Ilmu Pertanian (Agricultural Science)

http://journal.ugm.ac.id/jip

Vol. 10 No. 3 December, 2025: 175– 181| DOI: doi.org/10.22146/ipas.109084

Nitrogen, Phosphorus and Sulfur Stocks in Soils under different Land Use Systems at the University of Benin Nigeria.

Adams Emomu[1*], Eseuwa Naomi Aigbobo[2], Bisola Elizabeth Olukini[1]

[1]Department of Soil Science and Land Management, Faculty of Agriculture, University of Benin, P.M.B. 1154 Benin City, Edo State, Nigeria.
[2]Department of Crop and Animal Science, Faculty of Agriculture, University of Delta, Agbor, P.M.B. 2090 Agbor Delta State, Nigeria.
*Corresponding author: adams.emomu@uniben.edu

Article Info

Received : 11th July 2025
Revised : 22th August 2025
Accepted : 24th November 2025
Published : 30th December 2025

Keywords:
Arable, Forested, Land use, Nutrients, Sport land

Abstract

Understanding how land use and soil depth influence nutrient storage is essential for sustainable soil management in tropical ecosystems. This study quantified nitrogen (N), phosphorus (P), and sulfur (S) stocks in soils under four contrasting land-use systems—arable, forested, sport, and plantain fields—within the University of Benin, Nigeria. Soil samples were collected at 0–30 cm and 30–60 cm depths and analyzed using standard laboratory methods. Nutrient stocks were calculated based on soil nutrient concentration, bulk density, and depth increments. Land use and soil depth significantly affected N and P stocks, while S stock variation at the surface layer was not significant. At 0–30 cm, the highest N stock (2,360 Mg ha^{-1}) occurred in arable land, likely due to continuous inorganic N fertilizer use, whereas plantain fields stored the highest P (2,354 Mg ha^{-1}) and S (164 Mg ha^{-1}), reflecting greater organic inputs and improved soil chemical properties. At 30–60 cm, N stock peaked in sport land (3,890 Mg ha^{-1}), possibly due to turfgrass management and regular biomass return, whereas forested land stored the most sulfur (433 Mg ha^{-1}), attributed to litter accumulation and microbial activity. Differences in nutrient stocks across land uses corresponded closely to variations in soil organic carbon, pH, and cation exchange capacity. These findings highlight strong land use–driven redistribution of essential nutrients in tropical Ultisols. Promoting land-use practices that enhance organic matter input—such as agroforestry, mixed cropping, or managed fallows—can improve nutrient storage, support long-term soil fertility, and strengthen nutrient cycling in degraded tropical landscapes.

INTRODUCTION

Comprised of mixture of individual components, each soil type has distinctive characteristics and structure (Mitchell et al., 2025; Rodrigues et al., 2023). The properties of soils are interrelated, making it an effective medium for plant to grow with additional function (Sharma and Kumar, 2023; Osman, 2016), such as nutrient stocking capacity. Nutrient stocking is the accumulation of nutrients via soil particles, sediments and atmospheric deposits (Oyedele et al., 2014). Changes in nutrient stock and other soil health indicators soil are significantly influenced by land use, management practices, and soil depth (Mirbakhsh et al., 2022). Understanding Nitrogen (N), Phosphorus (P) and Sulfur (S) stocks as influenced by land use and soil depth may be vital for planning crop cultivation, land use, ecological restoration and soil fertility management. Besides nitrogen and phosphorus, sulfur is a major plant nutrient and an important component of balanced fertilization (Prasad and Shivay, 2018). Besides the effects of land use and soil depth on nutrient stocks, the restoration of

How to cite: Emomu, A., Aigbobo, E.A., Olukini , B.E. (2025). Nitrogen, Phosphorus and Sulfur Stocks in Soils under different Land Use Systems at the University of Benin Nigeria. *Ilmu Pertanian (Agricultural Science)*, 10(3), pp. 175–181.

