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Impact of Forest Management Types on Soil Properties and Soil Organic Carbon Storage in Benue State, Nigeria

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ABSTRACT

Forest management practices influence soil fertility and nutrient availability through different mechanisms. Despite the importance of soil fertility and nutrient availability in forest ecosystems, there is limited research on the effects of management practices on soil properties in mixed-species forests. This study investigates the impact of different management types (community forest area (CFA), Forest area (FR), and Sacred Grove (SG)) on soil physicochemical properties, organic matter, and organic carbon storage in Benue State, Nigeria. Soil samples from three forest management types were collected and analyzed using established laboratory standard procedures. Descriptive statistics, analysis of variance, and correlation analysis revealed significant differences ($p<0.05$) in soil texture, pH, organic carbon, and total nitrogen across the management types. CFA and FR were predominantly sandy loam soils, while SG had higher clay loam content. Soil pH ranged from 4.82 – 6.07 with SG having the highest pH value (6.07). The forest reserve has the highest sand content (75.0%) and SG has the highest clay content (34.6%). The highest soil organic matter content (3.13%) was recorded under CFA, while organic carbon of 1.83% was recorded under FR. The highest values of Mg (0.97 Cmol/kg), N (0.28%), P (3.77 ppm), K (0.20 Cmol/kg) Na (0.18 Cmol/kg), and Ca (1.24 Cmol/kg) were at their peak under the Sacred grove management types. Thus, the various types of forest management significantly impact soil properties and organic carbon content in the study area. It is recommended that SG or CFA management should be adopted for forest resource conservation in the study area.

***Keywords*:** Forest management, Organic matter, Soil carbon, Soil conservation, Sustainable management

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1. INTRODUCTION

Forest ecosystems are crucial in maintaining soil fertility and nutrient availability, which are essential for sustainable forest management (Page-Dumroese *et al.*, 2021; Antwi *et al.*, 2024). Natural tropical forests in Benue State, Nigeria, are managed under various forest management types, including Community Forest Areas, Forest Reserves, and Sacred Groves. These management types can impact soil properties (physical and chemical), soil organic contents (organic carbon and organic matter), and nutrient availability (Bezabih *et al.*, 2016).

Forest management types practised in the study area have evolved, from traditional to modern management approaches. Among the traditional forest management practices in Nigeria, the Sacred Groves system is the most prominent (Onyekwelu, 2021). Sacred groves are forests set aside for cultural and spiritual purposes. Modern management approaches include the establishment of Forest Reserves, which are conservation forests that are managed principally for timber production, and Community Forest Areas, which are managed by local communities for multiple purposes.

These forest management types can influence soil formation, nutrients, and microorganisms over time (Colombo *et al.*, 2015; Mayer *et al.*, 2020). Soil fertility and nutrient availability are critical components of forest ecosystems, influencing tree growth, site productivity, and ecosystem services (Hansson *et al.*, 2020; Antwi *et al.*, 2024). Soil physical properties, such as texture and structure, affect water infiltration, aeration, and root growth (Morel *et al.*, 2005; Munnaf *et al.*, 2020). Soil chemical properties, such as pH and nutrient availability, affect tree nutrition and site productivity (Morel *et al.*, 2005; Robbins *et al.*, 2021).

Forest management practices can impact soil fertility and nutrient availability through different mechanisms (Mayer *et al.*, 2020). For instance, different tree species have varying nutrient requirements and litter quality, affecting soil nutrient availability (Haghverdi and Kooch, 2019; Amorim *et al.*, 2022). Litter production and decomposition rates vary among tree species, affecting soil organic carbon and nutrient availability (Krishna and Mohan, 2017; Giweta, 2020). Forest management practices, such as logging and thinning, can disturb soil structure and affect soil physical properties (Eroğlu *et al.*, 2016). Also, forest management practices can affect nutrient cycling, with implications for soil nutrient availability (Nazari *et al.*, 2021; Page-Dumroese *et al.*, 2021; Effiom, 2022).

Despite the importance of soil fertility and nutrient availability in forest ecosystems, there is scanty published research on the effects of forest management practices on soil properties natural tropical forest ecosystems, especially in Benue State, Nigeria. Consequently, this study was designed to contribute in closing this knowledge gap by providing baseline information on the soils of the study forest management types. This study investigated the effects of three tropical forest management types in Benue State, Nigeria on soil physical and chemical properties, soil organic carbon, and soil nutrient availability.

