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Soil Fertility Management Strategies for Sustainable Crop Production at Ifite Ogwari, Southeastern Nigeria

***Nnabuihe, E. C[1], Okafor, M.J[1], Nwosu, T.V[1], Ugochukwu, G.U[4],Onunwa, A.O[1], Apalowo, O.A[3], Ibigweh, M. N[1], Nwaiwu, C. J[1],Anarah, S. E[5], Steve-Obi, C. E[1], Madueke, C.O[2]**

[1]Department of Soil Science and Land Resources Management, Nnamdi Azikiwe University Awka Anambra state Nigeria.

[2]Institute of Soil Science and Land Evaluation, University of Hohenheim, Stuttgart, Germany

[3]Department of Crop Science and Horticulture, Nnamdi Azikiwe University Awka Anambra state Nigeria.

[4]Department of Bioenvironmental Science, Morgan State University Baltimore MD, U.S.A

[5]Department of Agricultural Economics and Extension, Nnamdi Azikiwe University Awka Anambra state Nigeria.

**Corresponding author: Nnabuihe, E. C*

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ABSTRACT **Original research paper**

Sustainable agricultural production in southeastern Nigeria is hindered by declining soil fertility, where continuous cultivation and poor management have intensified nutrient depletion. This study evaluated soil fertility under arable, pasture, and forest land uses at the Ifite Ogwari Campus of Nnamdi Azikiwe University (06°60′14″N, 06°95′02″E) to identify key constraints and propose management options. A transect method was employed, and three representative soil profiles were dug across the land uses, from which twelve samples were collected along genetic horizons and analyzed for physical and chemical properties. Results revealed that soils were predominantly sandy loam (SL) to loam (L) in arable and pasture lands, and sandy loam (SL) to loamy sand (LS) in forest land use. Bulk density (1.30-1.55 Mg m^{-3}) and porosity (41.5-50.9%) suggested favorable structure, but wide spatial variability was recorded for organic carbon (OC), total nitrogen (TN), and clay (CV >30%). The soils were strongly acidic (pH 4.9-5.6), with low organic carbon (<4.5 g kg^{-1}), total nitrogen (<0.4%), and critically deficient available phosphorus (<3 mg kg^{-1}). Exchangeable Ca^{2+} and Mg^{2+} were also below critical levels. Correlation heatmaps showed strong positive associations between OC and TN ($r \approx 0.99$) and between Ca2+ and total exchangeable bases ($r \approx 0.98$), with BD and TP inversely related ($r \approx -0.99$). These findings identify soil acidity, organic matter decline, and phosphorus deficiency as the dominant fertility constraints. Recommended strategies include integrated use of organic amendments, liming, and phosphorus fertilization to restore soil productivity and support sustainable intensification in southeastern Nigeria.

Keywords: Soil fertility, Nutrient constraints, Sustainable crop production, Ultisols, Land use management.

Introduction

Declining soil fertility is a major constraint to agricultural productivity in Sub-Saharan Africa, where nutrient depletion surpasses replenishment due to continuous cultivation, erosion, and poor management practices (Lal, 2015; Sanchez, 2019). In southeastern Nigeria, increasing population pressure and the expansion of farming into marginal lands have accelerated soil degradation, leading to reduced crop yields and weakened resilience to climate variability (Nnabuihe*et al*., 2025).

Integrated soil fertility management has been widely promoted as a sustainable pathway, but its effectiveness requires site-specific knowledge of soil properties and constraints (Mugwe*et al*., 2019). Such understanding is critical for developing strategies to ensure sustainable crop production and food security in the region (Mrabet, 2023).

Although previous studies have characterized Ultisols in southeastern Nigeria (Ezeaku *et* al., 2015; Madueke *et al*., 2020, 2021; Nnabuihe *et al*., 2023, 2024; Udofia *et al*., 2024), limited attention has been given to fertility dynamics in Ifite Ogwari, Ayamelum L.G.A. This area serves as an important agricultural hub, supporting crops like rice, maize, and pigeon pea, along with pasture grasses and forestry plantations. Despite its significance for regional food supply, systematic soil fertility evaluations across its diverse land uses remain scarce (Nnabuihe *et al*., 2023). This knowledge gap hampers the development of site-specific soil fertility interventions necessary for sustainable intensification. The present study aimed to: assess the physical and chemical fertility status of soils under arable, pasture, and forest land uses in Ifite Ogwari. Identify key nutrient and structural constraints limiting productivity. Recommend sustainable soil management practices to enhance crop production in southeastern Nigeria.

Materials and Methods

Study Area

The study was conducted at the Ifite Ogwari Campus of Nnamdi Azikiwe University, southeastern Nigeria (06°60′14″N, 06°95′02″E; 42 m above sea level). The climate is tropical wet-and-dry (Köppen Aw), with mean annual rainfall of 1,700 mm and average temperature of 29°C (NIMET, 2024). Vegetation is a secondary forest–savannah mosaic (Igbozuruike, 1975). The underlying geology comprises Lower Coal Measures, False-Bedded Sandstone, and Imo Clay Shales (Orajaka, 1975).