ISSN 0126-4214 (print) ISSN 2527-7162 (online)

soil nutrients is essential to enhance the soil fertility and productivity (Miju et al., 2025). Land use refers to the purposes and activities through which people interact with land and terrestrial ecosystems (Meyfroidt et al., 2022). Land use has significant effects on the contents, restoration, and nutrient stocks such as total nitrogen, phosphorus and sulfur (Wang et al., 2023; Yan et al., 2021; Huang et al., 2020; Habtamu et al., 2014), thus influencing soil nutrient stocking capacity. Land uses and cropping systems have reportedly influenced soil health indicators including total Nitrogen (Mirbakhsh et al., 2023). Phosphorus stock capacity could be higher in agricultural land when compared with some other land use types (Gava et al., 2022). Moreover, changes in land use practices significantly affect the distribution of soil sulfur (S) fractions and their bioavailability, thereby affecting soil sulfur stock capacity (Padhan et al., 2023). The concentrations of some soil nutrients in vegetated areas may be generally greater compared to arable land (Powlson et al., 2022; Habtamu et al., 2014), while forested land may stock higher nutrient levels compared to other land use types, owing to several prevailing factors. Soil can act as nutrient source or sink, depending on the relationship between nutrient inputs and outputs (Mitchell et al., 2025; Guo and Gifford, 2002). Land use, on the other hand, involves how a land is utilized and maintained (Harefa, 2024), which influences its nutrient stocking capacity. Soils act as dynamic reservoirs for essential plant nutrients, and their capacity to store elements such as nitrogen (N), phosphorus (P), and sulfur (S) depends largely on land use, management practices, and soil depth. Although, numerous studies have explored soil carbon and nitrogen stocks under various land uses globally, little is known about N, P, and S dynamics in tropical soils of southern Nigeria, particularly within the University of Benin. Understanding these relationships is vital for sustainable land management and nutrient cycling. Therefore, this study aimed to quantify N, P, and S stocks in soils under four contrasting land uses and two depths, providing insights into Land use–driven nutrient redistribution.

MATERIALS AND METHODS

Description of the study area

The study was conducted within University of Benin Nigeria, which lies between latitude 06^o 36' 59.7" N and longitude 05^{o}37'15.8"E, in the tropical climate with average annual temperature of around 27^{0}C and an

Table 1. Locations, land uses, and coordinates of the study sites

Location	Land use	Coordinates
AGR305 Farm	Arable	06˚24'00"N05˚37'30"E
Faculty Arboretum	Forested	06˚24'03"N05˚37'25"E
Sport complex	Sport	06˚23'46"N05˚36'39"E
Project Farm	Plantain field	06˚24'15"N05˚36'37"E

Table 2. Some soil properties analyzed, methods adopted, and references

Soil properties	Method	Reference
Particle sized distribution	Hydrometer	Bouyoucos (1962), Day (1965).
Textural classification	Textural triangle	soil survey staff (2003)
Bulk density	Core sampler	Ibitoye (2008).
pH	Glass electrode	Tan (1996)
Organic carbon	Walkley-Black wet oxidation	Walkley and Black (1934)
Total exchangeable bases	Summation	Udo et al. (2009)
Exchangeable acidity	1 M KCl extraction	Juo (1979).
Base saturation	Calculation	Orhue and Emomu (2022)
Available nutrients		
Total Nitrogen (N)	Kjeldahl	Udo et al. (2009)
Available Phosphorus (P)	Bray-1 extraction, colorimetric	Bray and Kurtz (1945), Murphy and Riley (1962).
Sulfur (S)	Phosphate extraction, turbidometric	Udo et al. (2009)

annual rainfall of 2000 mm. Its mean annual relative humidity ranges from 89% in the morning to 75% in the evening (NIFOR, 2018).

Soil sampling and preparation

Completely randomized design with three replicates was used to collect auger soil samples from two (0-30 and 30-60 cm) depths, from four (arable, forested, sport and plantain farm) land use, to make a total of 24 soil samples. The locations, land uses and coordinates of the sampling sites are presented in Table 1.

Laboratory analysis

Soil samples were air-dried, ground, passed through 2 mm sieve and analyzed for selected properties following standard operating procedure shown in Table 2.

