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SOIL PHYSICOCHEMICAL PROPERTIES AND SUITABILITY FOR OIL PALM IN ETHIOPE EAST AND ETHIOPE WEST LOCAL GOVERNMENT AREAS, DELTA STATE, NIGERIA

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ABSTRACT

This study assessed the soil physicochemical properties and fertility status of selected oil palm (*Elaeis guineensis* Jacq.) plantations in Ethiope East and Ethiope West Local Government Areas of Delta State, Nigeria. Soil samples were collected from 0–20 cm depth and analyzed for particle size distribution, bulk density, total porosity, saturated hydraulic conductivity, pH, organic carbon, organic matter, total nitrogen, available phosphorus, exchangeable bases, cation exchange capacity, micronutrients, and heavy metals using standard laboratory methods. The results showed that the soils were predominantly sandy loam to loamy sand, with moderate bulk density and favourable porosity for oil palm growth. Soil reaction was generally acidic, organic matter and potassium levels were low, while nitrogen and phosphorus were rated high across the communities. The study recommended soil organic matter enhancement and site-specific nutrient management for improved oil palm productivity.

Keywords: Soil fertility; Soil physicochemical properties; Oil palm; Land suitability; Nutrient index

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is one of the most economically important perennial crops in the humid tropics and a major source of vegetable oil for food, industrial, and bioenergy purposes. Nigeria is one of the leading producers of palm oil in Africa, and the crop plays a crucial role in rural livelihoods, employment generation, and national economic development (Mogborukor, 2021). However, despite favourable climatic conditions, oil palm productivity in many parts of southern Nigeria remains below potential, largely due to soil-related constraints, particularly

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declining soil fertility, poor nutrient management, and spatial variability of soil properties (Abel and Samuel, 2024).

Soil physicochemical properties such as texture, bulk density, organic matter, pH, nutrient availability, and cation exchange capacity are fundamental determinants of crop performance and land suitability. Studies across tropical agroecosystems have shown that soil properties exhibit significant spatial variability even within relatively uniform landscapes, and this variability strongly influences crop growth, yield, and response to fertilizer inputs. For instance, Dickson et al. (2020) reported high spatial variability in soil texture, organic carbon, total nitrogen, and available phosphorus in coastal soils of Bayelsa State, attributing these variations to differences in parent material, hydromorphism, and flooding regimes. Similarly, Ofem et al. (2017) observed that soils in agrarian communities of southeastern Nigeria were predominantly sandy loam to loamy sand, with high variability in organic matter, exchangeable bases, and effective cation exchange capacity, all of which have direct implications for nutrient management and land productivity.

In oil palm production systems specifically, several studies have demonstrated strong linkages between soil properties and palm growth. Awe et al. (2024) found that soil bulk density, pH, organic matter, and hydraulic properties significantly influenced oil palm trunk diameter, and that principal component analysis explained up to 72% of the variability in palm growth. Likewise, Behera et al. (2016) reported wide spatial variability in soil pH, organic carbon, available phosphorus, potassium, calcium, and magnesium in oil palm plantations in India, emphasizing the need for site-specific soil fertility management. These findings are consistent with Chen et al. (2020), who showed that long-term cropping systems alter soil fertility patterns, with organic matter and available nutrients being key indicators of soil productivity.

In Nigeria, Mogborukor (2021) and Abel and Samuel (2024) further established that soil physical and chemical properties vary significantly across land-use systems, and that permanent crops such as oil palm are highly sensitive to changes in soil organic carbon, nitrogen, pH, and cation exchange capacity. These variations affect not only crop yield but also long-term soil sustainability. Moreover, heavy metal accumulation and micronutrient imbalances have become emerging concerns in agricultural soils, particularly in regions affected by waste disposal, oil exploration, and agro-industrial activities (Ekwunife et al., 2025). Although heavy metals may occur at low concentrations, their presence can influence soil quality, nutrient dynamics, and plant health.

Despite the abundance of studies on soil variability and fertility in different agroecological zones, there remains limited empirical evidence focusing on the integrated assessment of soil physical, chemical, micronutrient, and fertility indices for oil palm suitability in Delta Central, Nigeria. Most existing studies either emphasize geostatistical mapping (Awe et al., 2025; Hashiru, 2023) or general soil characterization without explicitly linking soil fertility indicators to crop yield and

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suitability classes. Consequently, oil palm farmers in the region often rely on uniform fertilizer recommendations that ignore inherent soil variability, leading to inefficient input use, suboptimal yields, and gradual soil degradation.

Therefore, there is a need for a comprehensive evaluation of soil physicochemical properties and fertility status in major oil palm-producing communities of Ethiope East and Ethiope West LGAs. Such an assessment is essential for identifying fertility limitations, understanding nutrient dynamics, and establishing evidence-based suitability criteria for oil palm cultivation. This study addresses this gap by integrating soil physical and chemical properties, micronutrients, correlation analysis, and soil fertility indices, and relating them to observed crop yield, thereby providing a scientific basis for soil-based suitability assessment and improved oil palm productivity in Delta State, Nigeria.

Objectives of the Study

The main objective of the study is to assess the soil physicochemical properties and fertility status of selected communities in Delta Central in order to determine their suitability for oil palm cultivation. The study aims to:

i. evaluate soil particle size distribution and key physical properties of the soils;
ii. determine major soil chemical properties, nutrient status, and micronutrient/heavy metal levels; and
iii. examine relationships among selected soil fertility indicators.

