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Variability in Soil Physicochemical Properties along a Grid in Ifite-Ogwari, Southeast Nigeria

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Abstract

This study examined the physicochemical properties of soils along a grid in Ifite-Ogwari, Ayamelum Local Government Area of Anambra State to identify variability in soil parameters and determine soil quality along the grid. Three topographic positions were identified, namely: the lower, middle, and upper slopes. Soil samples were collected from each topographic position along the grid. A total of eighteen (18) disturbed samples were collected at 0-15 cm and 15-30 cm depths and nine undisturbed samples from the nine different positions along the grid. The samples were analyzed using standard analytical procedures. Parr's Soil Quality Evaluation/Ranking Index was used to estimate soil quality. The results showed that the soil texture was clay loam. Sand and clay content, as well as bulk density and hydraulic conductivity, showed significant differences along the grid but not within the depths. The soil was slightly acidic. It was observed that soil nutrient levels and quality varied across the different topographic positions. While there were no variations in soil physical properties between depths, a few chemical parameters did vary with depth. The soil quality index by Parr indicated that soils at the lower slope were more fertile and productive, followed by the middle slope, while the upper slope was the least fertile. The implication is that crops planted at the lower and middle slopes will perform better than those planted at the upper slope due to variations in nutrient availability. Farmers are therefore advised to apply more manure and crop residues, as well as adopt more sustainable management techniques at the upper slope positions to enhance soil fertility and improve crop production.

Keywords: Variability, Grid, Soil Quality, Topographic positions, Parr's Soil Quality Index

Introduction

Soil is a living medium that exhibits remarkable variability in size, function, properties, and composition. This diversity and variation are evident across the earth's surface. Soil fertility, one of the key indicators of soil quality, is a primary factor influencing agricultural production, especially in tropical regions. Scientists face numerous challenges in developing sustainable crop production management systems (Bakhsh et al., 2000), making the assessment of soil physicochemical variability crucial for designing effective crop management strategies (Mamun et al., 2015). Agricultural sustainability requires periodic evaluation of soil fertility (Chimdi et al., 2012). The spatial variability of soil encompasses variations in chemical, physical, and biological properties at a given location, with significant differences often occurring even within short distances for the same soil type (Li et al., 2012). The high degree of spatial variability in soils is attributed to a combination of physical, chemical, and biological processes occurring at different intensities and scales. The soil's capacity to produce food, feed, and fiber largely depends on its physical, chemical, and biological characteristics.

Several studies have highlighted how environmental factors significantly influence the variability of soil properties along a grid (Abdulwahab et al., 2019), and extensive research has been conducted on variations in soil physical and chemical properties (Brady and Weil, 2007; Omotade and Alatise, 2017; Abdulwahab et al., 2022). Factors such as parent material, topography, climate, vegetation, time, and human activities, particularly in agro-ecologically sensitive highland zones, contribute to soil variability. Topography, in particular, plays a crucial role in shaping the landscape, with slope position, aspect, and gradient directly influencing soil properties. These topographic factors affect local and regional climatic conditions, including rainfall, temperature, humidity, and evapotranspiration, which in turn impact soil properties and plant growth processes essential to ecosystem function. Soil properties continuously change over time and space (Rogerio et al., 2006), and their heterogeneity can occur at both large (regional) and small (community) scales, even within the same soil type (Du Feng et al., 2008). Understanding the spatial variation of physicochemical properties is vital for effective soil management and the development of appropriate agricultural practices. Monitoring and quantifying variations in soil properties are essential for assessing the impacts of land use and management systems on soil health. Evaluating land management practices requires knowledge of soil spatial variability and an understanding of the relationships among different soil properties. Spatial variability allows for the prediction or estimation of values at unsampled locations within a region (Xuewen et al., 2001) and provides the foundation for defining distinct management zones in a field.

The study area, characterized by rolling topography, likely influences soil properties as one move from upper to lower slopes. It is essential to understand the dynamics and distribution of soil properties for sustainable soil utilization. A key feature of soil variability is the difference in soil properties at various depths. Due to the absence of previous studies in this area, it is difficult to assess the nutrient profile of the land and recommend appropriate management practices to farmers. This research, therefore, aims to determine the variability of physicochemical properties of soils along a grid at the Faculty of Agriculture research farm, Ifite Ogwari annex, Anambra State.