Soil nutrient stock determination

Soil nutrient stocks were calculated by fitting N, P, S values obtained from laboratory analysis to equations adapted from Chave et al. (2014) and Azeez et al. (2024) based on modified FAO (2019) formula given as:

$$SNS = SOQ \times Qb \times Z \times 0.1 \quad \text{.........................} \quad (1)$$

Where;

SNS = Soil nutrient stock (Mg nutrient ha^{-1})

SOQ = soil nutrient content (mg nutrient of fine earth) in the depth increment "i.",

Qb = bulk density (cm^3) in the depth increment),

Z = soil depth or the thickness of the soil horizon (cm) of the depth increment "i.",

0.1 = factor for converting nutrient from mg cm^{-1} to Mg ha^{-1}

Statistical analysis

The data obtained from laboratory analysis were tested for normality and subjected to ANOVA, using Genstat (GenStat 12.1, VSN International, UK) statistical package. The statistical differences between means were separated using Duncan multiple range test at 5% level of probability.

Table 3. Some soil physical and chemical properties across different land uses

Land use	Sand	Silt	Clay	Text	pH	OC	CEC	EA	ECEC	BS
	$g\ kg^{-1}$					%	$cmol\ kg^{-1}$			%
					0-30 cm					
Arable	83.85 a	5.33 a	10.81 a	LS	4.15^{a}	0.42^{a}	0.51^{a}	0.48^{a}	0.99^{a}	51.30^{a}
Forested	81.85 a	5.33 a	12.81 a	SL	5.11^{a}	0.93^{a}	1.44^{a}	0.27^{a}	1.70^{a}	84.10^{b}
PF	80.85 a	7.00 b	12.15 a	SL	5.30^{b}	1.04^{a}	3.37^{b}	0.51^{a}	3.88^{b}	84.50^{b}
Sport	81.52 a	4.67 a	13.81 a	SL	5.44^{b}	0.95^{a}	1.44^{a}	0.48^{a}	1.92^{a}	75.30^{b}
LSD(0.05)	5.85	4.53	5.44		1.08	0.69	1.57	0.46	1.34	20.60
SEM	1.69	1.31	1.57		0.31	0.20	0.45	0.13	0.39	5.96
SED	2.39	1.85	2.22		0.44	0.28	0.64	0.19	0.55	8.42
%cv	3.60	40.60	22.00		10.80	41.50	46.40	52.60	31.50	13.90
					30-60 cm					
Arable	81.19 a	4.17 a	14.65 a	SL	4.61^{a}	0.22^{a}	0.62^{a}	0.67^{a}	1.29^{a}	49.40^{a}
Forested	80.52 a	4.00 a	15.48 a	SL	4.85^{a}	0.42^{a}	1.18^{a}	0.24^{a}	1.44^{a}	80.20^{b}
PF	77.85 a	8.33 b	13.81 a	SL	5.04^{ab}	0.55^{a}	2.51^{b}	0.67^{a}	3.17^{b}	77.90^{ab}
Sport	78.19 a	4.00 a	17.81 a	SCL	5.37^{b}	0.31^{a}	0.82^{a}	0.91^{a}	1.73^{a}	50.60^{a}
LSD(0.05)	5.08	3.37	5.93		0.50	0.52	0.98	0.81	1.17	28.03
SEM	1.71	1.13	1.99		0.14	0.15	0.28	0.23	0.34	8.10
SED	2.42	1.60	2.82		0.20	0.21	0.34	0.33	0.48	11.46
%cv	5.30	54.2	31.60		5.00	69.10	38.1	64.70	30.60	21.70

Text-texture, OC-organic carbon, CEC-cation exchange capacity, EA-exchangeable acidity, ECEC-effective cation exchange capacity, BS-base saturation, PF-plantain field, LS-loamy sand, SL-sandy loam, SCL-sandy clay loam, LSD-least significant difference, SEM-standard error of mean, SED-standard error of difference cv-coefficient of variation. Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Ranged Test at α = 5%

RESULTS AND DISCUSSION

Some soil physical and chemical properties across different land uses

Table 3 presents some soil physical and chemical properties across various land uses at 0–30 and 30–60 cm soil depths. Sand, silt and clay contents showed no significant differences across land uses, except in plantain field, which had significantly lower (80.85%) sand and higher (7%) silt content, indicating similarity of the soils. Sand was the dominant soil fraction, likely due to coastal plain sand parent material on which the soils were formed (Emomu 2022; Orhue et al., 2021). Plantain field's higher silt content suggests better water and nutrient retention, as sandy soils generally risk nutrient loss due to leaching (Burakova and Bakšiene, 2021; Szogi et al., 2021). The roles of soil texture in water movement and nutrient flux have been reported by Rodrigues et al. (2024).

