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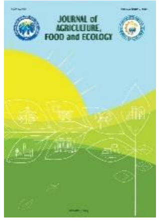

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The Influence of Soil Dynamics on Physico-Chemical Properties of Teak and Coconut Cultivation Soils

Isaiah Ufuoma EFENUDU[a*], Anthonia Osayanmon BAKARE[b]

[a,b]Department of Soil Science and Land Management, Faculty of Agriculture, University of Benin, Benin City, Edo State

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Abstract

This study investigated the influence of soil dynamics on soil physico-chemical properties in teak and coconut cultivation soils. The rationale for this study stems from the critical knowledge gap in understanding how soil dynamics differentially impact these agroecosystems, which are vital for tropical agriculture yet prone to degradation. Soil samples were collected from different depths (0–30 cm, 30–60 cm, 60–90 cm, and 90–120 cm) and analyzed for various physical and chemical properties. The results showed significant correlations between organic carbon (2.23–8.43 g/kg), total nitrogen (0.23–0.83 g/kg), electrical conductivity (90.33–110.33 µS/cm), exchangeable acidity (1.73–2.33 cmol/kg), and available phosphorus (0.61–1.42 mg/kg). The study found that soils in the coconut cultivation area tend to be more acidic than those in the teak cultivation area, with pH levels ranging from 4.87 to 5.20. Soil texture varied with depth, with sand content ranging from 744.1 to 835.0 g/kg and clay content ranging from 112.0 to 242.5 g/kg. Both cultivation areas had relatively high levels of organic carbon and organic matter, which can improve soil fertility and structure. The findings highlight the importance of integrated soil management practices that consider interactions between soil properties. Regular soil testing and monitoring are recommended to maintain optimal soil conditions for plant growth. These insights are critical for addressing soil degradation challenges and promoting sustainable agriculture in tropical regions.

Keywords: Soil dynamics; physico-chemical properties; teak and coconut cultivation areas; soil fertility; sustainable soil management;

1. Introduction

Soil dynamics play a pivotal role in shaping the physical and chemical properties of soils, which in turn influence plant growth, ecosystem health, and environmental sustainability [1]. Teak (Tectona grandis) and coconut (Cocos nucifedra) are two economically significant crops in tropical regions, valued for their timber, food, oil, and fiber [2, 3]. However, the intensive cultivation of these crops often leads to soil degradation, nutrient depletion, and environmental pollution [4]. Understanding the influence of soil dynamics on soil properties in teak and coconut cultivation areas is essential for developing sustainable soil management practices [5]. Soil physical properties, such as texture, structure, and porosity, are significantly influenced by soil dynamics. For instance, soil

* *Efenudu I. U.*
Email: isaiah.efenudu@gmail.com
https://orcid.org/ 0000-0002-0931-5135

compaction—caused by heavy machinery or foot traffic—can reduce soil porosity and increase soil density, leading to poor aeration, reduced water infiltration, and restricted root growth [6]. Similarly, soil chemical properties, including pH, nutrient availability, and contaminant levels, are also affected by soil dynamics. Intensive fertilizer use or acidic rainfall, for example, can cause soil acidification, reducing pH and increasing the availability of toxic elements like aluminum and manganese [7]. These changes can have profound impacts on soil fertility and ecosystem health. Reduced soil pH increases the availability of toxic elements such as aluminum and manganese, which can harm plant roots and inhibit nutrient uptake [8]. This, in turn, negatively impacts soil fertility, crop productivity, and overall ecosystem health. Additionally, acidification can alter microbial activity and nutrient cycling, further degrading soil quality and sustainability [9]. The interaction between soil dynamics and soil properties in teak and coconut cultivation areas is complex and multifaceted, influenced by factors such as soil type, climate, vegetation, and management practices [10]. Teak and coconut cultivation areas are often established on a range of soil types, from sandy to clayey. Sandy soils are prone to erosion and nutrient leaching, while clayey soils are susceptible to waterlogging and reduced aeration [11]. Climate variables, such as temperature, rainfall, and solar radiation, further influence soil dynamics. High temperatures and rainfall can exacerbate soil erosion and nutrient leaching, while low temperatures and rainfall can hinder plant growth and increase soil acidity [12]. Vegetation also plays a critical role in shaping soil properties. Teak trees, with their deep root systems, enhance soil aeration and reduce compaction, while coconut trees, with their shallow roots, have different impacts on soil structure and nutrient cycling [13]. Management practices, such as fertilizer application, irrigation, and pruning, further influence soil health. For example, excessive fertilizer use can lead to soil acidification and nutrient leaching, whereas sustainable practices like organic amendments can improve soil fertility and structure [14]. The consequences of soil degradation in teak and coconut cultivation areas are far-reaching, affecting soil health, plant growth, and ecosystem services [15]. Sustainable soil management practices, such as conservation tillage, cover cropping, and organic amendments, are essential for maintaining soil health, reducing greenhouse gas emissions, and promoting ecosystem resilience [16, 17]. Recent studies emphasize the role of integrated soil management in tropical agroecosystems, yet comparative analyses of teak and coconut systems remain limited [18, 19]. This study aims to: (1) investigate the influence of soil dynamics on the physical and chemical properties of soils in teak and coconut cultivation areas, providing insights into sustainable management strategies for these vital agroecosystems, and (2) examine the correlation coefficients between soil properties to better understand their interrelationships and their impact on soil health and productivity.