Materials and Methods

The study was conducted at the Faculty of Agriculture, Ifite Ogwari campus of Nnamdi Azikiwe University, located in Ayamelum Local Government Area (LGA), Anambra State. Ifite Ogwari is situated 45 kilometers from Awka, the capital of Anambra State, and features an undulating topography. The study area lies at coordinates latitude 06° 60' N and longitude 6° 95' E. False Bedded Sandstone was the predominant parent material. The region experiences two distinct climatic seasons: the rainy season, which spans from March to October (with annual rainfall ranging from 1,700 to 2,000 mm), and the dry season, lasting from November to February. The elevation is 91 meters above sea level, with temperatures ranging between 28 °C and 36 °C, and relative humidity levels from 63 % to 80 %. The vegetation is a secondary forest-savannah mosaic, significantly impacted by anthropogenic activities, which have reduced forest density. The soils in Ifite Ogwari are predominantly sandy, with clay and gravel accumulation in the subsurface horizon (Nnabuihe *et al,* 2023).

A reconnaissance study, including ground truthing, was conducted. A grid was established and divided into three slope positions: upper slope (Us), middle slope (Ms), and lower slope (Ls). Soil samples were collected at two depths (0-15 cm and 15-30 cm) from three different points on each slope; spaced 20 meters apart, using a soil auger and core samplers. A total of 18 disturbed soil samples and 9 undisturbed samples were collected, air-dried, passed through a 2 mm sieve (where necessary), and analyzed in the laboratory. The following parameters were analyzed using standard analytical procedures: particle size distribution (Gee and Or, 2002), bulk density (Grossman and Reinsch, 2002), saturated hydraulic conductivity (Ksat) (Topp and Dane 2002), soil pH (Thomas, 1996), organic carbon (Walkley and Black, 1945), total nitrogen (Bremner, 1996), available phosphorus (Bray and Kurtz, 1945), exchangeable bases (K^+, Ca^{2+}, Na^+, and Mg^{2+}) (Jackson, 1962), and exchangeable acidity (Al^+ and H^+) Mclean (1982). Effective cation exchange capacity (ECEC) was calculated by addition of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) and exchangeable acidity (Al^+ and H^+). Percent base saturation (% BS) was calculated by dividing total exchangeable bases (TEB) by ECEC and multiplying by 100, that is, (% $BS = TEB/ECEC \times 100 / 1$).

The collected data were subjected to analysis of variance (ANOVA) using GENSTAT 4th edition. Mean values were separated using Fisher's Least Significant Difference (FLSD) at a 5% level of significance. Additionally, soil quality along the grid was estimated using Parr's soil quality index (Parr *et al*., 1992), a scoring method where "1" was assigned to properties with sufficient amounts, "2" to properties with minimal levels, and "3" to properties with low qualities.

Results and Discussion

Soil Physical properties

The physical properties of the soil, as presented in Table 1, indicated that the texture of the soil along the grid was clay loam, a texture highly suitable for agricultural activities. Clay particles in clay loam soils enhance water and nutrient retention (Hillel, 2004). The high water-holding capacity of clay soils supports plant moisture access during drought or limited rainfall. Sand fraction values ranged from 29.07% to 44.40%, with the highest sand fraction recorded in the middle slope (Ms) and the lowest in the lower slope (Ls). This finding contradicts the reports by Gafar et al. (2004) and Nsor and Adesemuyi (2016), who suggested that sand fractions typically increase downslope due to sediment transport during erosion. A significant difference in sand fraction was observed along the grid; however, no significant difference was found between the depths (Gafar *et al*., 2004). There was no significant difference in silt content along the grid or between the two depths. Clay content ranged from 37.9 % to 42.1 %, which differs from the findings of Omotade and Alatise (2017), who reported an average clay content of 22.55%. The high clay content in the study area could be attributed to the breakdown of rocks through physical, chemical, and biological weathering, releasing clay minerals, iron, calcium, sodium, silica, magnesium, and other elements into the soil (Brady and Weil, 2007). While no significant difference in clay content was observed between the two depths, a significant difference was noted along the grid. The bulk density of the three slope positions along the grid ranged from 1.63 to 1.91 g/cm³. According to Horman et al. (2011), an ideal soil should have a bulk density of about 1.25 g/cm³; indicating that the soil under study exhibited signs of compaction. This finding aligns with the results of Omotade and Alatise (2017), who recorded an average bulk density of 1.47 g/cm³, also higher than the ideal. The lowest bulk density was observed in the lower slope (Ls), while the highest was in the middle slope (Ms). Plants typically perform best in bulk densities ranging from 1.4 to 1.6 g/cm³ for clayey and sandy soils, respectively (Miller and Donahue, 1990). A significant difference in bulk density was found along the grid, but no significant difference was observed between the depths. The higher bulk density in the middle slope may be due to agricultural practices such as tillage and the use of heavy machinery, as was observed during the sample collection. Bulk density also increased with depth, which could result from decreased pore spaces caused by compaction, excessive moisture, or clay accumulation. Compacted soils reduce pore space, limiting root growth, water infiltration, and air circulation, negatively affecting plant growth (Shaheb *et al*., 2021). The accumulation of organic matter and minerals over time can also increase soil bulk density. The saturated hydraulic conductivity (Ksat) values ranged from 0.03 to 0.06 cm/hr, with the middle slope (Ms) having the highest value. While no significant difference was observed between the depths, significant differences were noted across the grid. These findings align with those of Omotade and Alatise (2017), who recorded an average Ksat value of 0.027 cm/hr. Low Ksat values can have various implications, such as increased soil erosion, limited water infiltration, reduced nutrient movement, and decreased productivity.