2. MATERIALS AND METHOD

Location of Soil Collection

Soil samples were collected from three forest management types (Community Forest Areas (CFAs), Forest Reserves (FRs), and Sacred Groves (SGs)) in Benue State, Nigeria. For the soil sample collection, a total of six sites were sampled, comprising of two CFA, two FR, and two SG sites using purposive sampling methods. All the forest management types are situated in Benue state, Nigeria. The State is located between latitude 6° 25' and 8° 8' north and longitude 7° 47' and 10° 0' east. Benue State covers 34,059 square kilometers of land. Oranges, mangoes, sweet potatoes, cassava, soya beans, flax, yams, sesame, rice, groundnuts, and palm fruits are the prominent crops farmed in the state (Vange *et al.*, 2021).

Steep mountains, deep incised valleys, and harsh contours are common geographical features in the study area (Akintola, 2013). Benue State has diverse geology, featuring basement and sedimentary rocks (Akpen *et al.*, 2019). Sedimentary basins contain cretaceous to tertiary sediments, while igneous and metamorphic rocks dominate other areas. The region is rich in mineral deposits, including coal, lead-zinc, barytes, and gemstones (Fatoye and Gideon, 2013).

The climate is classified as Tropical Moist (AW), with a wet season lasting from April to October and a dry season spanning November to March. Annual rainfall ranges from 1120 to 1500 mm, with temperatures between 27-38 °C and relative humidity between 60-80% (Dau and Chenge, 2016). The vegetation is primarily Southern Guinea Savanna, characterized by thick forests, tall grasses, herbs, and riparian forests along streams. Common tree species include *Prosopis africana*, *Detarium microcarpum*, *Khaya senegalensis*, *Daniellia oliveri*, *Terminalia avicennioides* and *Nauclea latifolia* (Akintola, 2013; Fatoye and Gideon, 2013; Akpen *et al*., 2019).

Soil Sample Collections

Before the field survey, plot locations were delineated on high-resolution satellite imagery using Google Earth Pro (Desktop 7.1.4 version) to facilitate easy access to sample plots in the field (Japheth and Meer, 2023). In this study, random values generated by Microsoft Excel were used to select five coordinates on the Google Earth Pro map. Five points in each forest type were marked as starting points for plots laying, along with their coordinates using the (Universal Transverse Mercator (UTM) projection method commonly employed in Nigeria (Chenge and Osho, 2018). The points were then transferred to a Garmin e-Trex 10 GPS for field tracking. Five sample plots (35 × 35 m) were established at each coordinate point, following the FAO (2020) guidelines. A total of fifteen (15) sample plots were laid per forest type and 45 plots for the entire study. Soil samples were systematically collected within each plot at a depth between 0 - 30 cm, using a soil auger as described by Amonum *et al*. (2020). Collected soil samples were thoroughly mixed (bulked) from which composite samples were collected in triplicate before storing in the polythene bag for easy identification (Onyekwelu *et al.*, 2006 and 2008). Before laboratory analysis, the samples were air-dried, crushed, and sieved using a 2 mm sieve.

Laboratory procedure

Analyses of soil physicochemical properties and soil carbon were undertaken at the Laboratory of Soil Science Department, Nasarawa State University, Lafia campus, Nigeria. Standard laboratory procedures were followed during the soil analyzes. The Bouyoucos hydrometer method, with sodium hexameta-phosphate as a dispersing agent, was employed to determine soil texture and particle size fractions (Bouyoucos, 1962; Day, 1965). Soil pH was determined using a glass electrode in 1:1 soil-water suspension, with 1M potassium chloride (Van Reeuwijk, 1992). Soil organic carbon was determined using the wet-oxidation method developed by Walkley and Black (1934).

The soil samples were analyzed for various nutrients using established methods. Total Nitrogen was determined using micro-Kjeldahl method with selenium catalyst, which involved digestion, distillation, and titration (Bremner 1965). Available Phosphorus was measured using the Bray (P-1) acid Fluoride method (Olsen *et al*., 1954). Exchangeable bases, including Calcium, Magnesium, Potassium, and Sodium, were extracted using ammonium acetate (1N $NH_4C_2H_3O_2$) at a pH of 7.0, as described by FAO (2022).

Data Analysis

The data collected were analyzed using various statistical techniques to determine the effects of forest management practices on soil fertility and nutrient availability. Descriptive statistics, such as means and standard deviations, were calculated for each soil property (pH, organic carbon, nitrogen, phosphorus, potassium, and bulk density) across the three forest management types (CFA, FR, and SG). ANOVA was used to test significant differences in soil properties among the three forest management types at 0.05 levels. Post-hoc analysis (LSD) was used to separate treatment means (i.e. forest management types) found to be significantly different. Correlation analysis was used to investigate relationships between soil properties.