Field Sampling

Three land use types were selected: Arable land: rice–maize–pigeon pea rotation. Pasture land: dominated by *Pennisetum purpureum* (elephant grass) and *Panicum maximum* (guinea grass). Forested land: plantations of *Gmelina arborea*, *Tectona grandis*, and *Melicia excelsa*. Transects were cut across use types, and three representative soil profiles were dug following FAO (2006) guidelines.A total of 12 soil samples were collected along genetic horizons and composited for laboratory analysis.

Laboratory Analyses

Standard procedures were used to determine soil properties. Physical properties: particle size distribution by hydrometer method (Gee & or, 2002); bulk density by core (Grossman & Reinsch, 2002); gravimetric moisture content by oven-dry (Obi, 1990); saturated hydraulic conductivity by constant head permeameter (Topp and Dane, 2002). Chemical properties: soil pH in 1:2.5 soil–water suspension (Thomas, 1996); organic carbon by Walkley–Black wet oxidation (Nelson & Sommers, 1982); total nitrogen by micro Kjeldahl (Bremner, 1996); available phosphorus by Bray I extraction method (Bray & Kurtz, 1945); exchangeable bases using 1N ammonium acetate (Jackson, 1962); cation exchange capacity (CEC) by ammonium acetate method at pH 7 (Blakemore *et al*., 1987).

Data Analysis

Descriptive statistics, including mean, standard deviation, and range, along with the coefficient of variation, were computed to evaluate variability in soil properties (Wilding *et al*., 1994). This analysis provided insights into the distribution and variability of key soil characteristics. Pearson correlation analysis was employed to assess relationships among soil physical and chemical parameters, allowing for the identification of significant correlations that could inform management practices. Data visualization was performed using R software (version 4.3.0), which included the creation of bar charts, scatter plots, radar charts, and correlation heatmaps. These visual tools facilitated a clearer understanding of the data and highlighted important trends and relationships among soil properties.

Results and Discussion

Soil Physical Properties and Implications for Fertility

Soil texture varied across land uses in Ifite Ogwari (Table 1). Arable soils were predominantly sandy loam, with a mean composition of 61.1% sand, 22.7% silt, and 16.2% clay. In contrast, pasture soils contained higher silt (29.6%) and clay (17.3%), while forest soils were more sand-dominated (65.4%) (Figure 1). The sandy loam (SL) to loam (L) textures generally provides moderate water-holding capacity; however, the high sand fraction in forest soils indicates greater susceptibility to nutrient leaching. Boxplots (Figure 2) exhibited wider variability in silt and clay fractions, particularly in pasture and forest soils, consistent with selective erosion of fine particles due to cultivation and grazing (Debele, 2025).

Bulk density ranged from 1.30 to 1.55 Mg m^{-3}, with an average of 1.43 Mg m^{-3} in arable and pasture soils, and 1.44 Mg m^{-3} in forest soils (Table 1). These values were very close to the root-restrictive threshold of 1.50 Mg m^{-3}, indicating potential compaction risks under continuous cultivation (Vepraskas, 1988). Total porosity (41–51%) was inversely related to bulk density, with lower porosity in arable soils reflecting structural degradation (Figure 3). Saturated hydraulic conductivity (Ksat) was highest in pasture soils (0.94 cm hr^{-1}) and lowest in arable soils (0.78 cm hr^{-1}), suggesting that grass cover enhances soil aggregation and permeability (Kumar, 2009). Radar charts (Figure 4) further highlighted land-use contrasts, revealing that forest soils exhibited high sand dominance and, consequently, greater leaching potential.

The coefficient of variation (CV) indicated high heterogeneity in key soil properties. Arable soils showed high variability in clay (53.4%) and moderate variability in bulk density (18.6%) and Ksat (18.7%). Pasture soils exhibited moderate variability in sand (24.4%) and high variability in clay (50.1%), while forest soils demonstrated high variability in silt (35.6%) and clay (39.6%). This heterogeneity, influenced by land use, complicates uniform nutrient and water management, a pattern consistent with findings in other Ultisols across southeastern Nigeria (Ezeaku, 2013; Okebalama *et al.*, 2017; Uzo *et al.*, 2020; Igu*et al.*, 2023).

