



## Spatial Variability of Soil Chemical Properties of an Undulating Site within a University Farm at Okha, near Benin City in Nigeria

AJAYI, AA; \*OKONOKHUA, BO

Department of Agronomy and Environmental Management, Benson Idahosa University,  
Benin City, Nigeria

\*Corresponding Author Email: [ookonokhua@biu.edu.ng](mailto:ookonokhua@biu.edu.ng)

\*ORCID: <https://orcid.org/0000-0003-3189-6703>

\*Tel: 0806 025 7011

Co-author email: [ajayiadebola95@yahoo.com](mailto:ajayiadebola95@yahoo.com)

**ABSTRACT:** Assessment of spatial variability of soil properties due to inherent factors is critical for optimum crop production and environment protection. Hence, the objectives of this study was to evaluate the influence of climate, topography and land management on spatial variability of the soil chemical properties and fertility status of an undulating farmland at Okha, near Benin City. Twelve soil samples were collected from the depth of 0-20 cm at an interval of 30 m × 30 m on a regular grid design with a global positioning system and assessed using standard methods. Results revealed that the coefficient of variability (CV) was low for sand and clay (<15 %), moderate for silt (15 – 50 %), low for pH, moderate for organic C, N, K and ECEC but high for P (>50%). The soil texture was sandy loam and pH displayed very strongly, strongly as well as medium acid conditions. Concentrations of organic C were generally low, N and P were low, while K was very low. Low concentrations of ECEC were spread over the site with highest concentrations on the concave part of the landscape. Generated maps revealed a substantial influence of topography and land use on spatial variability of soil chemical properties even within a small part of a farmland which is quite useful for site-specific nutrient management.

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Variability of soil properties from one field to a larger regional scale during formation can be enhanced by land use type, land management and topography.

Deforestation and improper land use changes usually cause soil degradation (Bruum *et al.*, 2013) because of their influence on soil environment, plant nutrients and carbon cycle (Rezapour and Alipour, 2017). Topography greatly affects the spatial distribution of nutrients in soils due to its impact on erosion, runoff, infiltration and deposition processes (Li and Pan, 2020; Ritchie *et al.*, 2007). Consequently, an estimation of the geographical variability of soil

parameters is vital for environmental assessment (Inigo *et al.*, 2012), management of crop and assessment of field research studies (Ramzan *et al.*, 2017).

Map preparation using spatial interpolation of soil parameters based on point measurements with geostatistics is a well-developed technique which has been useful in categorizing the spatial variability of soil properties (Liu *et al.*, 2006). The data is critical for assessing nutrient behavior in soil and recommending effective techniques for increasing nutrient availability to plants. Application of blanket fertilizer constitutes one of the ways of managing land inappropriately in

\*Corresponding Author Email: [ookonokhua@biu.edu.ng](mailto:ookonokhua@biu.edu.ng)

\*ORCID: <https://orcid.org/0000-0003-3189-6703>

\*Tel: 0806 025 7011

Nigeria. Sustainable agriculture requires a regular evaluation of soil fertility status which is useful for proper land management practices and optimum crop production. Site-specific crop management requires mapping of the main macronutrients (Mazur *et al.*, 2022) and evaluation of soil pH for the optimization of soil fertilization and liming. Consequently, there is need to assess the spatial variability of such nutrients so as to identify and delineate critical zones that are deficient of nutrients. Therefore, the objectives of this paper were to evaluate the influence of climate, landscape position and land management on the variability of soil chemical properties and fertility status of an undulating farmland at Okha, near Benin City.

## MATERIALS AND METHODS

**Study Area:** The study was carried out in May, 2022 during the rainy season within the Teaching and Research Farm (06° 11'48" to 06° 11'44" N latitude and 05° 39'13" to 05° 39'17" E longitude), Faculty of Agricultural Technology, Benson Idahosa University, Okha. A gently sloping fallow undulating site measuring 120 x 90 m<sup>2</sup> (1.08 ha) dominated mainly with Guinea grass was delineated from the farm which had been cultivated with cassava, watermelon and avocado seedlings over a year ago. The humid tropical climate of this area in Edo State consists of the rainy season (April to October) with a two-week break in

August and a dry season (November to February). Generally, about 2,025 mm of rain falls yearly with mean temperatures of 25°C - 28°C. The class of soils is the very weathered and leached dominated sands and clayey sands called ultisols.