Table 1: Selected Soil Physical Properties along the Grid and Depth

Location	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk Density (g/cm^3)	Ksat (cm/hr)
Lower slope	29.07	28.70	42.10	Clayey Loam	1.63	0.03
Middle slope	44.40	28.80	32.30	Clayey Loam	1.91	0.06
Upper slope	33.40	32.20	37.90	Clayey Loam	1.81	0.03
$LSD_{0.05}$	4.59	NS	8.03	-	0.09	0.01
Depth (cm)						
0 – 15	36.40	29.1	34.9	-	1.76	0.22
15 – 30	34.85	26.7	39.9	-	1.79	0.50
$LSD_{0.05}$	NS	NS	NS	-	NS	NS

Ksat = Saturated hydraulic conductivity

Soil Chemical properties

The soils on the middle slope (Ms) had higher pH levels compared to other slopes, though there was no significant difference across the grid or between depths (Table 2). The soil pH, classified as moderately acidic (5.4-5.7), aligns with findings by Osujieke et al. (2016), who reported moderate acidity along various topographic positions with mean pH values of 5.43, 5.41, and 5.50 for summit, mid-slope, and foot-slope, respectively. The moderate pH levels could be due to intense rainfall in the area, leading to extensive leaching of basic cations. Interestingly, the pH was lower in the surface soil than in the subsoil, contrasting with Jimoh *et al*. (2016) and Sadiq et al. (2021), who observed decreasing pH with depth. Moreover, the middle slope recorded the highest pH, contradicting Seifu et al. (2020), who reported higher pH in lower slope soils. Soil organic carbon (OC) levels were generally low, below 1.9 mg/kg (Sanderman *et al*., 2017), and showed no significant variation along the grid or across depths. The low OC could be attributed to human activities such as intensive farming, deforestation, and bush burning, which accelerate carbon loss (Lal, 2019). Lower OC values in the middle and upper slopes support the conclusions of Hu et al. (2019) and Pierson and Mulla (1990) that higher OC is typically found in lower slopes due to erosion transporting organic matter from upper slopes. OC levels decreased with increasing depth, is in agreement with Chude *et al*. (2011), who observed similar patterns in various physiographic positions. Aluminum (Al^{3+}) levels varied significantly along the grid and across depths, while hydrogen ion (H^+) levels showed significant variation only along the grid. The relatively low levels of aluminum (0.70-0.95 cmol/kg) and hydrogen (0.40-0.72 cmol/kg) indicated a higher soil pH, promoting nutrient availability. Low aluminum levels also alleviate aluminum toxicity, allowing plants to grow without stress (Ma *et al*., 2019). Total nitrogen (TN) was highest in the lower slope (0.138 mg/kg), with values of 0.112 mg/kg and 0.130 mg/kg in the upper slope (Us) and middle slope (Ms), respectively. Surface soils had higher nitrogen levels (0.140 mg/kg) than deeper soils (0.113 mg/kg), with significant differences along the grid but not across the depths. The low TN values could be due to continuous cultivation, crop residue removal, and bush burning (Abu and Malgwi, 2011). The higher TN in the lower slope may result from erosion transporting nitrogen-rich topsoil from the upper slope. Calcium (Ca^{2+}) levels increased along the grid, from 2.887 m/kg in the Us to 4.367 m/kg in the Ls, but decreased significantly with depth. This increase could reflect the variation in deposited materials. However, the higher Ca^{2+} levels in the lower slope contradict Oku et al. (2010), who reported low calcium levels in southeastern Nigeria soils.