Soil Chemical Properties and Nutrient Constraints

The soils atIfite Ogwari were moderately acidic, with pH values ranging from 4.9 to 5.6, which is typical for Ultisols in southeastern Nigeria (Table 2) (Madueke *et al.*, 2021; Nnabuihe *et al.*, 2023, Igu *et al.*, 2023). Organic carbon (OC) was highest in arable soils (3.55 g kg^{-1}), intermediate in forest soils (3.00 g kg^{-1}), and lowest in pasture soils (2.43 g kg^{-1}). Total nitrogen (TN) levels were consistently low across all land uses, with the highest mean value found in arable soils (0.29%) and the lowest in pasture soils (0.19%). Available phosphorus (AP) was critically deficient (<3 mg kg^{-1}), indicating strong phosphorus fixation in the acidic sandy conditions (Amanze *et al*., 2022). Together, the low levels of TN and Avail. P present major constraints to cereal and legume productivity in the region. The distribution of OC, TN, and Avail. P across land uses is illustrated in Figures 5 and 6, while scatter plots (Figure 7) show weak synchrony among these variables.

Table 1: Physical properties of soils under different land uses at Ifite Ogwari

Horizon	Depth	sand	Silt	Clay	TC	MC	BD	TP	KSat
	(cm)	←→	(%)	←→		(%)	(Mg/m^3)	(%)	(cm/hr)
				Arable land					
A	0-17	80.93	14.33	4.74	LS	0.09	1.30	50.94	0.98
AB	17-33	64.72	20.24	15.04	SL	0.13	1.50	43.40	0.72
Bt1	33-54	53.80	26.13	20.04	SL	0.14	1.45	45.28	0.76
Bt2	54-152	45.01	30.00	24.99	L	0.11	1.47	44.53	0.64
Mean		61.12	22.68	16.20	SL	0.12	1.43	46.04	0.78
CV (%)		25.32	30.25	53.42		18.64	6.22	7.29	18.71
				Pasture land					
A	0-20	46.92	30.05	23.03	L	0.15	1.40	47.17	1.06
AB	20-44	39.92	35.04	25.04	L	0.09	1.30	50.94	1.00
Bt1	44-73	54.92	30.04	15.04	SL	0.13	1.50	43.40	0.82
Bt2	73-158	70.60	23.38	6.02	SL	0.21	1.55	41.51	0.89

Mean		53.09	29.62	17.29	SL	0.15	1.43	45.76	0.94
CV (%)		24.37	16.15	50.12		34.48	7.06	9.14	11.45
				Forested land					
A	0-12	66.50	20.44	13.06	SL	0.13	1.40	47.17	1.26
AB	12-20	53.82	28.14	18.04	SL	0.20	1.44	45.66	0.72
Bg1	20-50	60.92	30.04	9.04	SL	0.13	1.42	46.42	0.94
Bg2	50-150	80.20	12.30	7.50	LS	0.18	1.48	44.15	0.67
Mean		65.36	22.73	11.91	SL	0.16	1.44	45.85	0.90
CV (%)		17.09	35.62	39.55		22.50	2.37	2.81	29.96

Key: TC=textural class; LS = loamy sand; SL= sandy loam; L = loam; MC = moisture content; BD = bulk density; TP = total porosity; KSat = saturated hydraulic conductivity; CV = coefficient of variation.