**Soil Sampling and Analysis:** Twelve (12) soil samples were obtained from a depth of 0 - 20 cm within in a systematic grid design specified at a fixed distance of 30 x 30 m<sup>2</sup> using Arc GIS across the delineated site (Figure 1a) with undulating topography (Figure 1b). The samples were air-dried, mixed separately and ground to pass through 2mm sieve, before analysis. Particle size distribution was assessed by the hydrometer method of Bouyoucus as modified by Day (1965). Determination of the soil pH was carried out by a pH meter in a 1:2 soil/water ratio, soil organic C by the Walkley and Black method as outlined by Nelson and Sommers (1996), total N content by the Kjeldahl procedure (McGill and Figueiredo, 1993), and available P were measured using the method of Bray and Kurtz (1945). Assessment of the exchangeable base (EB) was determined by the ammonium acetate extracts; the EDTA titrimetric method was used to measure the concentrations of Ca and Mg while a flame photometer was used to analyze Na and K. The KCl extraction method was used to measure the exchangeable acidity (EA, H<sup>+</sup> and Al<sup>3+</sup>) as described by McLean (1965) and the total EB and EA were added to obtain the effective CEC (ECEC).

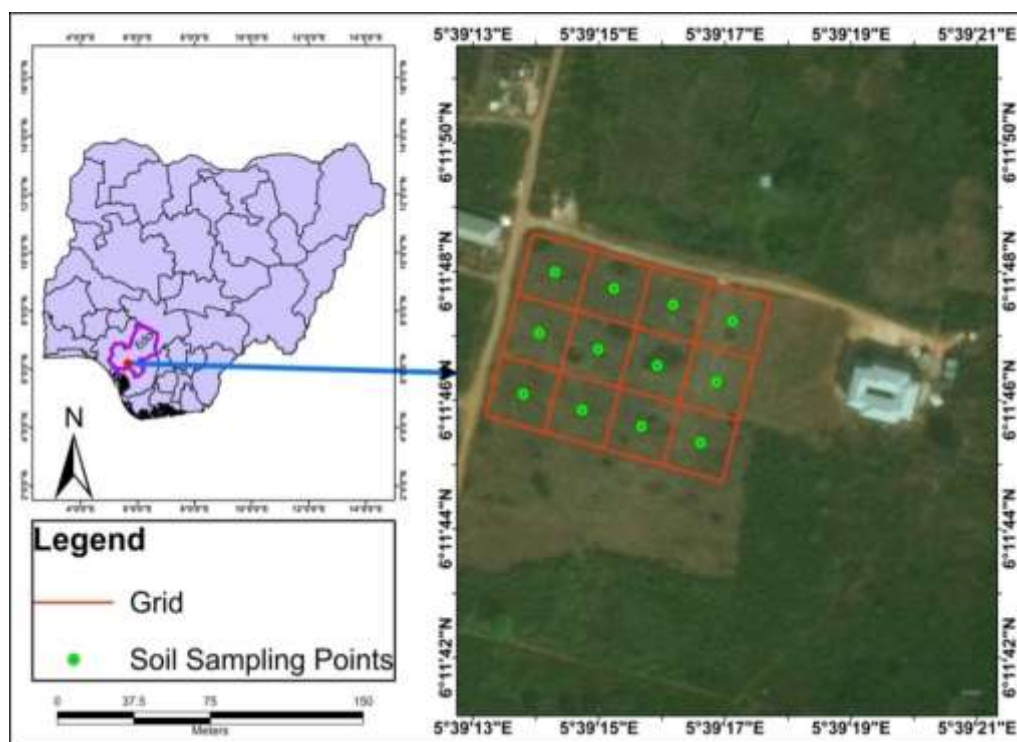


Fig 1a: Location of sampling points and the study area



**Fig 1b:** Topography of the study site

*Exploratory Statistical Analysis:* Descriptive statistics of mean, min and max values, standard deviation, coefficient of variation (CV), skewness and kurtosis were processed using SPSS 20.0 (2011). Pearson's correlation between the soil properties was computed with significance at 1% and 5% levels.