3. RESULTS

Soil Properties and Soil Organic Carbon

Soil physical properties

The results of soil physical properties for the three forest management types evaluated in this study are presented in Table 1.

Table 1. Physical properties of the Soil of three forest management types in Benue State, Nigeria

Forest types	Sand (%)	Silt (%)	Clay (%)
CFA	74.8±2.48 ^{a}	6.4±1.10 ^{a}	18.8±4.23 ^{b}
FR	75.0±4.47 ^{a}	6.4±1.10 ^{a}	18.6±5.55 ^{b}
SG	60.0±3.29 ^{b}	5.4±1.10 ^{a}	34.6±3.29 ^{a}
p-value	**0.000**	**0.116**	**0.000**

Values in columns with different superscripts (alphabets) are significantly different ($p \leq 0.05$)

Based on the results of soil *p*H (mean pH values: 4.82±1.89, 5.90±0.14, and 6.06±0.08 for FR, CFA and SG, respectively) of the study areas (Figure 1), the soils of forest reserve are generally acidic, however, those of community forest area and sacred grove are neutral (Figure 1). Forest Reserve had the highest mean percentage (75.0±4.47 %) sand content, followed by CFA with a mean sand content of 74.8±2.48%, while SG had the lowest mean percentage sand content of 60.0±3.29 % compared to the other forest management types. Results revealed that CFA and FR soils had equal mean silt content of 6.4±1.10%, while SG had a lower mean silt content of 5.4±1.10%. The soil of SG had the highest mean percentage clay content of 34.6±3.29% while CFA and FR had almost equal clay contents of 18.8±4.24% and 18.6±.55%, respectively (Table 1).

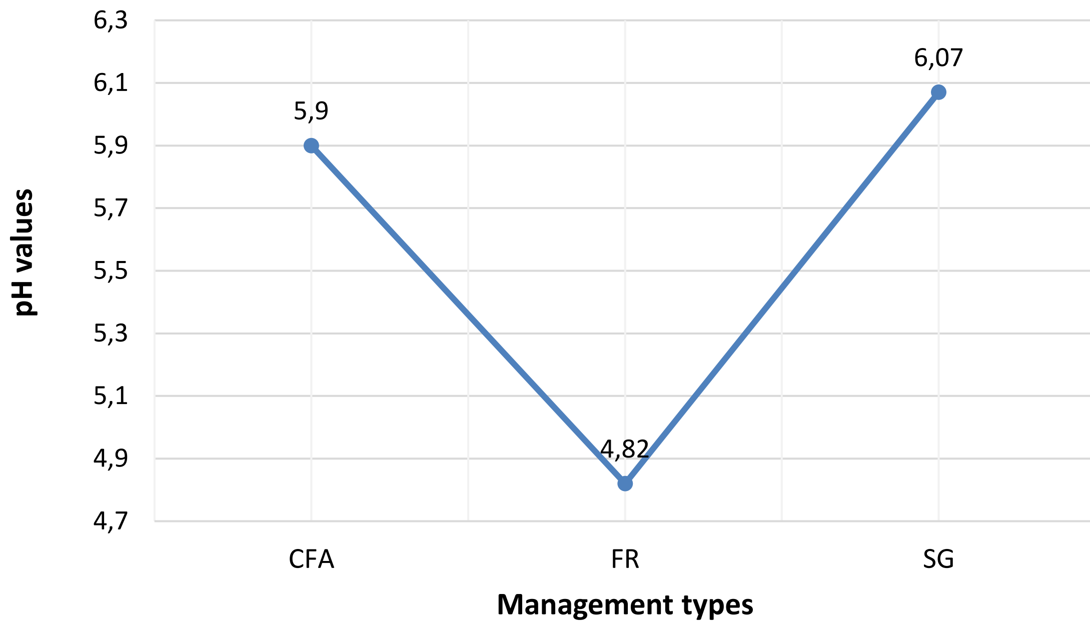

Figure 1. Soil pH across the three forest management types in the study area

The results of analysis of variance for pH, sand, clay, and silt contents of the three forest management types, revealed a significant difference ($p<0.05$) in their soil physical properties, except for silt content that showed no significant difference ($p=1.116$) (Table 1). The results of mean separation indicated that CFA and FR had statistically similar sand contents, however, both CFA and FR had significantly higher sand content than SG. (60.0±3.29%). Thus, the soil texture in SG is different and contains less sand than those of CFA and FR. On the other hand, there existed a significantly higher clay content in the SG site (34.6±3.29%) than those of FR (18.18±4.23%) and CFA (18.6±5.55%), which were not significantly different from each other (Table 1).