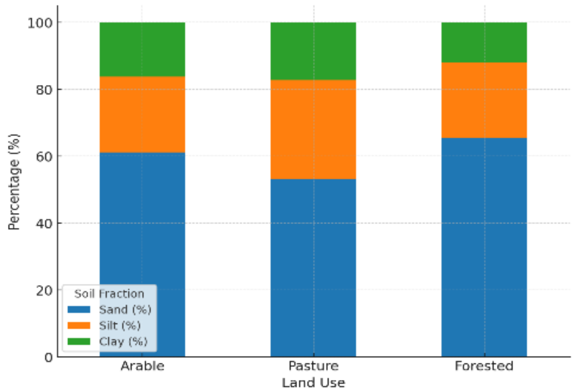

Figure 1: particle size distribution under different land uses

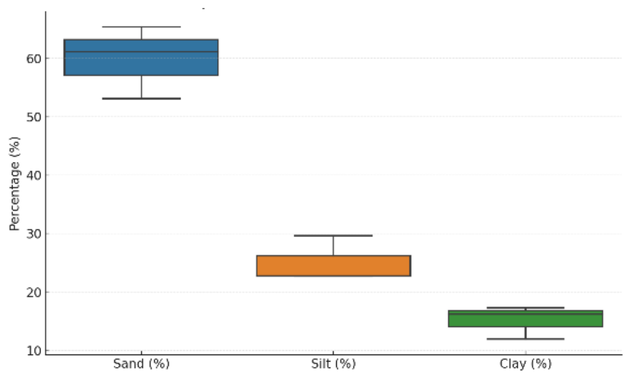

Figure 2: Boxplot of particle size fractions of different land uses

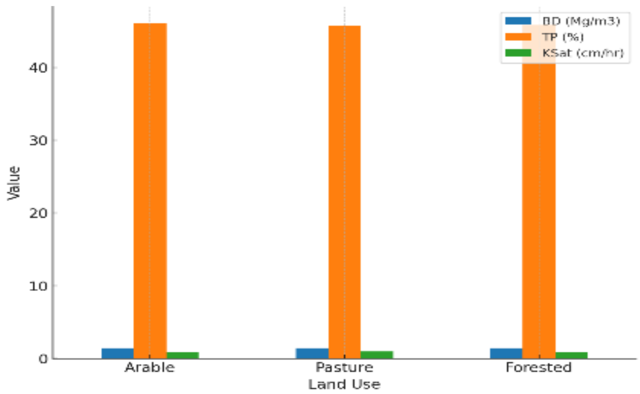

Figure 3: Mean BD, TP, Ksat under different land uses

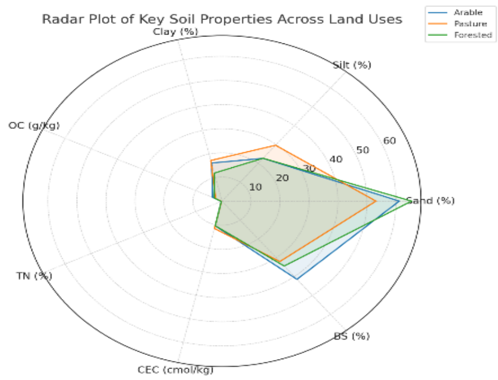

Figure 4: Radar chart comparing sand fraction distribution Across different land uses

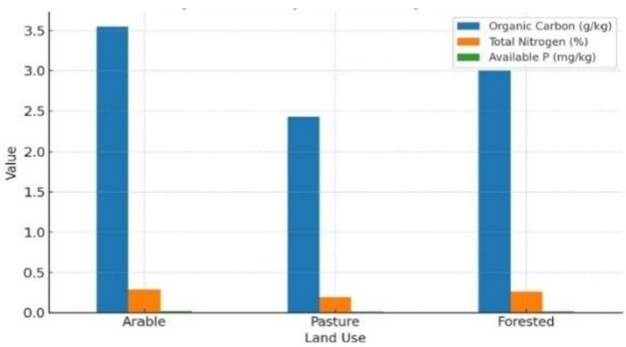

Figure 5: OC, TN, and AP levels in soils under different land uses

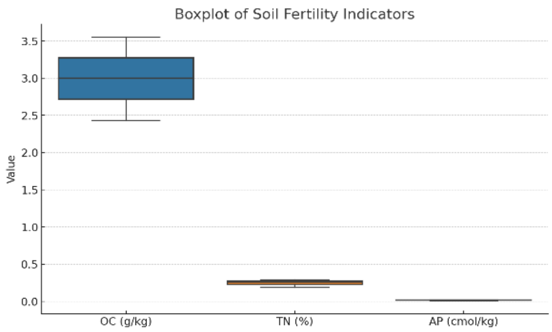

Fig. 6: Boxplot of OC, TN and AP levels across land uses

Table 2: Chemical Properties of Soils under different land uses at Ifite Ogwari

Horizon	Depth (cm)	pH	OC	TN (g/kg)	AP	Ca	Mg	Na	K (Cmol/kg)	H	Al	TEB	CEC	BS %
Arable land														
A	0-17	5.50	3.50	0.34	0.018	2.85	1.65	0.184	0.02	0.18	0.09	4.71	9.98	47.19
AB	17-33	5.10	4.40	0.39	0.022	2.70	1.40	0.226	0.23	0.38	0.19	4.55	9.92	45.87
Bt1	33-54	5.10	3.30	0.23	0.017	2.62	1.20	0.178	0.18	0.22	0.43	4.18	10.66	39.21
Bt2	54-152	5.10	3.00	0.21	0.015	2.25	1.60	0.015	0.02	0.43	0.24	3.88	11.56	33.56
Mean		5.20	3.55	0.29	0.02	2.61	1.46	0.15	0.11	0.30	0.24	4.33	10.53	41.46
CV (%)		3.85	16.99	29.69	1.69	9.79	14.01	61.58	98.18	40.32	60.25	8.61	7.25	15.24
Pasture land														
A	0-20	5.00	3.80	0.36	0.019	1.62	1.88	0.019	0.21	0.282	0.14	3.73	13.15	28.37
AB	20-44	5.20	2.30	0.16	0.012	2.50	1.70	0.012	0.13	0.386	0.20	4.34	11.92	36.41
Bt1	44-73	5.40	2.00	0.14	0.010	1.12	1.50	0.010	0.11	0.190	0.10	2.74	10.03	27.32
Bt2	73-158	5.40	1.60	0.11	0.008	2.42	1.58	0.008	0.11	0.224	0.11	4.12	11.45	35.98
Mean		5.25	2.43	0.19	0.01	1.92	1.67	0.01	0.14	0.27	0.14	3.73	11.64	32.02
CV (%)		3.64	39.59	59.07	41.67	34.57	9.91	41.67	34.29	31.73	32.85	18.97	11.08	15.12
Forested land														
A	0-12	5.60	3.80	0.33	0.02	2.50	1.50	0.019	0.21	0.250	0.40	4.22	10.60	39.81
AB	12-20	4.90	4.40	0.37	0.02	2.50	1.00	0.022	0.23	0.267	0.43	3.75	9.12	41.12
Bg1	20-50	4.90	3.00	0.30	0.02	1.20	1.12	0.015	0.18	0.267	0.40	2.51	11.97	20.97
Bg2	50-150	4.90	0.80	0.05	0.01	2.10	1.50	0.004	0.04	0.180	0.37	3.64	10.20	35.69
Mean		5.08	3.00	0.26	0.02	2.08	1.28	0.02	0.17	0.24	0.40	3.53	10.47	34.40
CV (%)		0.90	52.50	55.13	27.78	29.54	20.23	53.33	52.15	17.01	6.00	20.54	11.25	26.88