*Geostatistical Analysis:* Maps of spatial variability were carried out by a geostatistical method called Arc GIS 10.2 which applied variograms to measure the distribution of the sampled locations in space and the parameters necessary for kriging of the of the areas that were unsampled.

## RESULTS AND DISCUSSION

Results of the descriptive statistics of the soil properties are shown in Table 1. The site with high proportion of sand was sandy loam and the distribution for skewness and kurtosis were substantially skewed

for the entire measured properties being  $>$  or  $< \pm 1$  (Hair *et al.*, 2017). The extent of spatial variability of the properties was assessed with the coefficients of variability (CV) based on the guideline of Warrick (1998) who classified  $<15\%$  as low, 15-50% as medium and  $>50\%$  as high. The results revealed that CV was low for sand (3.84%) and clay (14.56 %) but moderate for silt (40%). The greatest variation was P (64.37%) which was high while the least was rated low for soil pH (3.84%). Similar observations for P and soil pH in this regard have been reported by Ramzan *et al.* (2017). Soil organic C, N, K, and ECEC all exhibited medium variation (15-50%). Medium variation in organic C which can be referred to as a stable parameter, like soil pH, have been associated with to pedogenic processes influenced by micro-topography as suggested by Vasu *et al.* (2017). The minimum and maximum values measured soil parameters are depicted in Figures 2 – 7 of their spatial variability.

**Table 1:** Descriptive statistics for the measured soil parameters

Parameters	Min	Max	Mean	Std. Deviation	CV (%)	Skewness	Kurtosis
Sand	750	850	805	30.9	3.84	-0.74	0.06
Silt	20	100	50	20	40.00	1.31	3.02
Clay	110	190	145	21.11	14.56	0.59	0.89
pH	4.86	6.06	5.46	0.34	6.29	0.00	-0.12
Org. C (g/kg)	6.74	14.85	9.64	2.35	24.41	1.04	0.80
N (g/kg)	0.48	1.05	0.68	0.17	24.34	1.04	0.80
P (mg/kg)	4.14	21.38	9.26	5.96	64.37	1.24	0.03
K (cmol/kg)	0.22	0.55	0.367	0.12	32.70	0.26	-1.00
ECEC cmol/kg	1.68	3.58	2.31	0.58	24.92	1.11	0.72

The variability of pH across the study site as shown in Figure 2. The northwest (4.86 – 5.19) part was very strongly acid, southeast (5.19 – 5.57) was strongly acid, northeast (5.57 - 6.06) was medium acid while the southwest was mainly strongly acid (5.37 -5.57) based on rating by Batjes *et al.* (1995). Such phenomenal can be influenced by acidic parent materials, leaching of basic cations by rainfall,

mineralization of nitrates and use of ammonium-based N fertilizers. Although the degree of variation in soil pH was low but the highest (5.75–6.06) values were about 10 times more than the lowest (4.84 – 5.19). This range is similar to that recorded for selected agricultural tropical soils of Hawaii as reported by Uchida and Hue (2000). The effect of soil pH on nutrient availability to crops is so profound that most

essential ones are available to majority of plants in the range of 6.0 to 6.5 (Goldy, 2011). Maintenance of optimum soil pH values across the field is essential for soil quality and health as well as for crop quality and yield.