At the topsoil depth (0–30 cm), all soils were acidic, with arable land showing extreme acidity (pH 4.15), while forested, plantain, and sports lands showed moderately acidic pH values (5.11–5.44). Similar acidity trends were observed at 30–60 cm depth, with significant differences among land uses. The soil acidity observed among different land use could be likely due to varying land-use activities and humid tropical environment. Organic carbon (OC) and effective cation exchange capacity (ECEC) followed a similar trend at 0–30 cm soil depth, with the highest values in plantain field and the lowest in arable land. OC ranged from 0.42% (arable) to 1.04% (plantain field), while ECEC ranged from 0.99 to 3.88 cmol kg^{-1}. These differences in OC and ECEC could be attributed to variations in litter fall and organic matter decomposition (Valencia, et al., 2025; Jimoh and Aliyu, 2024). Orhue et al. (2024) reported similar values for ECEC in soils of the study area. At 30–60 cm soil depth, OC and ECEC also varied, with plantain field showing the highest values (OC: 0.55 %; ECEC: status and possibly due to organic input from a nearby animal farm. These findings were consistent with previous studies of Law-Ogbomo and Osaigbovo (2018) and Okebalama et al. (2020), who reported improvement in fertility due to manure input.

Table 4. Soil nutrient (Nitrogen, Phosphorus and Sulfur) stock (Mg ha^{-1}) across different land use

Land use	Nitrogen	Phosphorus	Sulfur
0-30 cm			
Arable	2360.00^{a}	363.00^{a}	122.00^{a}
Forested	1450.00^{a}	332.00^{a}	123.00^{a}
Plantain field	2250.00^{a}	2354.00^{b}	164.00^{a}
Sport	1890.00^{a}	332.00^{a}	123.00^{a}
LSD(0.05)	1546.00	1604.60	282.20
SEM	447.00	463.70	81.50
SED	632.00	655.80	115.30
%cv	38.9.00	95.00	106.00
30-60 cm			
Arable	2740.00^{ab}	405.00^{a}	85.00^{a}
Forested	2020.00^{a}	442.00^{a}	433.00^{a}
Plantain field	2150.00^{a}	971.00^{b}	116.00^{a}
Sport	3890.00^{b}	403.00^{a}	181.00^{a}
LSD(0.05)	1480.00	432.10	400.50
SEM	428.00	124.90	115.80
SED	605.00	176.60	163.70
%cv	27.40	38.90	98.50

LSD-least significant difference, SEM-standard error of mean, SED-standard error of difference cv-coefficient of variation. Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Ranged Test at α = 5%

Soil nutrient (Nitrogen, Phosphorus and Sulfur) stock across different Land use

N, P and S stocks across land use types at 0–30 and 30–60 cm soil depths are presented in Table 4. At the 0–30 cm soil depth, N stocks ranged from 1,450 Mg ha^{-1} in forested land (FL) to 2,360 Mg ha^{-1} in arable land (AL), with no statistically significant differences obtained among the land-use types. The highest N stock obtained for arable land could be due to continuous use of inorganic N fertilizer for arable crop production, while the variations in N stock among different land use may be related to differences in organic carbon and total nitrogen (Azeez et al., 2024). Phosphorus and sulfur stocks were the highest (2,354 Mg ha^{-1} for P, 164 Mg ha^{-1} for S) in the plantain field (PF). Higher P and S stocks in PF may be due to better nutrient availability and organic carbon content (Liu et al., 2024), in comparison to the other land uses.

At the 30–60 cm soil depth, N stocks were significantly different among land uses, and N stock values ranged from 2,020 Mg ha^{-1} in FL to 3,890 Mg ha^{-1} in SL, reflecting differences in management practices. The highest N stock obtained in SL could be due to turf management (Curk, 2017). Phosphorus stock was again the highest in the PF (971 Mg ha^{-1}), possibly due to animal waste input (Azeez et al., 2024; Burakova, and Bakšiene, 2021). Other land uses had lower P stock capacity compared to values obtained for PL. Sulfur stocks also varied, with the highest value (433 Mg ha^{-1}); meanwhile, S stock capacity was obtained for FL, followed by SL (181 Mg ha^{-1}). High S stock in FL may result from organic matter accumulation from litter fall in the forest vegetation, in line with the findings of Azeez et al. (2024). Effects of agricultural Land management practice on selected soil quality indicator have been reported in Ethopian soils (Abera and Wana, 2023). Nutrient stock patterns obtained in this study, suggests strong influence of Land use and organic inputs on nutrient stocking capacity, however PF consistently showed highest P and S stock levels across both depths, while FL favored S accumulation at deeper soil level, possibly due to natural litter decomposition.