Exchangeable magnesium (Mg^{2+}) levels were highest in the lower slope (2.50 cmol/kg), followed by the middle slope (2.00 cmol/kg) and upper slope (1.75 cmol/kg). These findings align with Omotade and Alatise (2017), who recorded average Mg^{2+} content of 2.56 cmol/kg). While significant differences in Mg^{2+} content were observed along the grid, there were no significant differences across depths. However, excessive magnesium could cause nutrient imbalances, affecting calcium, potassium, and manganese availability, potentially impacting plant growth. Sodium (Na^{+}) levels ranged from 0.213 to 0.218 cmol/kg, with no significant differences along the grid or across depths; corroborating Osujieke *et al*. (2017), who found similar results across physiographic positions. Potassium (K^{+}) levels ranged from 0.12 - 0.36 cmol/kg; showing no significant differences either along the grid or across depths. The higher K^{+} levels in surface soils may be linked to higher organic carbon content, which acts as a nutrient reservoir (Abba *et al*., 2016).

The effective cation exchange capacity (ECEC) was low across the grid, ranging from 6.61 - 8.95 cmol/kg; likely due to nutrient leaching. ECEC values were highest in the lower slope (8.95 cmol/kg), followed by the middle slope (7.21 cmol/kg) and the upper slope (6.61 cmol/kg). There was a significant decrease in ECEC with depth, and significant differences were observed both along the grid and across depths, possibly due to nutrient uptake by plants. These findings contrast with Abudulwahab *et al*. (2019), who reported higher ECEC values (16.35 cmol/kg) in Zaria soils, attributed to the dominance of 2:1 clay mineral. For available phosphorus (AP), significant differences were observed along the grid and across depths, with AP increasing down the slope. This contradicts the findings of Chude *et al*. (2011), who reported that AP decreased with slope and found no significant differences along physiographic positions. The lower slope (Ls) had the highest AP value (11.19 mg/kg), while the upper slope (Us) had the least (4.62 mg/kg). The higher AP in the lower slope may be attributed to the accumulation and mineralization of organic matter transported from the upper slope. Additionally, AP values decreased with depth, which aligns with Sadiq *et al*. (2021), who also reported that phosphorus concentrations decreased with increasing depth.

Base saturation was notably high, ranging from 79.25 % to 83.12 %, with significant differences observed across the grid. The lower slope recorded the highest base saturation (83.12%), while the upper slope had the least (79.25 %). According to Karuma *et al*. (2017), a base saturation of 70-80 % is ideal for optimal crop performance. The high base saturation in the study area indicates favorable soil conditions for crop production, consistent with Abudulwahab *et al*. (2022), who reported similar high base saturation levels in the soils of Gombe.

Table 2: Soil Chemical Properties along the Grid and Depth

Location	pH	OC(mg/kg^{-1})	TN(g/kg)	AP (m/kg)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	H^{+}	Al^{3+}	ECEC	BS (%)
					------------------cmol kg^{-1}--------------------							
Ls	5.7	1.51	0.138	11.19	4.37	2.50	0.21	0.32	0.72	0.88	8.95	83.12
Ms	5.7	1.42	0.130	7.21	3.30	2.00	0.22	0.33	0.40	0.95	7.21	81.15
Us	5.4	1.24	0.112	4.62	2.89	1.75	0.21	0.36	0.53	0.70	6.61	79.25
$LSD_{0.05}$	NS	NS	0.025	2.95	0.43	0.41	NS	NS	0.21	0.07	1.16	1.86
Depth (cm)												
0 - 15	5.7	1.48	0.140	9.40	3.98	2.22	0.23	0.37	0.51	0.93	8.32	81.93
15 - 30	5.7	1.42	0.113	5.98	3.04	1.94	0.20	0.31	0.58	0.07	6.87	80.41
LSD	NS	NS	NS	2.95	0.43	NS	NS	NS	NS	0.14	0.95	NS

Ls = Lower slope; Ms = Middle slope; Us = Upper slope; pH: pH in water; OC: Organic carbon; TN: Total nitrogen; ECEC: Effective cation exchange capacity; BS: Base saturation; AP: Available phosphorus; NS: Not significant.