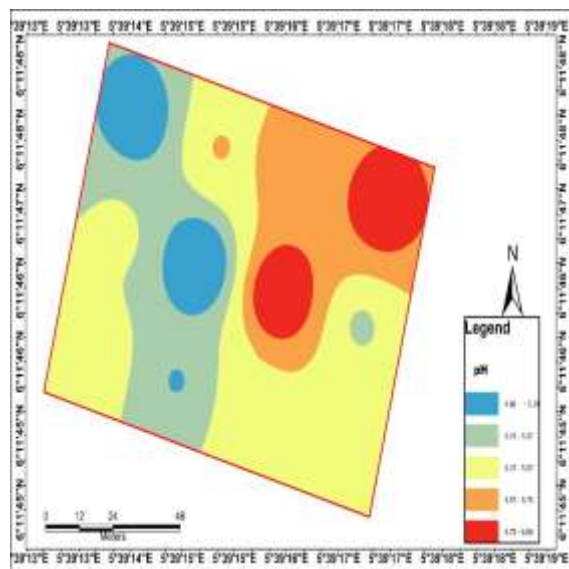


Fig 2. Spatial variability of soil pH across the study area

The spatial variability of organic C levels (Figure 3) were generally of low fertility status (6.74 – 10.91 g/kg) based on the guidelines provided by Landon (1991), with small patches of medium levels (12.39 – 14.85 g/kg) close to the middle and northwest end of the site. Organic C as well as soil pH is generally regarded as a stable parameter (Bouma *et al.*, 1993), thus medium variability of organic C observed in this study can be ascribed to pedogenic process affected by the micro-topography operating over different periods (Switoniak, 2014). Loss of C from soil is mainly from soil organic matter decomposition, erosion and leaching (Akala and Lal, 2000) aided by heavy rainfall in the tropics.

All parts of the delineated site were occupied with low levels of N in the range of 0.48 – 1.05 g/kg (Figure 4). The impact of rainfall along with the position of landscape caused the accumulation of N around the middle of the study site where the landscape is depressed with a concave shape. Nitrate, among nutrient anions, is very mobile in soil because it is leached easily due to its trivial interaction with the topsoils (Lehman and Schroth, 2003; Vinther *et al.*, 2005). Similar spatial distribution of total N and organic C observed in this present study have also been reported by Zhang *et al.* (2020) as well as Lelago and Buraka (2019) stated that organic C is essential for making N available and a precursor to organic matter

which is useful for maintaining soil structure and binding the nutrient element (Ye *et al.*, 2021).

Low (< 15 mg/kg) concentrations of available P were distributed across the field (Figure 5), with isolated patches of the medium concentrations (> 15 mg/kg) in the northeast (16.04 -21.38), southwest and middle (16.04 -21.38) parts of the site (Figure 4). Deficiency of P has been linked to transportation through erosion while being attached to sediments and its fixation to acidic soil pH (Alewell, 2020; Bakhshandeh *et al.*, 2014) which is much more pronounced in P-deficient parent material.