CONCLUSIONS

This study demonstrated that land use and soil depth significantly influenced N, P, and S stocks in Ultisol soils of southern Nigeria. Plantain fields and forested lands exhibited higher P and S reserves due to organic input accumulation, while sport land retained greater N stock. The results indicated that maintaining organic matter through agroforestry or mixed land-use systems can enhance nutrient storage and soil fertility. Long-term monitoring is recommended to assess nutrient dynamics under changing.

ACKNOWLEDGMENTS & FUNDING

We wish to acknowledge the mentorship of Professor E. R. Orhue of Department of soil science, faculty of Agriculture, University of Benin, Nigeria. The study was conceptualized and supervised by Dr. (Mrs.) A.O. Bakare and Dr. A. EMOMU, both of Department of soil science, faculty of Agriculture, University of Benin, Nigeria, and Funded by the authors.

REFERENCES

Abera, A. and Wana, D. (2023). Effect of agricultural land management practices on the selected soil quality indictors: empirical evidences from the south Ethiopian highlands. Environmental Systems Research, 12(1), p. 2.

Azeez, J.O., Onasanya, O.O., Bankole, G.O., Aghorunse, A.C. and Salaudeen, G.T. (2024). Changes in soil nitrate, phosphate, and sulfate stocks as a function of forest litter type in a derived Savannah ecosystem of Abeokuta, southwest Nigeria. Arabian Journal of Geosciences, 17(5), p. 146.

Bouyoucos, G.J. (1962). Hydrometer method improved for making particle size analysis of soil. Agronomy Journal, 54, pp. 464-465.

Bray, R.H. and Kurzt, L.T. (1945). Determination of total, organic and available forms of phosphorus in soil. Journal of Soil Science, 59, pp. 39-45.

Burakova, A. and Bakšiene, E. (2021). Leaching losses of main nutrients by incorporating organic fertilisers into light texture soils Haplic Luvisol. Environmental Engineering Research, 26(4), pp. 1-10.

Chave, J., Ejou-M, E.M.R,, Urquez, A.B., Chidumayo, E., Colgan, M.S., Delitti, W.B., Duque, A., Eid, T., Fearnside, P.M., Goodman, R.C., Henry, M., Martinez, Y.A., Mugasha, W.A., Muller-Landau, H.C., Mencuccini, M., Nelson, B.W., Ngomanda, A., Nogueira, E.M., Ortiz-Malavassi, E., Elissier, R.P., Ploton, P., Ryan, C.M., Saldarriaga, J.G. and Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biology, 20, pp. 3177–3190

Curk, M., Vidrih, M., Laznik, Ž. and Trdan, S. (2017). Turfgrass maintenance and management in soccer fields in Slovenia. Urban Forestry and Urban Greening, 26, pp. 191-197.

Day, P.R. (1965). Particle fractionation and particle size analysis. In, Methods of soil analysis Black, C.A. (Ed). Part 1 Agronomy, 9, pp. 545-547.

Emomu, A. (2022). Silicon sorption in soils overlying coastal plain sand, Imo shale and basement complex rock parent materials in Edo State, Nigeria. African Journal of Sustainable Agricultural Development, 3(1), pp. 10-22.

FAO-Food and Agriculture Organization (2019). Measuring and modeling soil carbon stocks and stock changes in livestock production systems: guidelines for assessment (Version 1). In Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy, p. 170.

Gava, C.A.T., Giongo, V., Signor, D. and Fernandes-Junior, P. I. (2022). Land-use change alters stocks of carbon, nitrogen and phosphorus in Haplic Cambisol in the Brazilian semi-arid region. Soil Use Management, 38: pp. 953-963.

Guo, L.B. and Gifford, R.M. (2002). Soil carbon stocks and land use change: a meta-analysis. Global change biology, 8(4), pp. 345-360.