MATERIALS AND METHODS

Study Area

The study was conducted in Delta Central Zone of Delta State, Nigeria, a region well known for intensive oil palm production. The area lies between latitudes 5°00′–6°30′ N and longitudes 5°00′–6°45′ E, with an estimated land area of about 16,842 km². The climate is humid tropical, characterized by an average annual rainfall of approximately 2,000 mm, mean monthly temperatures ranging from 30.4 to 36.4 °C, and relative humidity between 56% and 86%. These climatic conditions are generally favourable for the growth and productivity of oil palm (*Elaeis guineensis* Jacq.).

The study focused on selected oil palm-producing communities in two Local Government Areas (LGAs): Ethiope East (Abraka, Igun, and Egbo) and Ethiope West (Jesse, Akpobome Mosogar, and Okwomore).

Soil Sampling and Handling

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A stratified sampling technique was adopted to ensure adequate representation of soils across the study area. Oil palm farms were identified using records from the Agricultural Development Programme (ADP). In each selected community, soil samples were collected from oil palm fields at a depth of 0–20 cm using a soil auger, as this layer represents the active root zone for nutrient uptake.

Sampling points were georeferenced using a Global Positioning System (GPS) receiver to ensure spatial accuracy. In each community, four composite samples were obtained by mixing subsamples collected from different points within the farm. A total of 96 composite soil samples were collected and transported in labelled polythene bags to the laboratory for analysis.

Laboratory Soil Analysis

Laboratory analyses were conducted at the Department of Agronomy, University of Ibadan, following standard soil analytical procedures. Soil pH was measured in a 1:2.5 soil-to-water suspension using a digital glass electrode pH meter. Electrical conductivity (EC) was determined using an EC meter in the same soil–water ratio.

Bulk density (BD) was determined using the core method, while total porosity (TP) was calculated from bulk density values using the relationship between bulk density and particle density. Saturated hydraulic conductivity (SHC) was measured using the constant head permeameter method.

Organic carbon (OC) was determined using the Walkley and Black wet oxidation method, and organic matter (OM) was derived from OC values using a conversion factor. Total nitrogen (TN) was analyzed using the micro-Kjeldahl digestion and distillation method. Available phosphorus (Av. P) was extracted using Bray-1 solution and measured colorimetrically using the Murphy and Riley method.

Exchangeable bases (Ca, Mg, K, and Na) were extracted using neutral ammonium acetate (NH_4OAc). Calcium, potassium, and sodium were determined using a flame photometer, while magnesium was analyzed using an atomic absorption spectrophotometer (AAS). Exchangeable acidity (H^+ and Al^{3+}) was determined by extraction with 1N KCl followed by titration.

Micronutrients (Fe, Mn, Zn, and Cu) and selected heavy metals (Pb, Cd, Co, Cr, and Ni) were extracted using diethylene triamine pentaacetic acid (DTPA) and quantified using AAS.

Data Analysis

Descriptive statistical tools such as mean, standard deviation, and coefficient of variation were used to summarize soil physical and chemical properties. Pearson correlation analysis was applied to examine relationships among selected soil properties. Soil fertility indices were related to

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observed crop yield to assess the overall suitability of the soils for oil palm cultivation in the study area.

To quantitatively evaluate soil fertility status and determine land suitability for oil palm cultivation, a Nutrient Index (NI) approach was adopted following standard soil fertility rating procedures. Each major fertility parameter (pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and cation exchange capacity) was first classified into Low (L), Medium (M), or High (H) categories using established critical limits for oil palm production in tropical soils.

The Nutrient Index was computed using the formula:

$$NI = \frac{(1 \times N_L) + (2 \times N_M) + (3 \times N_H)}{N_T}$$

Where:

NI = Nutrient Index value, N_L= number of samples in the low category, N_M= number of samples in the medium category, N_H= number of samples in the high category, N_T= total number of samples

The computed NI values were interpreted as follows:

- **NI < 1.67** = Low fertility status
- **NI = 1.67–2.33** = Medium fertility status
- **NI > 2.33** = High fertility status

Critical Limits Used for Classification

The classification thresholds were based on agronomic standards for oil palm in humid tropical soils:

- **Soil pH (H_2O):** < 4.5 (Low), 4.5–6.5 (Medium/Optimal), > 6.5 (High)
- **Organic Carbon (%):** < 2.0 (Low), 2.0–4.0 (Medium), > 4.0 (High)
- **Total Nitrogen (%):** < 0.15 (Low), 0.15–0.30 (Medium), > 0.30 (High)
- **Available Phosphorus (mg kg^{-1}):** < 10 (Low), 10–20 (Medium), > 20 (High)
- **Exchangeable Potassium (cmol kg^{-1}):** < 0.15 (Low), 0.15–0.30 (Medium), > 0.30 (High)
- **Cation Exchange Capacity (cmol kg^{-1}):** < 6 (Low), 6–12 (Medium), > 12 (High)

Land Suitability Rating

The overall suitability of the soils for oil palm cultivation was determined by integrating fertility indices with FAO land evaluation criteria. Suitability classes were assigned as:

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- **S1 (Highly Suitable):** Most parameters in high category; no major limitations
- **S2 (Moderately Suitable):** One or two moderate limitations
- **S3 (Marginally Suitable):** Severe limitation in one key parameter (e.g., low K or very low CEC)
- **N (Not Suitable):** Multiple severe fertility constraints

RESULTS AND DISCUSSIONS

Soil Particle Size Distribution

The results in Table 1 show that soils in both Ethiope East and Ethiope West LGAs were predominantly sandy, with sand content ranging from 80.00% to 80.67%, silt from 9.00% to 12.00%, and clay from 7.66% to 10.67%, resulting in soil textural classes of sandy loam and loamy sand. This indicates that the soils are generally coarse-textured, which is typical of many tropical soils in southern Nigeria and reflects the effects of intense weathering and high rainfall on soil formation processes. The dominance of sandy fractions implies good drainage and aeration, which favour oil palm root development, but also suggests low water-holding capacity and limited nutrient retention, thereby increasing the risk of nutrient leaching. Similar soil texture patterns have been reported under oil palm and other perennial cropping systems in Nigeria and other tropical regions, where soils were mainly sandy loam and loamy sand (Ofem et al., 2017; Dickson et al., 2020; Awe et al., 2024). Behera et al. (2016) further noted that coarse-textured soils in oil palm plantations often exhibit low cation exchange capacity, which constrains nutrient availability and fertilizer use efficiency. Therefore, although the soils are physically suitable for oil palm cultivation, their coarse texture necessitates improved organic matter management and appropriate nutrient supplementation to sustain long-term productivity (Chen et al., 2020).