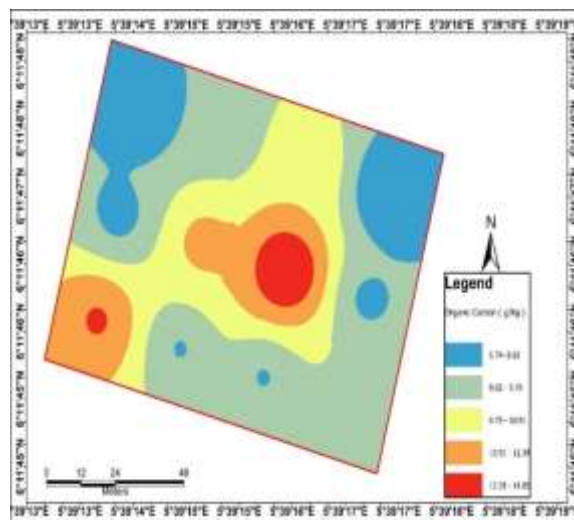


Fig 3. Spatial variability of organic C across the study area

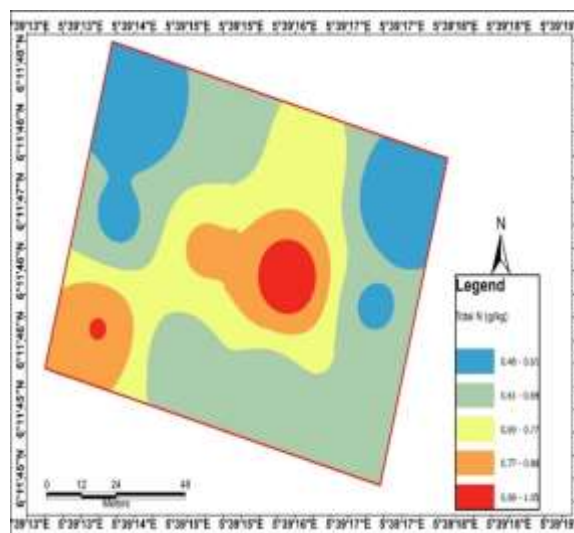


Fig 4. Spatial variability of N across the study area

Distribution of K across the study site at various concentrations were all very low (< 2 cmol/kg) as displayed (Figure 6) with high values occurring close to part of the southwest boundary. The status of K have

been reported to be deficient in many Nigeria soils (Taiwo *et al.*, 2009) as observed in this present study. Meanwhile, among the forms of K in soils, the water soluble and exchangeable forms of K which are readily available to plants consist of only 1-2% of the total while the fixed part bonded within soil minerals is about 98% (Brady and Weil, 2002).

*al.* 2014) due to weathering of primary minerals, as well as dissolution and leaching of nutrients e.g. Ca and Mg. Concentration of nutrients in topsoils suggest considerable quantities are worn away by wind and water (Guo and Gifford, 2002; Lal, 2019) causing them to be transported and accumulated from upper slope to lower and depressed parts of the landscape (Li and Pan, 2020).

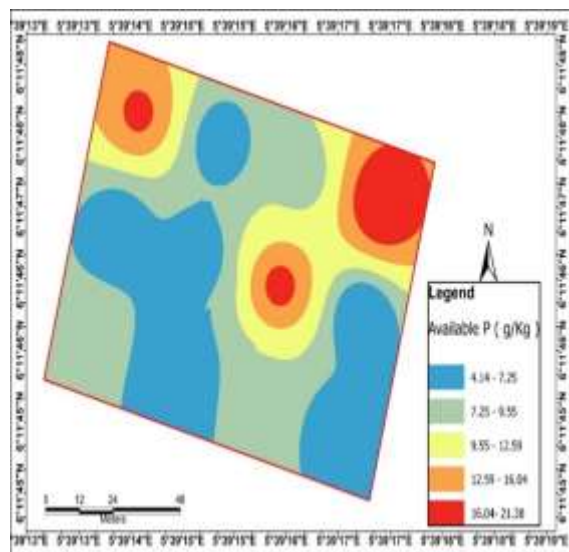


Fig 5. Spatial variability of available P across the study area

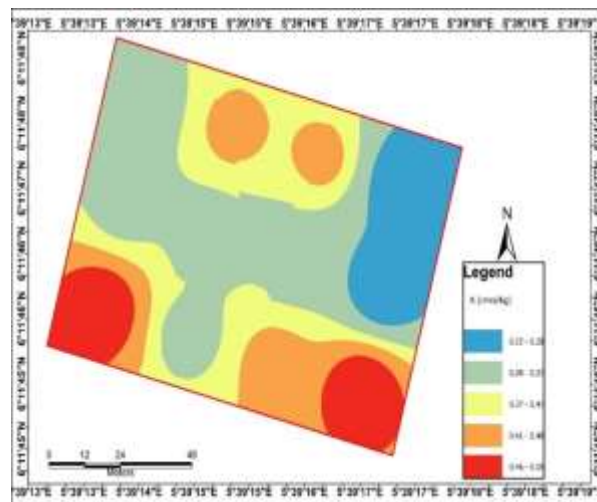


Fig 6: Spatial variability of K across the study area

Variations in concentrations (cmol/kg) of ECEC across the site (Figure 7) were all low based on the rating by Landon (1991). The least range (1.68 – 2.14) surrounded the site while the highest (2.96 – 3.50) were in the depressed and concave parts. This implies the effect of rainfall and topography on the accumulation of the basic cations (Ca, Mg, K), on such sites. However, lack of highest concentrations of K around the concave part of the site can be explained by Lehmann and Schroth (2003) who reported the most likely leached cations in most soils to be Mg and Ca.

