity and sustainable management, partitioning of the site on the basis of spatial variability ranking, especially for gravels, total porosity and organic carbon could be very useful.

Table 3: Spatial Variability of Selected Soil Properties at the Different Physiographic Units

Physiographic unit	Coefficient of variation (%)								
	Gravel	Sand	Silt	Clay	BD	PD	TP	pH	OC
Upper slope	42.93	4.58	67.45	4.05	3.16	2.08	9.79	0.87	28.21
Middle slope	31.91	2.50	15.91	15.59	11.11	2.29	22.84	1.82	25.53
Lower slope	44.62	10.39	44.54	17.34	11.26	2.45	24.91	0.44	35.46
Overall variability	45.62	10.90	96.67	14.27	8.92	3.70	18.19	2.45	38.03

Coefficient of Variability (%) ranking: 0-15, low; 16-35, moderate and ≥ 36 %, high (Wilding and Drees (1985). BD = bulk density, PD = particle density, TP = total porosity, OC = organic carbon

CONCLUSION

The results revealed that topography exert significant influence in the distribution of gravels, sand and silt. The dominance of gravels and sand in upper and middle slopes may have negative effect in soil moisture and nutrient retention capacities, hence there is need to incorporate organic matter to the soils which was deficient in the soil. Soil management related to compaction, drainage, acidity and application of organic matter can be handled uniformly irrespective of the topographic units. While, high spatial variability observed in gravels, silt and organic carbon may require dividing the site into smaller and homogenous units for precision farm management practices.

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