2. Materials and Methods

Soil Sampling and Preparation: Soil samples were collected from coconut and teak cultivation areas located within the University of Benin, Ovia North East Local Government Area of Edo State, Nigeria. The coconut cultivation area is situated beside the old Faculty of Agriculture building, while the teak cultivation area is located in front of the Vice Chancellor's lodge. Geographically, the sites lie between latitudes 6°23'59.106"N and 6°24'13.844"N and longitudes 5°37'23.994"E and 5°37'39.062"E. The sampling sites were selected based on their representativeness, accessibility, and agricultural significance [1]. A factorial experiment design was employed, with samples collected at four depths: 0–30 cm, 30–60 cm, 60–90 cm, and 90–120 cm, using a soil auger. A total of 24 samples were collected from different locations, following a 2×4×3 factorial arrangement in a completely randomized design. The collected soil samples were air-dried, crushed, sieved (2 mm), and stored in airtight containers for analysis [2].

Laboratory Analysis of Soil Samples: Soil pH: Determined using the soil:water (1:1) method [18]. Particle size distribution: Determined using the hydrometer method [8]. Organic carbon (Org.C): Analyzed via wet oxidation methods [19]. Organic matter (Org.M): Calculated by multiplying organic carbon by a factor of 1.724 [13]. Exchangeable acidity (EA): Determined using Jackson's method [10]. Exchangeable cations (Ca, Mg, K, Na): Calcium (Ca) and magnesium (Mg) were determined from the extract of 0.01M EDTA [10]. Potassium (K) and sodium (Na) were determined using a photometer [10]. Total nitrogen (T.N) and available phosphorus (Av.P): Determined using the Bremner and Mulvaney method [7].

Statistical Analysis: The data obtained were analyzed using the Genstat statistical package. Differences between means were separated using Duncan's Multiple Range Test at a 5% probability level to determine significant differences among treatment means.

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3. Results

Table 1. Physical and chemical properties in soils from coconut and teak cultivation areas

Depth (cm)	pH	EC	Org. C	Org. M	T. N	EA	Na	K	Ca	Mg	Av. P	Sand	Clay	Silt
		µS/cm	→	g/kg	←	→		mg/kg of soil	←			→	g/kg	←
COCONUT FARM														
0-30	5.10a	110.33a	8.43a	14.43a	0.83a	1.73b	0.18a	0.44a	0.96a	0.72a	1.42a	835.0a	112.0b	53.00a
30-60	5.20a	95.00b	5.30b	9.10b	0.50b	1.8b	0.14a	0.34b	0.74b	0.56b	0.87b	791.7ab	178.7a	29.67b
60-90	4.87b	90.33c	2.23d	3.67d	0.23c	2.33a	0.06b	0.15d	0.33d	0.25d	0.61d	744.1b	222.7a	33.20b
90-120	5.10a	94.33b	5.07c	8.40c	0.53b	1.77b	0.13a	0.24c	0.54c	0.37c	0.63c	734.1b	242.5a	23.33b
MEAN	5.07	97.5	5.26	8.9	0.53	1.91	0.13	0.29	0.65	0.48	0.88	776.2	189	34.8
TEAK FARM														
0-30	5.0a	128.0a	7.40a	12.70a	0.70a	1.60c	0.35a	0.88a	1.93a	1.45a	1.21a	858.3a	88.7c	53.00a
30-60	4.67b	97.7d	4.07d	6.43d	0.47b	2.73a	0.15d	0.37d	0.83d	0.63c	0.87b	791.7b	181.7b	26.67b
60-90	4.50c	115.0b	6.10b	10.50b	0.60a	2.60b	0.32b	0.80b	1.74b	1.31b	1.04ab	754.3c	211.7ab	34.00b
90-120	4.53c	113.3c	4.83c	8.20c	0.40b	2.54b	0.29c	0.73c	1.63c	1.23b	0.75b	734.3c	241.7a	24.00b
MEAN	4.68	113.5	5.6	9.46	0.54	2.37	0.28	0.69	1.53	1.16	0.97	784.7	180.9	34.4

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability.