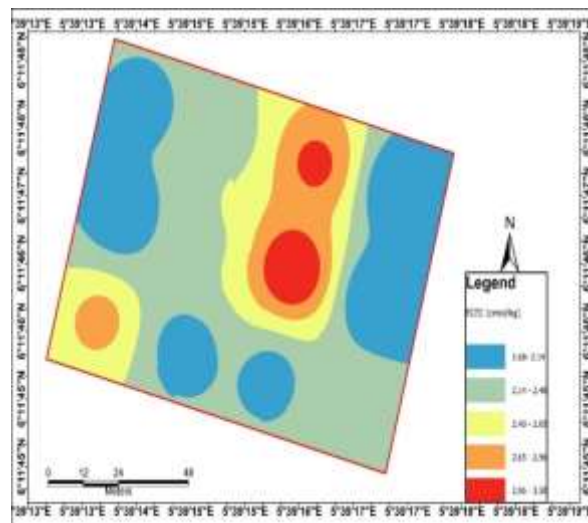


Fig 6: Spatial variability of ECEC across the study area

Pearson’s correlation coefficient was used to assess the relationship among the soil properties (Table 2). There were very strong significant negative correlations of sand with silt ( $r = -.736$ ;  $P < 0.01$ ), clay ( $-.767$ ;  $P < 0.01$ ) and ECEC ( $-.826$ ;  $P < 0.01$ ). Strong significant positive correlations for silt with organic C ( $r = .922$ ;  $P < 0.01$ ), N ( $r = .922$ ;  $P < 0.01$ ), and ECEC ( $r = .852$ ;  $P < 0.01$ ) were observed. There were very strong significant positive correlations between organic C and N ( $r = 1.000$ ;  $P < 0.01$ ), organic C and ECEC ( $r = 0.898$ ;  $P < 0.01$ ), as well as between N and ECEC ( $r=0.896$ ;  $P < 0.01$ ). Correlation between C and N has also been observed to be significantly positive by authors that include Ye *et al.* (2021) and Zhang *et al.* (2022). Ultisols have the problems of acidity, low organic C, macronutrients and available P (Fitriatin *et*

The spatial variability and nutrient status of this delineated part of farmland can be attributed to topography (steepness, landscape position and surface shape), land use and environmental factors. This supports Zhang *et al.* (2022) who reported that quite a number of studies about agricultural ecosystems in many regions have revealed the spatial distribution of organic C and total N to be controlled by combinations of the climate, topography, soil type, fertilization practices, cropping system and tillage method.

**Table 2:** Correlation coefficient among soil chemical properties of the site

	Sand	Silt	Clay	pH	C	N	P	K	ECEC
Sand	1								
Silt	-.736**	1							
Clay	-.767**	0.129	1						
pH	-0.226	0.508	-0.15	1					
C	-.828**	.922**	0.339	0.313	1				
N	-.826**	.922**	0.336	0.317	1.000**	1			
P	-0.023	0.12	-0.08	0.464	-0.001	-0.001	1		
K	-0.34	0.228	0.281	0.032	0.367	0.367	-0.348	1	
ECEC	-.939**	.852**	0.568	0.458	.898**	.896**	0.173	0.429	1

\*\*Correlation is significant at 0.01 level; \*Correlation is significant at 0.05 level

**Conclusions:** The study showed that topography and land management can have a considerable influence on the variation of soil chemical properties. Variability of soil pH was low, soil organic C, N, P, K, and ECEC were medium while available P was high across the site. Map of the site showed very strongly, strongly and medium acid ratings of soil pH while the measured soil nutrient indicators were low, besides K which was very low. Highest levels of organic C, N, and ECEC occupied the concave part of the farm. Assessment of spatial variability of soil chemical properties proved useful towards enhancement of site-specific nutrient management.

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