Key: pH = soil reaction (1:2.5 H_2O); OC = organic carbon; TN=total nitrogen; AP=available phosphorus; TEB=total exchangeable bases; CEC=cation exchange capacity; BS = base saturation; CV = coefficient of variation.

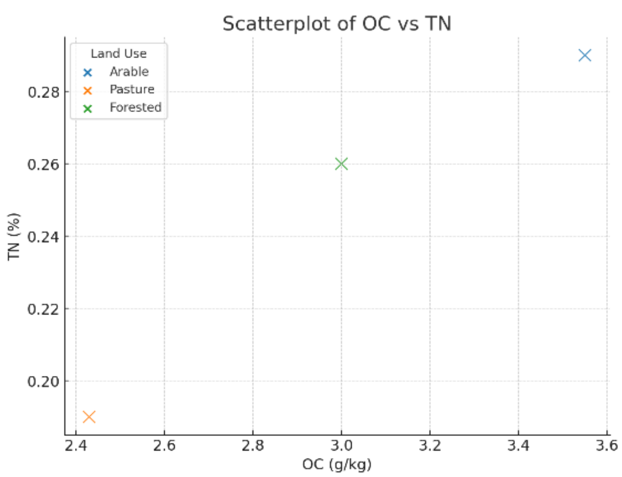

Figure 7: Scatterplot showing the relationship between OC and TN across land uses

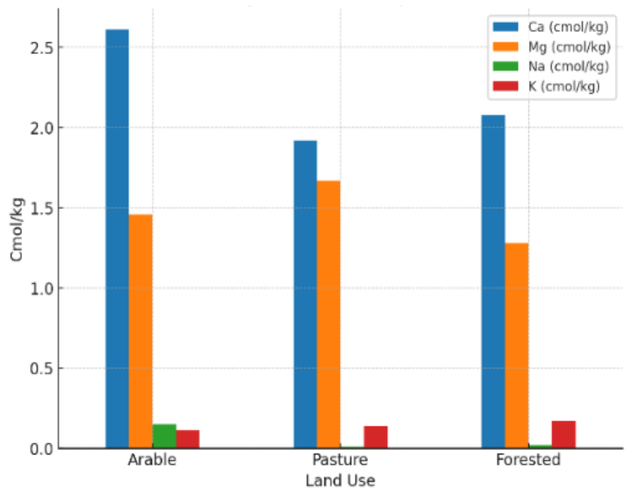

Figure 8: Exchangeable bases (Ca, Mg, K, Na) in soils under different land uses

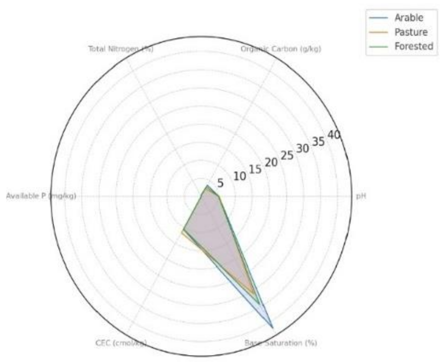

Figure 9: Radar chart comparing soil fertility parameters (pH, OC, TN, AP) across land uses

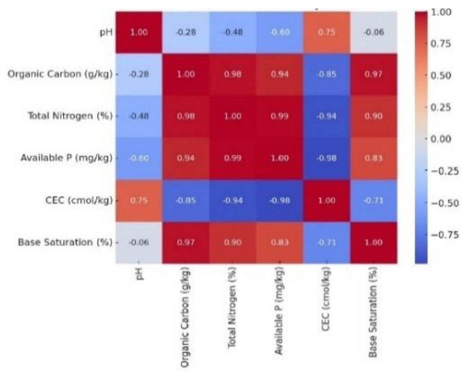

Figure 10: Correlation heatmap showing relationships among selected soil physical and chemical properties