Soil Chemical Properties

The results of the chemical properties of the soils of the three forest management types are presented on Table 2. Magnesium (Mg) content (0.97 Cmol/kg) was highest in the soil from SG. The magnesium content of the CFA was 0.79 Cmol/kg, which was lower than that of SG. With a magnesium content of 0.77±0.23 Cmol/kg, the FR soil had the lowest magnesium content among the three management types. The mean Nitrogen (N) content of the soils of the study forests were 0.22±0.05 % in CFA, 0.23±0.16 % in FR and 0.28±0.0 % in soils under SG. Thus, SG soils exhibited a higher nitrogen content, suggesting enhanced soil fertility and increased nutrient availability. Phosphorus content were: 2.70±0.70 ppm in CFA, 2.71±0.70 ppm for soil from FR and 3.67±0.02 ppm for soils under SG, indicating that the highest soil Phosphorus content was obtained under SG while the lowest value was from CFA soils. The soil from SG had the highest potassium (K) content of 0.20±0.02 Cmol/kg, followed by soils from CFA with a Potassium content of 0.16±0.02 Cmol/kg, while the lowest soil Potassium content (0.14±0.07 Cmol/kg) was from soil from FR. In all three forest management types, sodium (Na) concentration levels was similar, particularly between the CFA and FR. Results indicated that soils from SG had a mean Na content of 0.18 ±0.01 Cmol/kg, while soils from CFA and FR had Na contents of 0.15 ±0.03 Cmol/kg and 0.15 ±0.07 Cmol/kg, respectively.

Table 2. Soil Chemical Properties of Different Forest Management in the Study Area

Forest Mgt types	Mg (Cmol/kg)	N (%)	P (ppm)	K (Cmol/kg)	Na (Cmol/kg)	Ca (Cmol/kg)
CFA	$0.79±0.00^{b}$	$0.22±0.05^{a}$	$2.70±0.26^{a}$	$0.16±0.02^{ab}$	$0.15±0.03^{a}$	$0.99±0.03^{b}$
FR	$0.77±0.23^{b}$	$0.23±0.16^{a}$	$2.71±1.46^{a}$	$0.14±0.07^{b}$	$0.15±0.07^{a}$	$0.96±0.03^{b}$
SG	$0.97±0.00^{a}$	$0.28±0.00^{a}$	$3.67±0.02^{a}$	$0.20±0.02^{a}$	$0.18±0.01^{a}$	$1.24±0.01^{a}$
***p*-value**	**0.041**	**0.570**	**0.110**	**0.054**	**0.375**	**0.042**

Values in columns with different superscripts are significantly different ($p \leq 0.05$)

Table 3. Soil Organic Carbon and Organic Matter Storage of the three Forest Management Types

Forest Management Type	OC (%)	OM (%)
CFA	$1.82±0.02^{a}$	$3.13±0.03^{a}$
FR	$1.83±72.7^{a}$	$3.12±0.06^{a}$
SG	$1.80±0.01^{a}$	$3.10±0.02^{a}$
***p*-value**	**0.391**	***0.528***

Values in columns with similar superscripts are not significantly different ($p \leq 0.05$)

The results of the Analysis of Variance indicated that there were no significant differences in the N (%), P (ppm), and Na (Cmol/kg) contents of the soils from the three forest management types in the study area. However, there were significant differences ($p<0.05$) in the Mg (Cmol/kg) and Ca (Cmol/kg) contents of the soils from the three forest management types. Sacred grove had significantly higher Mg (0.97 Cmol/kg) and Ca (1.24 Cmol/kg) contents than CFA (Mg content of 0.79 Cmol/kg and Ca 0.99 of Cmol/kg) and FR (Mg content of 0.77 Cmol/kg and Ca of 0.96 Cmol/kg), which were not significantly different from each other.

The SG had the highest K (potassium) content, followed by CFA, while FR had the lowest K content. However, the p-value of 0.054 indicates that the K contents of the three forest management types were not statistically significant at the 0.05 level.

Table 3 presents the results of soil organic carbon (OC) and soil organic matter (OM) for three forest management types. The average OC content was 1.82±0.02 under CFA while OM content for this forest type was 3.13±0.03%.