4. Discussions

Soil Texture in Teak and Coconut Cultivation Areas: The texture of soils in teak and coconut cultivation areas exhibited significant vertical heterogeneity (Table 1). In the coconut farm, sand content decreased with depth (835.0 g/kg at 0–30 cm to 734.1 g/kg at 90–120 cm), while clay content increased (112.0 to 242.5 g/kg). Similarly, in the teak farm, sand content declined from 858.3 g/kg (0–30 cm) to 734.3 g/kg (90–120 cm), with clay content rising from 88.7 to 241.7 g/kg. These trends align with typical pedogenic processes in tropical soils, where weathering and illuviation redistribute finer particles to deeper horizons [8]. The dominance of sand (mean: 776.2–784.7 g/kg) underscores the inherent challenges of nutrient leaching and low water retention in these soils [10]. However, the substantial clay content (mean: 180.9–189 g/kg) in deeper layers suggests potential for nutrient retention, albeit with risks of compaction and reduced aeration in clay-rich zones [12]. The low silt content (24.0–53.0 g/kg) further limits the soils' ability to balance drainage and moisture retention, a critical factor for crop productivity in rain-fed tropical systems [9]. These findings corroborate studies by Agbede et al. [6], who reported similar textural profiles in degraded Ultisols under teak plantations in Nigeria. The high sand fraction likely reflects the residual nature of these soils, derived from weathered parent materials under intense tropical conditions [5].

Soil Chemical Properties in Teak and Coconut Cultivation Areas: The coconut farm exhibited marginally higher pH (mean: 5.07) than the teak farm (mean: 4.68), though both were acidic (Table 1). This acidity is consistent with tropical soils where high rainfall accelerates base cation leaching and organic matter mineralization [15]. The lower pH in the teak farm may stem from greater organic acid production from leaf litter decomposition, a phenomenon documented in Tectona grandis systems by Kumar et al. [3]. Despite the acidity, exchangeable Al^{3+} levels (indirectly inferred from EA values: 1.73–2.33 cmol/kg) remained below toxicity thresholds for most crops, as defined by Sumner [17]. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) varied significantly between farms. The teak farm had higher Ca^{2+} (1.53 vs. 0.65 cmol/kg) and Mg^{2+} (1.16 vs. 0.48 cmol/kg), likely due to deeper root systems mobilizing subsurface nutrients [13]. In contrast, the coconut farm showed elevated Na^{+} (0.13 vs. 0.28 cmol/kg), potentially linked to irrigation practices or proximity to saline groundwater [14]. These trends highlight the role of vegetation type in shaping cation dynamics, as coconut's shallow roots favor surface nutrient uptake, while teak's deep roots access subsoil reserves [7]. Organic carbon (Org.C) and total nitrogen (T.N) were moderately high in both farms (Org.C: 2.23–8.43 g/kg; T.N: 0.23–0.83 g/kg), reflecting the tropical climate's rapid organic matter turnover [19]. The strong correlation between Org.C and T.N ($r = 0.988$, coconut farm; $r = 0.906$, teak farm) underscores the interdependence of carbon and nitrogen cycling, mediated by microbial activity [2]. However, available phosphorus (Av.P: 0.61–1.42 mg/kg) was critically low, particularly in the teak farm, where high Fe/Al oxide content likely immobilized P into insoluble forms [4]. This aligns with Lal's [2] observations of P deficiency as a key constraint in tropical agroecosystems.

Table 2. Correlation coefficient between some soil physical and chemical properties from coconut farm cultivation area

	pH	EC	Org.C	T. N	EA	Na	K	Ca	Mg	Av. P	Sand	Clay	Silt
pH	1												
EC	0.449	1											
Org.C	0.661*	0.939*	1										
T. N	0.590*	0.944*	0.988*	1									
EA	-0.810*	-0.613*	-0.844*	-0.796*	1								
Na	0.825*	0.869*	0.955*	0.916*	-0.848*	1							
K	0.781*	0.902*	0.959*	0.937*	-0.797*	0.991*	1						
Ca	0.785*	0.900*	0.962*	0.938*	-0.807*	0.993*	0.999*	1					
Mg	0.789*	0.897*	0.961*	0.936*	-0.807*	0.993*	0.999*	0.999*	1				
Av. P	0.528*	0.972*	0.897*	0.889*	-0.555*	0.890*	0.924*	0.921*	0.919*	1			
Sand	0.558*	0.759*	0.713*	0.708*	-0.441	0.761*	0.797*	0.791*	0.791*	0.825*	1		
Clay	-0.499	-0.800*	-0.722*	-0.714*	0.410	-0.758*	-0.795*	-0.789*	-0.789*	-0.863*	-0.990*	1	
Silt	0.166	0.797*	0.613*	0.592*	-0.202	0.597*	0.629*	0.626*	0.621*	0.838*	0.753*	-0.837*	1

*Significantly correlated at 5% level of probability.