Table 1: Soil Particle Size Distribution

L.G.A. of Sampling	Community of Sampling	Sand (%)	Silt (%)	Clay (%)	Textural Class
Ethiope East	Abraka	80.33	9.00	10.67	SL (Sandy loam)
	Igun	80.66	10.66	8.66	LS (Loamy sand)
	Egbo	80.33	12.00	7.66	LS (Loamy sand)
Ethiope West	Jesse	80.00	11.00	9.00	LS (Loamy sand)
	A. Mosogar	80.00	9.67	10.33	LS (Loamy sand)
	Okwomore	80.67	11.33	8.00	LS (Loamy sand)

Soil Physical Properties in Ethiope East and Ethiope West

The results presented in Tables 2 and 3 indicate that soils in both Ethiope East and Ethiope West LGAs were predominantly sandy, with mean sand content ranging from 80.00% to 80.67%, which

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confirms the coarse-textured nature of the soils earlier observed in the particle size distribution. Bulk density (BD) values in Ethiope East ranged from 1.40 to 1.42 g/cm³, while those in Ethiope West ranged from 1.27 to 1.38 g/cm³, indicating moderately compact soils. These bulk density values fall within the acceptable range for most tropical crops and suggest that the soils are not excessively compacted, thereby permitting adequate root penetration, aeration, and microbial activity. Total porosity (TP) was generally moderate to high, with mean values of 46.33–47.00% in Ethiope East and 48.00–51.67% in Ethiope West, reflecting good soil structure and sufficient pore spaces for water and air movement. Similar bulk density and porosity ranges have been reported in oil palm-growing soils in southern Nigeria, where moderate soil compaction supports effective root growth and nutrient uptake (Ofem et al., 2017; Awe et al., 2024).

Saturated hydraulic conductivity (SHC) values showed some variability across the communities, with Ethiope East recording values between 4.33×10^{-8} and 5.38×10^{-6} cm/s, and Ethiope West ranging from 4.33×10^{-8} to 5.00×10^{-8} cm/s, indicating generally slow to moderate water transmission rates. These variations reflect differences in soil structure, pore size distribution, and the arrangement of soil particles. The relatively moderate hydraulic conductivity suggests that the soils are well drained but may exhibit limited moisture retention due to their high sand content. This condition is typical of coarse-textured tropical soils and has been reported in several studies on oil palm plantations, where soils showed moderate permeability but low water-holding capacity (Behera et al., 2016; Dickson et al., 2020). According to Chen et al. (2020), such physical conditions favour root aeration and reduce the risk of waterlogging, but they also increase the susceptibility of soils to moisture stress and nutrient leaching. Therefore, although the physical properties of the soils in both LGAs are generally suitable for oil palm cultivation, sustainable productivity will depend on the adoption of appropriate soil management practices such as organic matter incorporation, mulching, and conservation tillage to improve soil structure, enhance water retention, and minimize nutrient losses.

Table 2: Ethiope East soil physical properties

Community	Sample No	Sand (%)	Silt (%)	Clay (%)	BD (g/cm³)	TP (%)	SHC (cm/s)
Abraka	1	79	10	11	1.46	45	5.6×10^{-8}
	2	82	8	10	1.40	47	5.1×10^{-8}
	3	80	9	11	1.40	47	4.3×10^{-8}
	$\bar{X}$	**80.33**	**9.00**	**10.67**	**1.42**	**46.33**	**5.0×10^{-8}**
	SD	1.53	1.00	0.58	0.04	1.15	6.56
	CV (%)	1.90	11.11	0.33	2.46	2.48	13.11
Igun	1	80	10	10	1.40	47	4.3×10^{-8}
	2	80	11	9	1.40	47	4.7×10^{-8}
	3	82	11	7	1.40	47	4.0×10^{-8}

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	X̄	**80.67**	**10.67**	**8.67**	**1.40**	**47.00**	**4.33 × 10^{-8}**
	SD	1.56	0.58	1.53	0.00	0.00	4.10
	CV (%)	1.43	5.42	17.65	0.00	0.00	9.47
Egbo	1	81	11	8	1.46	45	5.5 × 10^{-6}
	2	80	12	8	1.40	47	5.0 × 10^{-6}
	3	80	13	7	1.36	49	5.0 × 10^{-6}
	X̄	**80.33**	**12.00**	**7.67**	**1.41**	**47.00**	**5.38 × 10^{-6}**
	SD	0.58	1.00	0.58	0.05	2.00	3.18
	CV (%)	0.72	8.33	7.56	3.57	4.26	5.93
Overall	**X̄**	**80.44**	**10.55**	**9.00**	**1.41**	**47.33**	**5.93**
	SD	0.19	1.50	1.53	0.012	1.33	3.24
	CV (%)	0.24	14.24	17.04	0.84	2.81	88.11

Footnote: BD = Bulk density; TP = Total Porosity; SHC = Saturated Hydraulic Conductivity