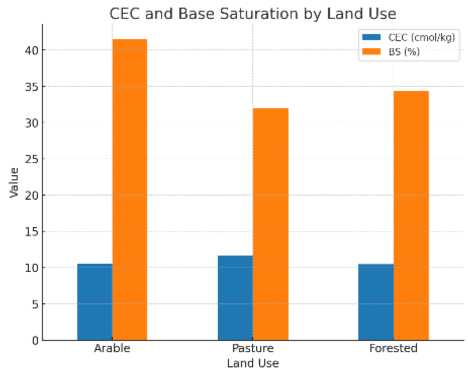

Figure 11: Mean CEC and Base saturation in soils under different land uses

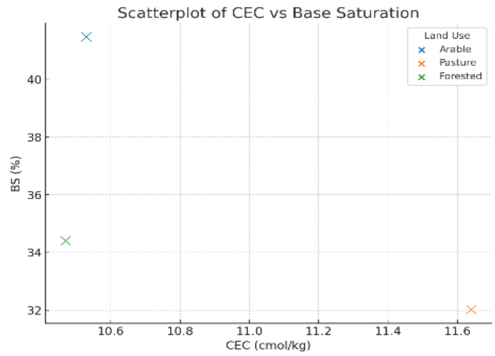

Figure 12: Scatterplot CEC and BS illustrating the relationship between CEC and BS across land uses

Exchangeable bases followed the order $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ across the different land uses. Pasture soils contained relatively higher levels of Mg^{2+}, while forest soils had increased K^{+}. Both exchangeable Ca^{2+} and Mg^{2+} were below sufficiency thresholds, with base saturation remaining below 42%, indicating considerable leaching losses (Yimer *et al*., 2008). These findings align with characteristics of ferrallitic soils in humid tropical regions (Esu, 2010). Total exchangeable bases (TEB) were generally low, and cation exchange capacity (CEC) ranged from 9.12 to 13.15 cmol kg^{-1}, being slightly higher in pasture soils compared to forest and arable soils. The predominance of acidic cations (H^{+}, Al^{3+}) on exchange sites reflects severe leaching and acidity stress (FDALR, 2015). Exchangeable bases are summarized in Figure 8, while fertility indicators are compared across land uses in Figure 9.The coefficient of variation (CV) indicated high heterogeneity in OC (39–53%), TN (30–59%), and exchangeable Na^{+} (53–62%) across land uses, suggesting inconsistent organic matter management and nutrient cycling. This variability implies that blanket fertilizer recommendations may be inefficient and reinforces the need for site-specific nutrient management strategies (Nakachew *et al*., 2024).

Relationships Among Soil Properties

Correlation analysis (Figure 10) demonstrated a strong positive association between organic carbon (OC) and total nitrogen (TN) (r = 0.99), indicating that organic matter serves as the primary reservoir for nitrogen in these soils. Additionally, bulk density exhibited a nearly perfect negative correlation with total porosity (r = -0.99), highlighting the essential role of organic matter in maintaining soil structure. The sand content was positively correlated with saturated hydraulic conductivity (Ksat) (r = 0.95), while clay content showed a negative correlation with Ksat (r = -0.92), underscoring the significant influence of soil texture on infiltration and water transmission dynamics.A scatterplot depicting the relationship between cation exchange capacity (CEC) and base saturation (BS) (Figure 12) revealed a weak association, suggesting that moderate CEC does not correspond to higher BS due to the predominance of acidic cations (H^{+}, Al^{3+}). These findings align with previous studies on Ultisols in southeastern Nigeria and other humid tropical environments (FDALR, 2015; Esu, 2010; Madueke *et al*., 2021; Nnabuihe *et al*., 2023; 2024; 2025).

Implications for Crop Production and Recommendation

The soil fertility assessment atIfite Ogwari identified specific constraints associated with various land uses. Arable soils demonstrated high levels of organic carbon (OC) and total nitrogen (TN) but faced challenges related to acidity and significant phosphorus deficiency, necessitating the application of lime and phosphorus to enhance crop yields. In contrast, pasture soils, while exhibiting favorable physical conditions, recorded the lowest OC and TN levels, indicating a need for manure and organic amendments to maintain forage productivity. Forest soils presented a relatively balanced nutrient profile; however, their coarse texture predisposes them to nutrient leaching, underscoring the importance of mulching and residue retention practices. To effectively address these constraints, we recommend site-specific fertility strategies. For arable soils, essential practices include liming, phosphorus fertilization, and the recycling of organic matter. Pasture soils would benefit from nitrogen enrichment through the application of manure, compost, or the incorporation of legumes. In forest soils, conservation approaches such as mulching, cover cropping, and agroforestry should be implemented to mitigate leaching and promote soil health. Integrating organic inputs with mineral fertilizers, enhancing soil organic matter, and adopting reduced tillage practices can significantly improve nutrient cycling, soil structure, and long-term productivity across all land uses.