Habtamu, A., Heluf, G., Bobe, B. and Enyew, A. (2014). Fertility status of soils under different land uses at Wujiraba Watershed, North-Western Highlands of Ethiopia. Agriculture, Forestry and Fisheries, 3(5), pp. 410-419.

Harefa, D. (2024). The Influence Of Local Wisdom On Soil Fertility In South Nias. Jurnal Sapta Agrica, 3(2), pp. 18-28.

Huang, C., Zeng, Y., Wang, L. and Wang, S. (2020). Responses of soil nutrients to vegetation restoration in China. Regional Environmental Change, 20(3), p. 82.

Ibitoye, A.A. (2008). Laboratory Manual on Basic soil Analysis. Foladave Nigeria limited, pp. 34-35.

Jimoh, I.A. and Aliyu, J. (2024). Assessment of impact of land uses on soil carbon stock and quality. In Agroforestry to Combat Global Challenges: Current Prospects and Future Challenges (pp. 441-460). Singapore: Springer Nature Singapore.

Juo, A.S.R. (1979). Selected Methods for Soil and Plant Analysis. Manual Series No. 1, IITA, Ibadan.

Law-Ogbomo, K.E. and Osaigbovo, A.U. (2018). Productivity of cucumber (*Cucumis Sativus* L) and post-harvest soil chemical properties in response to organic fertilizer types and rates in an Ultisol. Tropical and Subtropical Agroecosystems, 21(3), pp. 513-520.

Liu, J., Gou, X., Liu, J., Yin, D. and Zhang, D. (2024). Comparative Analysis of the Drivers of Soil Organic Carbon, Total Nitrogen, and Phosphorus Stocks in Different Coniferous Plantations on the Eastern Tibetan Plateau. Journal of Soil Science and Plant Nutrition, 24(1), pp. 331-342.

Meyfroidt, P., De Bremond, A., Ryan, C.M., Archer, E., Aspinall, R., Chhabra, A., Camara, G., Corbera, E., DeFries, R., Díaz, S. and Dong, J. (2022). Ten facts about land systems for sustainability. Proceedings of the National Academy of Sciences, 119(7), p. e2109217118.

Miju, C., Kiflu, A. and Gizachew, S. (2025). Effects of land use/land cover change on soil physicochemical properties and soil carbon stock in Kochore district, southern Ethiopia. Arabian Journal of Geoscience, 18 (41), pp. 1-12.

Mirbakhsh, M., Brouder, S.M. and Volenec, J.J. (2022). Temporal Change of Carbon Stocks and Soil Health Indicators on a Long-Term Experimental Site: Annual Vs. Perennial Systems [Abstract]. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD.

Mirbakhsh, M., Sohrabi Sedeh, S.S. and Zahed, Z. (2023). The impact of Persian clover (*Trifolium resupinatum* L.) on soil health. Black Sea Journal of Agriculture, 6(5), pp. 564-570.

Mitchell, J.K., Soga, K. and O'Sullivan, C. (2025). Fundamentals of soil behavior. John Wiley & Sons.

Murphy, J. and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analytical Chemistry ACTA, 27, pp. 31-36.

Nigerian Institute for Oil Palm Research (NIFOR) (2018). Weather data (Temperature, Rainfall, Relative Humidity): 1993-2018. Nigerian Institute for Oil Palm Research Main Station, Benin-City, Nigeria.

Okebalame, C.B., Ogunezi, K.C., Agbo, I.C. and Asogwa, K.C. (2020). Influence of soil amendment with poultry droppings on the soil properties and productivity of cumbers (*Cucumis sativus* L.) on a degraded Ultisol in Nsukka Area, Southeast Nigeria. Nigerian Journal of Soil Science, 30(2), pp. 85-94.

Orhue, E.R., Emomu, A., Obazuaye, E., Aimiesomon Michael Erhayimwen, M.A. and Bepo, G.A. (2021). Phosphorus Sorption in Soils Overlying Basement Complex Rock, Alluvium, Coastal Plain Sand and Imo Shale Parent Materials. Asian Journal of Soil Science and Plant Nutrition, 7(3), pp. 41-54.