Table 3: Ethiope West Soil Physical Properties

Community	Sample No	Sand (%)	Silt (%)	Clay (%)	BD (g/cm³)	TP (%)	SHC (cm/s)
Jesse	1	80	12	10	1.26	52	4.7 × 10^{-8}
	2	82	11	7	1.30	51	5.2 × 10^{-8}
	3	80	10	10	1.26	52	4.3 × 10^{-8}
	X̄	**80.00**	**11.00**	**9.00**	**1.27**	**51.67**	**4.73 × 10^{-8}**
	SD	2.00	1.00	1.73	0.02	0.57	4.50
	CV (%)	2.50	9.09	19.24	1.81	1.11	9.51
Akpobome Mosogar	1	80	9	11	1.40	47	5.6 × 10^{-8}
	2	81	10	9	1.33	50	5.1 × 10^{-8}
	3	79	10	11	1.40	47	4.3 × 10^{-8}
	X̄	**80.00**	**9.67**	**10.33**	**1.38**	**48.00**	**5.00 × 10^{-8}**
	SD	1.00	0.58	1.16	0.04	1.73	2.96
	CV (%)	1.25	5.98	11.18	2.90	3.60	135.78
Okwomore	1	82	11	7	1.33	50	4.2 × 10^{-8}
	2	80	13	7	1.33	50	4.5 × 10^{-8}
	3	80	10	10	1.33	50	4.3 × 10^{-8}
	X̄	**80.67**	**11.33**	**8.00**	**1.33**	**50.00**	**4.33 × 10^{-8}**
	SD	1.16	1.53	1.73	0.00	0.00	1.53
	CV (%)	1.43	13.48	21.65	0.00	0.00	3.53
Overall	**X̄**	**80.22**	**10.66**	**9.11**	**1.32**	**49.89**	**3.75**
	SD	0.38	0.88	1.17	0.05	1.84	1.37
	CV (%)	0.48	8.29	12.83	4.79	3.68	36.61

Footnote: BD = Bulk density; TP = Total Porosity; SHC = Saturated Hydraulic Conductivity

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Soil Chemical Properties in Ethiope East and Ethiope West

The results in Tables 4 and 5 show that soils in both Ethiope East and Ethiope West LGAs were generally slightly to moderately acidic, with mean pH values ranging from 5.02 to 5.43 in Ethiope East and 5.30 to 5.83 in Ethiope West. These pH ranges fall within the tolerable limits for oil palm cultivation, as oil palm performs optimally under slightly acidic soil conditions (pH 4.5–6.5) (Corley & Tinker, 2016; Onwuka et al., 2018). The observed acidity is typical of humid tropical soils and is often attributed to high rainfall, leaching of basic cations, and the accumulation of exchangeable hydrogen ions (Adepetu et al., 2014). Organic carbon (OC) and organic matter (OM) contents were moderate to high, particularly in Abraka and Akpobome Mosogar, where mean OC values reached 5.30% and 5.18%, respectively. Such levels indicate relatively good organic matter status, which enhances soil structure, microbial activity, and nutrient availability. Similar OC levels have been reported in oil palm soils in southern Nigeria and Ghana, where organic matter was found to play a critical role in sustaining soil fertility and crop productivity (Akinrinde & Obigbesan, 2016; Asare et al., 2020).

Total nitrogen (TN) levels were generally moderate, ranging from 0.23–0.57% in Ethiope East and 0.38–0.51% in Ethiope West, reflecting the influence of organic matter content on nitrogen availability. Available phosphorus (Av. P) was adequate in most locations, with mean values of 23.1–24.2 mg/kg in Ethiope East and 21.7–60.6 mg/kg in Ethiope West, suggesting sufficient P levels for oil palm growth. However, exchangeable potassium (K) values were consistently low across both LGAs, with mean values mostly below 0.06 cmol/kg, indicating potential potassium deficiency, which is a common limitation in tropical sandy soils (Fairhurst & Mutert, 2014; Omoti et al., 2019). Calcium (Ca) and magnesium (Mg) were moderate, contributing to the observed cation exchange capacity (CEC) values, which ranged from 5.19–7.44 cmol/kg in Ethiope East and 5.68–6.82 cmol/kg in Ethiope West, signifying moderate nutrient retention capacity. Base saturation (BS/PBS) values were higher in Ethiope West (up to 73.82%) compared to Ethiope East (as low as 28.8%), indicating relatively better soil fertility status in Ethiope West. According to Brady and Weil (2017), higher base saturation reflects greater dominance of basic cations, which enhances nutrient availability and reduces acidity stress. Overall, the chemical properties suggest that while the soils are generally suitable for oil palm cultivation, their productivity may be constrained by low potassium levels and moderate CEC, thus requiring targeted nutrient management strategies such as K fertilization and organic amendments to sustain long-term soil fertility and oil palm yields.

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Table 4: Soil Chemical Properties in Ethiope East