Conclusion

The soils of Ifite Ogwari display typical fertility limitations characteristic of Ultisols found in southeastern Nigeria, including moderate acidity, low nutrient retention, and vulnerability to degradation under cultivation. The application of data visualization techniques, such as bar charts, scatter plots, heatmaps, and radar plots has yielded valuable insights, revealing that land use significantly impacts both the physical and chemical properties of the soil. Arable soils, while rich in organic carbon and total nitrogen, are constrained by acidity and structural degradation. Pasture soils maintain a favorable physical structure but exhibit poor fertility. In contrast, forest soils retain a relatively balanced nutrient profile, although they are susceptible to leaching.To promote sustainable crop production, an integrated soil fertility management (ISFM) approach is imperative. This strategy should include liming, organic amendments, targeted fertilizer applications, and conservation practices. Implementing these measures will enhance soil productivity and contribute to agricultural sustainability and resilience in the humid tropics of southeastern Nigeria. Future research efforts should focus on precision soil fertility management through digital soil mapping, long-term fertility monitoring, and economic assessments of various amendment options to bolster food security in the region.

References

1. Amanze, C. T., Amulu, L. U., Ukabiala, M. E., Kayode, A. P., Omatule, L. A., Ozomata, A. S., &Kolo, J. (2022). Combined influence of ash and poultry manure on soil reaction and performance of maize (Zea mays) in a coarse-textured acid soil of South-East, Nigeria. Agro-Science, 21(4), 69–76.
2. Blakemore, L. C., Searle, P. L., & Daly, B. K. (1987). Methods for chemical analysis of soils (Scientific Report 80). N.Z. Soil Bureau, Lower Hutt, New Zealand.
3. Bray, R. H., & Kurtz, L. T. (1945). Determination of total organic and available forms of phosphorus in soils. Soil Science, 59(1), 22–229.
4. Bremner, J. M. (1996). Nitrogen—Total. In D. L. Sparks (Ed.), Methods of soil analysis. Part 3: Chemical methods (pp. 1085–1125). Soil Science Society of America.
5. Debele, F. K. (2025). Effect of land use land cover change on soil erosion and sediment yield in Gara Wadeso Watershed, North Shewa Zone, Ethiopia.
6. Esu, I. E. (2010). Soil characterization, classification and survey. In Principles of soil classification (pp. 119–156). HEBN Publishers Plc. ISBN 9789780813734.
7. Ezeaku, P. I., Eze, F. U., & Oku, E. (2015). Profile distribution and degradation of soil properties of an Ultisol in Nsukka semi-humid area of Nigeria. African Journal of Agricultural Research, 10(11), 1306–1311.
8. Food and Agriculture Organization (FAO). (2006). Guidelines for soil description (4th ed.). FAO of the United Nations.
9. Federal Department of Agriculture and Land Resources (FDALR). (1990). The reconnaissance soil survey of Nigeria (Vol. 1, pp. 338–339).