Table 3. Correlation coefficient between some soil physical and chemical properties from teak farm cultivation area

	pH	EC	Org.C	T. N	EA	Na	K	Ca	Mg	Av. P	Sand	Clay	Silt
pH	1												
EC	0.529*	1											
Org.C	0.585*	0.916*	1										
T. N	0.602*	0.665*	0.906*	1									
EA	-0.869*	-0.867*	-0.822*	-0.668*	1								
Na	0.238	0.948*	0.855*	0.580*	-0.664*	1							
K	0.239	0.949*	0.848*	0.565*	-0.666*	0.999*	1						
Ca	0.246	0.950*	0.858*	0.583*	-0.673*	0.999*	0.998*	1					
Mg	0.245	0.949*	0.863*	0.594*	-0.672*	0.998*	0.997*	0.999*	1				
Av. P	0.708*	0.930*	0.975*	0.859*	-0.902*	0.821*	0.817*	0.822*	0.823*	1			
Sand	0.962*	0.450	0.555*	0.626*	-0.786*	0.171	0.170	0.175	0.175	0.672*	1		
Clay	-0.959*	-0.526*	-0.627*	-0.675*	0.823*	-0.261	-0.259	-0.264	-0.264	-0.737*	-0.992*	1	
Silt	0.806*	0.749*	0.817*	0.771*	-0.851*	0.577*	0.575*	0.576*	0.576*	0.885*	0.820*	-0.882*	1

*Significantly correlated at 5% level of probability.

Correlation Analysis and Management Implications from Teak and Coconut Cultivation Areas: The robust correlations between Org.C and key nutrients (T.N, Av.P) in both farms (Tables 2 and 3) emphasize organic matter's role as a nutrient reservoir. For instance, the positive Org.C–Av.P relationship (r = 0.897, coconut farm) suggests that organic acids enhance P solubility by chelating Fe/Al ions, a mechanism detailed by Havlin et al. [9]. These findings advocate for organic amendments (e.g., compost, green manure) to improve nutrient availability, particularly in P-deficient soils [16]. Although electrical conductivity (EC: 90.33–128.0 μS/cm) did not indicate acute salinity, the correlation between EC and Na^+ (r = 0.869, coconut farm) signals incipient sodicity risks. Over time, Na^+ accumulation could degrade soil structure by dispersing clay particles, reducing hydraulic conductivity [18]. Regular monitoring and gypsum application are recommended to mitigate sodium hazards, as proposed by Rhoades et al. [14]. The negative correlations between exchangeable acidity (EA) and nutrients (e.g., EA vs. Org.C: r = -0.844, coconut farm) highlight acidity-driven nutrient depletion. Liming (2–4 t/ha of agricultural lime) could neutralize Al^{3+} toxicity and improve Ca^{2+} availability, aligning with Brady and Weil's [5] recommendations for tropical acid soils.

5. Conclusion

The study demonstrates the complex relationships between various soil physical and chemical properties in teak and coconut cultivation areas The results emphasize the importance of integrated soil management practices that consider the interactions between different soil properties. Specifically, the study found that: Organic carbon content ranged from 2.23 to 8.43 g/kg, with a mean value of 5.26 g/kg. Total nitrogen content ranged from 0.23 to 0.83 g/kg, with a mean value of 0.53 g/kg. Electrical conductivity values ranged from 90.33 to 110.33 μS/cm, with a mean value of 97.5 μS/cm. Exchangeable acidity values ranged from 1.73 to 2.33 cmol/kg, with a mean value of 1.91 cmol/kg. Available phosphorus content ranged from 0.61 to 1.42 mg/kg, with a mean value of 0.88 mg/kg. The coconut farm soils tend to be more acidic than the teak farm soils. Both farms have relatively high levels of organic carbon and organic matter, which can help to improve soil fertility and structure. These findings have significant implications for soil fertility management, soil salinity management, and sustainable agriculture in tropical regions.

Recommendation

In summary, the study recommends implementing integrated soil management practices that include: Managing soil organic carbon through conservation agriculture practices, implementing soil salinity management strategies, conducting regular soil testing to monitor soil physical and chemical properties, maintaining optimal pH levels through liming, using salt-tolerant crops or implementing drainage systems to mitigate soil salinity.

Ethics Approval and Consent to Participate

The study was conducted with ethics approval from the University of Benin, Department of Soil Science and Land Management, Faculty of Agriculture, and the relevant national guidelines. Written informed consent was obtained from all participants before data collection.

Consent for Publication

All participants provided consent for the publication of their data.

Availability of Data and Materials

The datasets used and analyzed in this study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no competing interests.

Author Contributions

Isaiah Ufuoma EFENUDU and Anthonia Osayanmon BAKARE conceived and designed the study, collected and analyzed the data, and drafted the manuscript.

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