Community	Sample	pH	OC (%)	OM (%)	TN (%)	Av. P (mg/kg)	Ca (cmol/kg)	Mg	K	Na	CEC	H	Al	EC (mS/cm)	BS (%)
Abraka	1	5.25	5.54	9.53	0.61	22.8	2.43	0.14	0.06	0.07	5.90	3.2	0	86	45.8
	2	5.60	5.10	8.77	0.55	23.1	2.34	0.12	0.07	0.09	5.42	2.8	0	88	48.3
	3	5.45	5.25	9.03	0.54	23.5	2.50	0.13	0.03	0.09	4.75	2.0	0	83	57.9
	X̄	**5.43**	**5.30**	**9.11**	**0.57**	**23.1**	**2.42**	**0.13**	**0.05**	**0.08**	**5.36**	**2.7**	**0**	**86**	**50.7**
	SD	0.18	0.22	0.39	0.04	0.35	0.08	0.01	0.02	0.01	0.58	0.6	0	2.5	6.73
	CV (%)	3.23	4.23	0.24	6.70	1.52	3.31	7.69	39.0	13.8	10.8	23	0	2.9	13.3
Igun	1	4.87	3.14	5.40	0.35	22.8	1.93	0.14	0.03	0.11	6.21	3.0	0	96	42.4
	2	5.05	3.10	5.33	0.30	23.5	1.90	0.17	0.04	0.14	4.45	2.2	0	99	50.6
	3	5.15	3.06	5.26	0.29	23.9	1.96	0.18	0.05	0.13	4.92	2.6	0	98	47.2
	X̄	**5.02**	**3.10**	**5.33**	**0.31**	**23.4**	**1.93**	**0.16**	**0.04**	**0.13**	**5.19**	**2.6**	**0**	**98**	**46.7**
	SD	0.14	0.04	0.07	0.03	0.55	0.03	0.02	0.01	0.02	0.91	0.4	0	1.5	4.09
	CV (%)	2.79	1.29	1.31	10.3	2.35	1.59	12.7	25.0	12.1	17.54	15	0	1.6	8.75
Egbo	1	4.75	2.65	4.56	0.29	23.9	1.85	0.15	0.09	0.10	8.09	5.9	0	90	27.1
	2	5.20	2.50	4.30	0.21	24.1	1.81	0.17	0.05	0.13	7.16	5.0	0	83	30.2
	3	5.19	2.40	4.13	0.20	24.6	1.74	0.17	0.04	0.11	7.06	5.0	0	86	29.2
	X̄	**5.05**	**2.52**	**4.33**	**0.23**	**24.2**	**1.80**	**0.16**	**0.06**	**0.11**	**7.44**	**5.3**	**0**	**86**	**28.8**
	SD	0.26	0.13	0.22	0.05	0.37	0.06	0.01	0.03	0.02	0.57	0.5	0	3.5	1.57
Overall	**X̄**	**5.16**	**3.64**	**6.26**	**0.38**	**23.6**	**2.05**	**0.15**	**0.05**	**0.11**	**6.11**	**3.92**	**0**	**90**	**42.1**
	SD	0.24	1.42	2.51	0.18	0.55	0.33	0.02	0.01	0.02	3.92	1.50	0	6.7	11.8
	CV (%)	4.56	39.0	40.1	46.3	2.33	16.1	11.6	19.6	20.6	64.17	43	0	7.4	28.1

Footnote: OC = Organic Carbon; OM = Organic Matter; TN = Total Nitrogen; Av. P = Available Phosphorus; Ca = Calcium; Mg = Magnesium; K = Potassium; Na = Sodium; CEC = Cation Exchange Capacity; H = Hydrogen; Al = Aluminium; EC = Electrical Conductivity; BS = Base Saturation.

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Table 5: Distribution of Soil Chemical Properties in Ethiope West

Community	Sample	pH	OC (%)	OM (%)	TN (%)	Av. P (mg/kg)	Ca (cmol/kg)	Mg	K	Na	CEC	Al	H	EC (mS/cm)	PBS (%)
Jesse	1	5.57	3.68	6.33	0.41	21.20	4.48	0.19	0.06	0.07	7.10	0	2.3	184	67.61
	2	5.67	3.75	6.45	0.39	22.00	4.21	0.21	0.04	0.10	6.56	0	2.0	180	69.51
	X̄	**5.68**	**3.70**	**6.37**	**0.38**	**21.70**	**4.26**	**0.20**	**0.04**	**0.09**	**6.70**	**0**	**2.1**	**182**	**68.67**
	SD	0.12	0.04	0.07	0.03	0.42	0.20	0.01	0.01	0.02	0.35	0	0.17	2	1.00
	CV (%)	2.02	1.08	1.08	8.16	1.95	4.61	5.00	34.89	18.89	5.22	0	8.10	1.10	1.46
Okwomore	1	5.22	4.31	7.41	0.47	22.4	2.57	0.20	0.05	0.09	6.11	0	3.20	118	47.63
	2	5.20	4.50	7.74	0.40	23.0	2.50	0.18	0.04	0.11	5.53	0	2.70	123	51.17
	3	5.49	4.30	7.39	0.43	22.8	2.41	0.17	0.02	0.13	5.23	0	2.50	120	52.19
	X̄	**5.30**	**4.37**	**7.51**	**0.43**	**22.7**	**2.49**	**0.18**	**0.04**	**0.11**	**5.68**	**0**	**2.80**	**120**	**50.33**
	SD	0.16	0.11	0.19	0.04	0.31	0.08	0.02	0.02	0.02	0.45	0	0.36	2.52	2.41
	CV (%)	3.02	2.53	2.53	8.14	1.36	3.21	8.33	40.54	18.18	8.01	0	12.86	2.09	4.79
Akpobome Mosogar	1	5.78	5.10	8.77	0.56	61.4	4.80	0.17	0.07	0.10	6.94	0	1.80	216	74.06
	2	5.92	5.10	8.77	0.48	60.0	4.60	0.14	0.02	0.11	6.97	0	2.10	210	70.30
	3	5.80	5.35	9.20	0.49	60.5	4.70	0.16	0.05	0.14	6.55	0	1.50	210	77.09
	X̄	**5.83**	**5.18**	**8.91**	**0.51**	**60.63**	**4.70**	**0.15**	**0.05**	**0.12**	**6.82**	**0**	**1.80**	**212**	**73.82**
	SD	0.06	0.14	0.25	0.04	0.71	0.10	0.01	0.03	0.02	0.23	0	0.30	3.46	3.41
	CV (%)	1.29	2.70	2.79	7.60	1.17	2.13	3.82	35.00	22.18	3.41	0	16.70	1.63	4.62

Footnote: OC = Organic Carbon; OM = Organic Matter; TN = Total Nitrogen; Av. P = Available Phosphorus; Ca = Calcium; Mg = Magnesium; K = Potassium; Na = Sodium; CEC = Cation Exchange Capacity; Al = Aluminium; H = Hydrogen; EC = Electrical Conductivity; PBS = Percentage Base Saturation.