10. Gee, G. W., & or, D. (2002). Particle-size analysis. In J. H. Dane & G. C. Topp (Eds.), Methods of soil analysis: Part 4—Physical methods (pp. 255–295). Soil Science Society of America.
11. Grossman, R. B., & Reinsch, T. G. (2002). Bulk density and linear extensibility. In J. H. Dane &G. C. Topp (Eds.), Methods of soil analysis: Part 4—Physical methods (pp. 201–228). Soil Science Society of America.
12. Igbozuruike, M. U. (1975). Vegetation types. In G. E. K. Ofomata (Ed.), Nigeria in maps: Eastern States (pp. 30–32). Ethiope Publishing.
13. Igu, N. I., Ayogu, C. N., Umeogu, C. C., &Obikwelu, M. C. (2023). Analysis of land use change and associated implications on soil ecosystem functions in South Eastern Nigeria. Journal of Geoscience and Environment Protection, 11(5), 126–134.
14. Ikemefuna-Ezeaku, P. (2013). Evaluating the spatial variability of soils of similar lithology under different land uses and degradation risks in a Guinea Savanna agro-ecology of Nigeria. IOSR Journal of Agriculture and Veterinary Science, 5(5), 21–31. https://www.iosrjournals.org
15. Jackson, M. C. (1962). Soil chemical analysis. Prentice Hall.
16. Kumar, S. (2009). Agroforestry and grass buffers for improving soil hydraulic properties and reducing runoff and sediment losses from grazed pastures. [Doctoral dissertation, University of Missouri-Columbia.
17. Landon, J. R. (Ed.). (1991). Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. John Wiley & Sons.
18. Madueke, C. O., Nnabude, P. C., Okore, I. K., Onunwa, A. O., Madueke, E. C., Okafor, M. J., Nnabuihe, E. C., & Nwosu, T. V. (2020). Evaluation of soils on a toposequence formed from the coastal plain sands of the Imo River Basin, Southeastern Nigeria. Nigerian Journal of Soil Science, 31(2), 1–9.
19. Madueke, C. O., Okore, I. K., Maduekeh, E. C., Onunwa, A. O., Okafor, M. J., Nnabuihe, E. C., Nwosu, T. V., Nwaiwu, C. J., & Nwosu, B. (2021). Characterization and land evaluation of three tropical rainforest soils derived from the coastal plain sands of Southeastern Nigeria. Agro-Science, 20(2), 25–36.
20. McLean, E. V. (1982). Aluminium. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), Methods of soil analysis: Part 2—Chemical and microbiological properties (pp. 977–998). American Society of Agronomy.
21. Mrabet, R. (2023). Sustainable agriculture for food and nutritional security. In Sustainable agriculture and the environment (pp. 25–90). Academic Press.
22. Mugwe, J., Ngetich, F., & Otieno, E. O. (2019). Integrated soil fertility management in sub-Saharan Africa: Evolving paradigms toward integration. In Zero Hunger (pp. 1–12). Springer.
23. Nakachew, K., Yigermal, H., Assefa, F., Gelaye, Y., & Ali, S. (2024). Review on enhancing the efficiency of fertilizer utilization: Strategies for optimal nutrient management. Open Agriculture, 9(1),
24. Nelson, D. W., & Sommers, L. E. (1982). Total carbon, organic carbon, and organic matter. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), Methods of soil analysis: Part 2— Chemical and microbiological properties (pp. 539–579). American Society of Agronomy.
25. Nigeria Meteorological Agency (NIMET). (2022). Climate weather and water information for sustainable development and safety: Annual climatic report.
26. Nigeria Meteorological Agency (NIMET). (2024). Climate weather and water information for sustainable development and safety: Annual climatic report.
27. Nnabuihe, E. C., Chukwu, E. D., Apalowo, O. A., Ugochukwu, G. U., Osisi, F. A., Madueke, C. O., Mbe, J. O., Chukwu, O., Chukwuma, T. R., & Uko, I. (2025). Profile characteristics and classification of selected Ultisols under varying land use types in Owerri, Southeastern Nigeria. International Journal of Horticulture and Agriculture Research, 1(1), 37–47.
28. Nnabuihe, E. C., Madueke, C. O., Okafor, M. J., Nwosu, T. V., Ibeh, C. U., Ibigweh, M. N., Nwaiwu, C. J., Ike, C. R., Onunwa, A. O., Okore, I. K., & Nnabude, P. C. (2024, March 14). Morphology, physico-chemical properties and classification of soils of coastal plain sands in Owerri, Imo State, Southeastern Nigeria. In e-Proceedings of the Faculty of Agriculture International Conference (pp. 232–239).
29. Nnabuihe, E. C., Nwadibia, M. U., Nwosu, T. V., Okafor, M. J., Ibeh, C. U., Ibigweh, M. N.,

Nwaiwu, C. J., Nwankwo, J. E., & Osujieke, D. N. (2023, March 23). Characterization of soils of Ifite Ogwari Campus of Nnamdi Azikiwe University, Anambra State, South Eastern Nigeria. In e-Proceedings of the Faculty of Agriculture International Conference (pp. 177–182).

30. Obi, M. E. (1990). Soil physics: A compendium of lectures. University of Nigeria, Nsukka.
31. Ofomata, G. E. K. (1975). Landform regions. In G. E. K. Ofomata (Ed.), Nigeria in maps: Eastern States (pp. 33–34). Ethiope Publishing.
32. Olsen, S. R., & Sommers, L. E. (1982). Phosphorus. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), Methods of soil analysis: Part 2—Chemical and microbiological properties (pp. 15–72). American Society of Agronomy.
33. Orajaka, S. O. (1975). Geology. In G. E. K. Ofomata (Ed.), Nigeria in maps: Eastern States (pp. 5–7). Ethiope Publishing.
34. Okebalama, C. B., Igwe, C. A., & Okolo, C. C. (2017). Soil organic carbon levels in soils of contrasting land uses in Southeastern Nigeria. Tropical and Subtropical Agroecosystems,20(3), 493–504.
35. Thomas, G. W. (1996). Soil pH and soil acidity. In D. L. Sparks (Ed.), Methods of soil analysis. Part 3: Chemical methods (pp. 159–165). Soil Science Society of America.
36. Topp, G. C., & Dane, J. H. (2002). Methods of soil analysis: Part 4—Physical methods. Soil Science Society of America Book Series, 5. Madison, WI.
37. Udofia, P. A., Adesemuyi, E. A., & Iroha, J. N. (2024). Soil inventory and spatial distribution of fertility potential of an Ultisol under different land use types in Isingwu, Southeast Nigeria. Journal of Agriculture, Forestry & Environment, 8(1), 51–72.
38. Uzoh, I. M., Igwenagu, C. M., & Obalum, S. E. (2020). Effect of land use type on organic C, physical properties and stability indices of soils in Nanka area, Southeast Nigeria. Nigerian Journal of Soil Science, 30(1), 62–69.
39. Vepraskas, M. J. (1988). Bulk density values diagnostic of restricted root growth in coarse-textured soils. Soil Science Society of America Journal, 52(4), 1117–1121.