The soil of FR had an OC content of 1.83±72.7% and an OM content of 3.12±0.06% while the OC and OM contents of the sol of SG were 1.80±0.01% and 3.10±0.02%, respectively. Results of the analysis of variance revealed soil OC and OM of the three forest management types did not differ significantly ($p>0.05$) (Table 3).

4. DISCUSSION

Soil Physical Properties

Soil texture analysis revealed a predominant sand composition, with sand constituting over 65% of the soil particle distribution (range: 60.0 - 75.0 %) of the three forest management types. In contrast, the amounts of silt and clay (silt range: 5.4 - 6.4 %, and clay: 17.1 – 34.6 %) in the three forest types are substantially lower, confirming the prevalence of sandy soils in the three forest types. A comparison of the soil physical properties of the CFA and SG revealed differences in their texture, particularly in the proportions of sand and clay, suggesting the influence of forest management types among other factors on the physical properties of the soils the study forests.

The sand and silt contents of the soils of three our forest types are lower than the percentage of sands (71.2-84.2 %) and silts (7.4-10.4 %) reported by Opeyemi *et al.* (2020) for Gambari Forest Reserve, Nigeria. The clay percentage range (17.1 – 34.6 %) observed in this study is higher than the values reported by Opeyemi *et al.* (2020) in their research. The result on the physical properties of soil in this study, aligned with the report of Unanaonwi and Chinevu (2013), who studied and reported sand particle size distribution of 74.96%, clay contents of 17.04 % and silt value of 8% in forest soil in Nasarawa state, located within the Southern Guinea Savanna of Nigeria. Our result is consistent with the report of Schweizer *et al.* (2021) who reported a clay value of between 18% and 37% in an arable toposequence in the north of Munich, Germany.

It has been demonstrated that soils with higher clay content tend to have greater carbon storage capacity due to higher organic matter content and better aggregation (Han *et al.*, 2010; Ontl and Schulte, 2012). Therefore, SG soils with higher clay content potentially stored more carbon than soils with lower clay content, such as those of CFA and FR. The variation in soil physical property observed in this study can impact soil biodiversity and habitat quality according to Doula and Sarris (2016). Burton *et al.* (2022) observed that differences in soil properties in different forest management types can affect the diversity and abundance of soil organisms, ultimately influencing ecosystem health and resilience.

For example, variations in sand, silt, and clay contents influence soil structure and stability (Santos *et al.*, 2018). Soils with high clay content, such as SG (34.6±3.29), tend to have better structural stability and water retention capacity (Yudina and Kuzyakov, 2023). However, excessive clay content can lead to poor drainage and aeration (Obia *et al.*, 2018).

Fisher and Binkley (2000) reported that the primary distinction between soil textures lies in the surface areas of various particle sizes, which impact water potential, organic matter binding, cation exchange, and overall biotic activity.

Soils from CFA and FR had high sand contents of 74.8±2.48 % and 75.0±4.47 %, respectively, such soil texture has been associated with high water filtration rate (drainage) but low water and nutrient retention capacity (Ma *et al*., 2016; Anaba *et al*., 2020), especially during heavy rainfall period. Soil texture affects water infiltration rates and erosion susceptibility (Ma *et al*., 2016; Santos *et al.*, 2019). Consequently, it can be inferred that SG soils with high clay content (34.6±3.29%) would have low water infiltration rates but better water retention rate as noted by Munnaf *et al.* (2020) thus potentially influencing vegetation productivity and composition (Santos *et al.*, 2018).

Variations in soil physical properties can be crucial to ecosystem health, biodiversity conservation, and land productivity. Changes in soil texture (sand, silt, and clay content) can impact on drainage, aeration, and soil water retention, affecting plant root growth, soil structure, and ecosystem resilience (Yudina and Kuzyakov, 2023). The differences in sand, silt, and clay contents of the three forest management types in this study is an indication that forest management types can have different degrees of influence on soil disturbance, water filtration and retention, and soil productivity.

Soil Chemical Properties

Soil nutrients are essential for plant growth and development (White and Brown, 2010). Variations in nutrient availability among different forest management types affect plant communities, potentially influencing ecosystem structure and function (Ma *et al*., 2023; Nguyen *et al.*, 2022). Soils with higher levels of essential nutrients have greater fertility and productivity, promoting tree growth and vegetation (Freyer *et al*., 2023). Conversely, nutrient-poor soils may require additional inputs like fertilizers to sustain forestry activities (Vanlauwe *et al*., 2023).