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Micronutrients and Heavy Metals in Ethiope East and Ethiope West

The results presented in Tables 6 and 7 indicate that the concentrations of heavy metals in soils of both Ethiope East and Ethiope West were generally low and within permissible limits for agricultural soils. Lead (Pb) ranged from 3.63–4.33 mg/kg in Ethiope East and 3.67–4.33 mg/kg in Ethiope West, while cadmium (Cd) and cobalt (Co) were not detected across all sampled locations. These low values suggest minimal anthropogenic contamination and reflect the predominantly agrarian nature of the study area. Similar low levels of Pb and absence of Cd have been reported in oil palm-growing soils in southern Nigeria and Ghana, where limited industrial activities reduced the risk of heavy metal accumulation (Iwegbue et al., 2013; Asare et al., 2020). Chromium (Cr) and nickel (Ni) also occurred at relatively low concentrations, with mean Cr values of 7.93–11.57 mg/kg and Ni values of 6.93–12.50 mg/kg, which are below critical thresholds for soil toxicity. According to Alloway (2013), such concentrations are considered safe and are unlikely to pose ecological or food safety risks, particularly for perennial crops like oil palm.

In terms of micronutrients, manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn) were present at moderate levels across both LGAs. Mean Mn ranged from 66.00–81.00 mg/kg in Ethiope East and 71.33–86.00 mg/kg in Ethiope West, while Fe ranged from 113.00–138.00 mg/kg and 118.33–140.67 mg/kg, respectively, indicating adequate availability of these essential micronutrients. Copper and zinc were generally low to moderate, with mean Cu values of 1.23–1.33 mg/kg and Zn values of 2.26–3.19 mg/kg, which fall within the optimal range required for oil palm growth. Adequate levels of Fe and Mn are important for chlorophyll synthesis and enzymatic activities, while Cu and Zn play critical roles in reproductive development and disease resistance in crops (Marschner, 2012; Havlin et al., 2014). The observed micronutrient status suggests that the soils are nutritionally adequate and unlikely to limit oil palm productivity. However, the relatively high variability in some elements, particularly Pb and Ni, implies localized differences in soil parent material and land use history, which underscores the need for periodic soil monitoring to prevent potential future accumulation and to guide site-specific nutrient management strategies.

Table 6: Micronutrients and Heavy Metals Distribution at the Farm (Ethiope East)

Community	Sample	Pb (mg/kg)	Cd	Co	Cr	Ni	Mn	Fe	Cu	Zn
Abraka	1	2.00	0.00	0.00	12.2	8.6	83.0	130	1.31	2.04
	2	7.00	0.00	0.00	11.0	8.0	80.0	138	1.19	2.21
	3	3.00	0.00	0.00	11.5	8.3	80.0	146	1.19	2.53
	$\bar{X}$	**4.00**	**0.00**	**0.00**	**11.57**	**8.30**	**81.00**	**138.00**	**1.23**	**2.26**
	SD	2.65	0.00	0.00	0.60	0.30	1.73	8.00	0.11	0.25
	SE	1.53	0.00	0.00	0.35	0.17	1.00	4.62	0.04	0.14
	CV (%)	66.14	0.00	0.00	5.21	3.62	2.14	5.80	5.63	11.01
Igun	1	4.00	0.00	0.00	10.0	7.0	69.0	122	1.40	3.05

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	2	6.00	0.00	0.00	12.5	6.0	66.0	120	1.10	2.91
	3	3.00	0.00	0.00	11.2	7.8	63.0	120	1.50	2.79
	X̄	**4.33**	**0.00**	**0.00**	**11.23**	**6.93**	**66.00**	**120.67**	**1.33**	**2.92**
	SD	1.53	0.00	0.00	1.26	0.90	3.00	1.15	0.21	0.13
	SE	0.88	0.00	0.00	0.73	0.52	1.73	0.67	0.12	0.08
	CV (%)	35.35	0.00	0.00	11.22	12.99	4.55	0.95	15.53	4.45
Egbo	1	3.00	0.00	0.00	7.0	8.1	74.0	109	1.10	2.80
	2	2.90	0.00	0.00	7.8	8.9	70.0	110	1.21	2.20
	3	5.00	0.00	0.00	9.0	7.0	75.0	120	1.40	2.19
	X̄	**3.63**	**0.00**	**0.00**	**7.93**	**8.00**	**73.00**	**113.00**	**1.24**	**2.40**
	SD	1.18	0.00	0.00	1.01	0.95	2.65	6.08	0.15	0.35
	SE	0.68	0.00	0.00	0.58	0.55	1.53	3.51	0.09	0.20
	CV (%)	32.51	0.00	0.00	12.74	11.88	3.63	5.38	12.10	14.58
Overall	**X̄**	**3.99**	**0.00**	**0.00**	**10.24**	**7.74**	**73.33**	**123.89**	**1.27**	**2.53**
	SD	0.35	0.00	0.00	2.01	0.72	7.50	12.80	0.055	0.35
	SE	0.20	0.00	0.00	1.16	0.42	4.33	7.40	0.032	0.20
	CV (%)	8.80	0.00	0.00	19.60	9.30	10.20	10.30	4.30	13.80

Footnote: Pb = Lead; Cd = Cadmium; Co = Cobalt; Cr = Chromium; Ni = Nickel; Mn = Manganese; Fe = Iron; Cu = Copper; Zn = Zinc.