Orhue, E.R. and Emomu, A. (2022). Freundlich, Langmuir and Temkin isotherm studies of silicon sorption on soils derived from three parent materials in Edo State, Nigeria. Agro-Science, 21(3), pp. 1-12.

Orhue, E.R., Bakare, A.O., Emomu, A. (2024). Zinc, Cobalt and Chromium status in soils under Citrus and Teak Plantation in University of Benin, Edo State, Nigeria. Journal of Sustainable Development, 22(1), pp. 88-98.

Osman, K.T. (2016). Soils: principles, properties and management. Springer Science and Business Media.

Oyedele, D.J., Awotoye, O.O., and Popoola, S.E. (2014). Soil Physical and Chemical properties under continuous maize cultivation as influenced by hedgerow tree species on Alfisols in South Western Nigeria. African Journal of Agricultural Research, 4(8), pp. 736-739.

Padhan, D., Rout, P.P. and Sen, A. (2023). Changes in land use practices influence soil sulfur fractions and their bioavailability. Frontiers in Sustainable Food Systems, 7, p. 1233223.

Powlson, D.S., Poulton, P.R., Glendining, M.J., Macdonald, A.J. and Goulding, K.W. (2022). Is it possible to attain the same soil organic matter content in arable agricultural soils as under natural vegetation?. Outlook on Agriculture, 51(1), pp. 91-104.

Prasad, R. and Shivay, Y.S. (2018). Sulphur in soil, plant and human nutrition. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 88(2), pp.429-434.

Rodrigues, C.I.D., Brito, L.M. and Nunes, L.J. (2023). Soil carbon sequestration in the context of climate change mitigation: A review. Soil Systems, 7(3), p. 64.

Rodrigues, J.R., Solander, K.C., Cropper, S., Newman, B.D., Collins, A.D., Warren, J.M., Negron-Juarez, R., Gimenez, B.O., Spanner, G.C., Menezes, V.D.S. and Ríos-Villamizar, E.A. (2024). Soil water percolation and nutrient fluxes as a function of topographical, seasonal and soil texture variation in Central Amazonia, Brazil. Hydrological Processes, 38(4), pp. e15148.

Sharma, P.K. and Kumar, S. (2023). Soil Physical Environment and Plant Growth. Berlin/Heidelberg, Germany: Springer.

Soil Survey Staff. (2003). Keys to Soil Taxonomy. 9th Edition, United States Department of Agriculture, United States Department of Agriculture Natural Resources Conservation Service, p. 322.

Szogi, A.A., Shumaker, P.D., Billman, E.D. and Bauer, P.J. (2021). Leaching Potential of Phosphite Fertilizer in Sandy Soils of the Southern Coastal Plain, USA. Environments, 8(11), p.126.

Tan, K.M. (1996). Soil sampling preparation and analysis. In: African Research Review (Volume 3, 23-33). Mercel Dekkes Inc., New York, Basel, Hong Kong

Udo, E.J., Ogunwale, J.A., Fagbami, A., Ano, A.O. and Esu, I.E. (2009). Manual of soil, plant and water resources. Sibon books limited, p. 177.

Udoh, B.T. and Ibia, T.O. (2022). Fertility capability classification for agricultural land use planning in the beach sands area of Akwa Ibom State, Nigeria. Agro-Science, 21 (2), pp.74-78

Valencia, V.A.M., Casas, A.F., Pinto, D.J.M.P.M. and Rosas, R. (2025). Soil Organic Carbon Storage in Different Land Uses in Tropical Andean Ecosystems and the Socio-Ecological Environment. Preprints.org, pp. 1-13.

Walkley, A and Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic matter and the proposed modification of the chromic acid wet titration method. Journal of Soil Science, 37, pp. 29-38.

Wang, C., Mao, Q., Mori, T., Huang, J., Mo, H., Mo, J. and Lu, X. (2023). Resource allocation theory reveals sulfur shortage for microbes under phosphorus amendment in tropical forests with divergent land use history. Soil Biology and Biochemistry, 184, p. 109126.

Yan, X., Yang, W., Muneer, M.A., Zhang, S., Wang, M. and Wu, L. (2021). Land-use change affects stoichiometric patterns of soil organic carbon, nitrogen, and phosphorus in the red soil of Southeast China. Journal of Soils and Sediments, 21(7), pp. 2639-2649.