Soil quality ranking along the grid

The soil quality ranking index results revealed that soils in the lower slope (Ls) had the best soil quality, scoring 17, followed by the middle slope (Ms) with a score of 19, and the upper slope (Us) with the lowest quality, scoring 29 (Table 3). According to Parr et al. (1992), a lower quality index indicates better soil quality. Soils in the lower slope (Ls) had higher organic matter and nutrient content, making them more fertile compared to the other slopes. This slope exhibited the highest values for total nitrogen, organic carbon, effective cation exchange capacity

(ECEC), available phosphorus, calcium, magnesium, and base saturation. In contrast, the upper slope had the lowest levels of these key nutrients and organic matter, likely due to the removal of soil particles and nutrients through erosion and runoff, which accumulated at the lower slope. The middle slope showed higher levels of aluminum, sodium, saturated hydraulic conductivity (Ksat), and bulk density, but still ranked lower in soil quality than the lower slope. The movement of water and sediments from the upper to the lower slope contributed to the higher nutrient content in the lower slope. Table 3 illustrates the soil quality index ranking based on this evaluation method, where a score of '1' is given to sufficient soil properties, '2' to minimal properties, and '3' to low-quality properties. Figure 1 visually presents the soil quality index ranking in a bar chart, highlighting the differences across the slopes.

Table 3: Soil Quality Ranking index by Parr

Parameter	Lower slope	Middle slope	Upper slope
Bulk density	1.63 (3)	1.91 (1)	1.81 (2)
pH	5.67 (2)	5.72 (1)	5.41 (3)
Organic carbon	1.51 (1)	1.42 (2)	1.24 (3)
Avail. phosphorus	11.19 (1)	7.26 (2)	4.62 (3)
Total nitrogen	0.14 (1)	0.13 (2)	0.11 (3)
Ca^{2+}	4.38 (1)	3.30 (2)	2.88 (3)
Mg^{2+}	2.50 (1)	2.00 (2)	1.76 (3)
Na^{+}	0.21 (2)	0.22 (1)	0.21 (2)
K^{+}	0.32 (3)	0.33 (2)	0.36 (1)
ECEC	8.95 (1)	7.21 (2)	6.61 (3)
Base saturation	83.12 (1)	81.15 (2)	79.25 (3)
Total/Rank	17/1	19/2	29/3

ECEC: Effective cation exchange capacity; Ca2+: Calcium ion; Mg2+: Magnesium ion; Na+: Sodium ion; K+: Potassium ion;

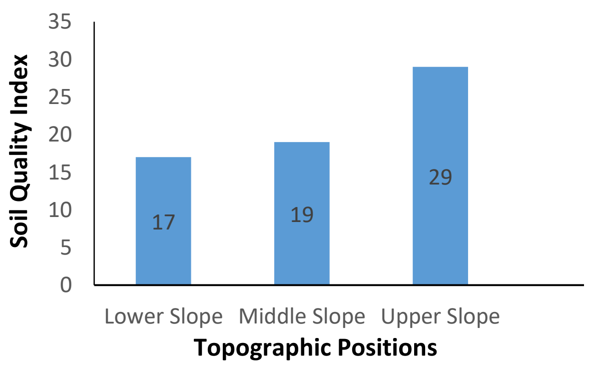

Figure 1: Variation in the soil quality index along the grid in Ifite Ogwari

Key: The lower the soil index, the better the soil quality. Category 1= lower slope, category 2: middle slope, category 3: upper slope

Conclusion

The soils in the area were clay loam, slightly compacted, moderately acidic, and generally low in organic carbon and nitrogen. The effective cation exchange capacity (ECEC) was low but increased progressively along the slope, while base saturation was high (above 70%) and also increased down the slope.

Recommendation

Improving organic matter content, soil structure, and nutrient retention, farmers in the study area should incorporate organic manure into their farming practices. Adopting sustainable farming techniques such as crop rotation, cover cropping, and mixed farming can help reduce runoff and prevent excessive leaching of nutrients down the soil profile. This approach will enhance soil fertility and promote sustainable crop production in the area.

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