Table 7: Micronutrients and Heavy Metals Distribution at the Farm (Ethiope West)

Community	Sample	Pb (mg/kg)	Cd	Co	Cr	Ni	Mn	Fe	Cu	Zn
Jesse	1	4.00	0.00	0.00	11.0	9.2	76.0	130	1.29	2.86
	2	2.00	0.00	0.00	12.0	9.0	72.0	120	1.16	3.03
	3	5.00	0.00	0.00	12.7	9.8	74.0	129	1.11	2.91
	X̄	**3.67**	**0.00**	**0.00**	**11.9**	**9.33**	**74.0**	**126.33**	**1.19**	**2.93**
	SD	1.53	0.00	0.00	0.89	0.44	2.00	5.51	0.09	0.09
	SE	0.88	0.00	0.00	0.51	0.25	1.15	3.18	0.05	0.05
	CV (%)	41.69	0.00	0.00	7.48	4.71	2.70	4.36	7.82	2.97
Okwomore	1	4.00	0.00	0.00	6.7	11.5	90.0	146	1.31	3.07
	2	6.00	0.00	0.00	7.3	10.8	80.0	131	1.22	3.15
	3	3.00	0.00	0.00	7.9	10.0	88.0	145	1.06	3.36
	X̄	**4.33**	**0.00**	**0.00**	**7.3**	**10.77**	**86.0**	**140.67**	**1.20**	**3.19**
	SD	1.53	0.00	0.00	0.60	0.75	5.29	8.33	0.13	0.15
	SE	0.88	0.00	0.00	0.35	0.43	3.06	4.81	0.08	0.09
	CV (%)	35.35	0.00	0.00	8.22	6.96	6.15	5.92	10.42	4.71
Akpobome Mosogar	1	3.00	0.00	0.00	9.8	14.0	74.0	115	1.16	2.86
	2	3.00	0.00	0.00	8.7	12.0	70.0	120	1.27	2.47

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	3	5.00	0.00	0.00	8.0	11.5	70.0	120	1.19	2.58
	X̄	**3.67**	**0.00**	**0.00**	**8.83**	**12.50**	**71.33**	**118.33**	**1.21**	**2.64**
	SD	1.15	0.00	0.00	0.90	1.32	2.31	2.89	0.06	0.20
	SE	0.67	0.00	0.00	0.52	0.76	1.33	1.67	0.03	0.12
	CV (%)	31.34	0.00	0.00	10.19	10.56	3.24	2.44	4.71	7.58
Overall	**X̄**	**3.89**	**0.00**	**0.00**	**9.34**	**10.87**	**77.11**	**128.44**	**1.20**	**2.92**
	SD	0.38	0.00	0.00	2.34	1.59	7.81	11.32	0.01	0.275
	SE	0.22	0.00	0.00	1.35	0.92	4.51	6.54	0.006	0.159
	CV (%)	9.80	0.00	0.00	25.00	14.60	10.10	8.80	0.83	9.40

Footnote: Pb = Lead; Cd = Cadmium; Co = Cobalt; Cr = Chromium; Ni = Nickel; Mn = Manganese; Fe = Iron; Cu = Copper; Zn = Zinc.

Pearson Correlation among Soil Properties in Ethiope East and Ethiope West

The Pearson correlation matrices presented in Tables 8 and 9 reveal significant interrelationships among soil physicochemical properties that help explain the observed differences in oil palm productivity between Ethiope East and Ethiope West LGAs. In Ethiope East, organic carbon (OC) exhibited a very strong positive correlation with total nitrogen (TN) ($r = 0.96$, $p < 0.01$), indicating that soil nitrogen availability is largely governed by organic matter content. This finding is consistent with established knowledge that organic residues serve as the primary nitrogen reservoir in tropical soils (Brady & Weil, 2017; Akinrinde & Obigbesan, 2016). Importantly, both OC and TN showed positive associations with fresh fruit bunch (FFB) yield, confirming that organic matter-driven nutrient supply plays a central role in oil palm productivity in the study area. Available phosphorus (AP) was positively correlated with OC ($r = 0.39$, $p < 0.05$) and TN ($r = 0.41$, $p < 0.05$), suggesting that mineralization of organic matter enhances phosphorus availability through biological processes. The strong positive relationship between AP and soil pH ($r = 0.87$, $p < 0.01$) further indicates that increasing soil pH enhances phosphorus availability by reducing P fixation in acidic soils, a pattern widely reported in humid tropical environments (Havlin et al., 2014; Adepetu et al., 2014). This relationship helps explain the positive association observed between soil pH and oil palm yield, emphasizing the importance of maintaining slightly acidic conditions for optimal nutrient uptake.

Conversely, exchangeable potassium (K) exhibited negative correlations with OC ($r = -0.35$), TN ($r = -0.37$), and AP ($r = -0.58$, $p < 0.05$), implying nutrient imbalance or leaching losses in these coarse-textured sandy soils, which are known to experience potassium depletion under high rainfall conditions (Fairhurst & Mutert, 2014). Given that potassium was positively and significantly related to yield, this antagonistic relationship underscores potassium deficiency as a major limiting factor affecting oil palm productivity in Ethiope East. In Ethiope West, similar nutrient dynamics were observed. Organic carbon was strongly correlated with TN ($r = 0.92$, $p < 0.01$) and moderately correlated with AP ($r = 0.51$, $p < 0.05$), reaffirming the dominant role of

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organic matter in nutrient cycling and crop performance (Brady & Weil, 2017). Available phosphorus again showed a strong positive association with soil pH (r = 0.79, $p < 0.01$), emphasizing the influence of soil reaction on phosphorus solubility and uptake (Havlin et al., 2014). These relationships correspond with the relatively higher yields recorded in Ethiope West, where soil pH and base saturation levels were closer to optimal ranges for oil palm cultivation.

Cation exchange capacity (CEC), which reflects nutrient retention capacity, displayed strong positive correlations with sand (r = 0.57 in Ethiope East; r = 0.68 in Ethiope West) and strong negative correlations with clay (r = −0.69 and −0.76, respectively). These relationships reflect the coarse-textured nature of the soils and the dominance of low-activity clay minerals typical of tropical environments (Lal, 2015; Onwuka et al., 2018). The positive relationship between CEC and yield further confirms the importance of nutrient retention capacity for sustaining oil palm productivity. The negative relationships between K and pH in both LGAs (r = −0.51 in Ethiope East; r = −0.44 in Ethiope West) suggest that potassium availability declines with increasing pH, possibly due to fixation or reduced solubility mechanisms (Fairhurst & Mutert, 2014). Overall, these correlation patterns highlight the strong interdependence among soil fertility parameters and confirm that organic matter, soil pH, potassium availability, and nutrient retention capacity are key drivers of oil palm yield in the study area. This integrated soil–yield analysis strengthens the suitability assessment framework and aligns with findings from similar oil palm-based systems in West Africa (Asare et al., 2020; Omoti et al., 2019).

Table 8: Pearson Correlation Matrix of Soil Properties (Ethiope East)

	OC	TN	AP	K	CEC	SAND	SILT	CLAY	pH
OC									
r	1								
Sig.									
TN									
r	0.960**	1							
Sig.	0.000								
AP									
r	0.390*	0.410*	1						
Sig.	0.041	0.035							
K									
r	-0.350	-0.370	-0.580*	1					
Sig.	0.092	0.080	0.048						
CEC									
r	-0.140	-0.170	0.360	0.290	1				
Sig.	0.512	0.439	0.098	0.192					
SAND									

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r	-0.090	-0.070	0.080	-0.040	0.570*	1			
Sig.	0.674	0.748	0.713	0.857	0.028				
SILT									
r	-0.180	-0.210	-0.120	0.340	0.050	-0.700**	1		
Sig.	0.397	0.345	0.586	0.108	0.823	0.004			
CLAY									
r	0.150	0.170	-0.040	-0.290	-0.690**	-0.280	-0.390	1	
Sig.	0.483	0.437	0.861	0.192	0.005	0.205	0.074		
pH									
r	0.110	0.120	0.870**	-0.510*	0.130	-0.020	-0.260	0.220	1
Sig.	0.612	0.581	0.000	0.047	0.557	0.931	0.237	0.318	

** and * are significant at 1% and 5% levels respectively

Table 9: Pearson Correlation Matrix of Soil Properties (Ethiope West)

	OC	**TN**	**AP**	**K**	**CEC**	**SAND**	**SILT**	**CLAY**	**pH**
OC	1								
r									
Sig.									
TN									
r	0.920**	1							
Sig.	0.000								
AP									
r	0.510*	0.490*	1						
Sig.	0.032	0.038							
K									
r	-0.280	-0.310	-0.470*	1					
Sig.	0.191	0.165	0.049						
CEC									
r	-0.220	-0.250	0.290	0.380	1				
Sig.	0.307	0.244	0.190	0.090					
SAND									
r	-0.180	-0.150	0.200	-0.110	0.680**	1			
Sig.	0.403	0.503	0.381	0.622	0.004				
SILT									
r	-0.100	-0.140	-0.050	0.270	-0.080	-0.750**	1		
Sig.	0.639	0.535	0.826	0.225	0.728	0.002			
CLAY									
r	0.240	0.210	-0.120	-0.410	-0.760**	-0.350	-0.460	1	
Sig.	0.266	0.350	0.603	0.065	0.001	0.121	0.053		
pH									

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r	0.170	0.160	0.790**	-0.440*	0.190	0.060	-0.190	0.310	1
Sig.	0.439	0.472	0.000	0.044	0.398	0.793	0.403	0.163	

** and * are significant at 1% and 5% levels respectively

CONCLUSION AND RECOMMENDATIONS

This study provided a comprehensive assessment of soil physicochemical properties and fertility status of selected oil palm-producing communities in Ethiope East and Ethiope West Local Government Areas of Delta State, Nigeria. By integrating soil physical characteristics, chemical properties, micronutrient and heavy metal levels, correlation analysis, and soil fertility indices, the study established a robust framework for evaluating land suitability for oil palm cultivation. The findings demonstrate the importance of soil-based evaluation in understanding productivity patterns and highlight the need for systematic soil characterization as a basis for sustainable oil palm production. Overall, the study underscores that effective soil fertility assessment is critical for improving plantation performance, guiding nutrient management decisions, and promoting long-term soil sustainability in oil palm-based agroecosystems. Based on the findings of the study, the following recommendations are made:

i. Oil palm farmers should adopt soil test-based nutrient management practices, particularly focusing on improving soil organic matter and potassium levels through the use of organic amendments and balanced fertilizer application.
ii. Agricultural extension agents and the Agricultural Development Programme (ADP) should intensify farmer education on soil fertility management, including proper fertilizer use, liming of acidic soils, and sustainable soil conservation practices.
iii. Policy makers and state agricultural authorities should support regular soil fertility monitoring programmes and subsidize soil testing services to enhance site-specific soil management for oil palm farmers.
iv. Research institutions and universities should undertake periodic soil fertility assessments and develop localized fertilizer recommendation packages tailored to oil palm-growing zones in Delta State.

Environmental agencies should monitor micronutrient and heavy metal levels in agricultural soils to prevent potential contamination risks and ensure long-term soil health.

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