The soil pH from this study can be said to be slightly acidic to neutral (4.82-6.07) and this range provides the best growing condition and influences the uptake of nutrients by plants (Dewangan *et al.*, 2023; Opeyemi *et al.*, 2020). The significant differences (p=0.001) in soil pH indicate variations in soil alkalinity and acidity across the forest management types. Differences in soil pH have important implications for soil fertility and nutrient availability, as pH affects nutrient solubility and availability for plant growth (Miller, 2016; Khaidem *et al.*, 2018). Soil pH was found to be highest under SG (6.07±0.08), and CFA (5.90± 0.14), while FR management had a lower (4.82±1.89) pH level. The acidic soil observed in FR may lead to restriction in the availability of essential nutrients like phosphorus and calcium as opined by some research workers (Johan *et al.*, 2021; Barrow and Hartemink, 2023). Soils with high pH levels (neutral soils), such as those under CFA and SG and and alkaline soil, create a more conducive environment for nutrient absorption and enhanced plant growth (Ferrarezi *et al.*, 2022).

Soil pH and texture influence microbial communities and soil fauna and play vital roles in nutrient cycling and ecosystem functioning (DeLuca *et al.*, 2019). The result of the pH level (4.82 to 6.07) in this study is within the range of the values of Atiku and Noma (2011), who reported a soil pH range of 4.23 to 6.94 in Wassaniya Forest Reserve. Opeyemi *et al.* (2020) reported a slightly acidic to neutral pH range of 5.90 - 6.60 for soils of Gambari Forest Reserve, Southwestern Nigeria, which is marginally higher than the values recorded in this study.

Our results are within the range reported by Yekini *et al*. (2022) who recorded a 5.80 to 7.90 (with a mean value of 6.85) pH level for two Sacred Forests in Adamawa State, Nigeria. The pH value recorded in SG in this study is lower than the pH value range of 7.30 to 7.55 reported by Oyelowo *et al*. (2021) for two sacred forests in Southwestern Nigeria.

Amonum *et al.* (2020) reported neutral soil (pH value of 6.30) for forest reserve in Ilorin, Nigeria, which is contrary to the acidic soil (pH value of 4.82±1.89) recorded in Forest reserve in this study. The difference between the pH of the soils in this study and some previous studies may be attributed to differences in ecological zones, management practices, and litter accumulation from litter fall.

The soil nutrient contents like magnesium (Mg), potassium (K), and calcium (Ca) varied across the forest management types, indicating that soil fertility status may be related to management types. The significant differences in Mg, K, and Ca contents across the management types can influence reforestation and regeneration practices (Mayer *et al.*, 2020). High concentrations of magnesium, nitrogen, phosphorus, and potassium were found in the soil from the SG, which may be an indication of improved soil fertility and nutrient accessibility in this forest type.

The Community Forest Area had slightly lower levels of these nutrients than SG, while FR had the lowest levels. Sodium content was similar across all three management types. Sacred Grove in this study had the highest potassium content, which was not statistically significant (p=0.054) from that of CFA. However, SG soil had the highest magnesium content (0.97 Cmol/kg), which is essential for photosynthesis and chlorophyll synthesis (Li *et al.*, 2018). Higher magnesium levels in soil are correlated with increased plant growth and ecosystem productivity (Wang *et al*., 2020).

The high K content (0.20 Cmol/kg) in SG soils implies the availability of essential nutrients for physiological processes in plants, such as water uptake, enzyme activation, and osmoregulation (Hasanuzzaman *et al.*, 2018). Soil with higher potassium levels significantly enhances plant health and boosts its ability to withstand environmental stress (Wang *et al*., 2013; Hasanuzzaman *et al.*, 2018). These findings imply that the SG management type had a more favourable soil chemical profile, yielding a more fertile and nutrient-rich soil environment. In contrast, the FR had the lowest soil nutrient levels, which could be an indication for the need for soil improvement or conservation practices to enhance soil fertility.

This result is contrary with the findings of Amonum *et al*. (2020) who reported lower Na, Mg, Pg and Ca in their study. For example, Amonum *et al.* (2020) reported a sodium levels ranging from 0.06 to 0.15 Cmol/kg, potassium from 0.27 to 0.43 Cmol/kg, magnesium from 0.0 to 0.18 Cmol/kg, and calcium from 0.57 to 1.09 Cmol/kg. However, the values of Mg, N, P, K, and Na across the forest types in this study are lower than values reported by Onyekwelu *et al.* (2008) from primary degraded tropical rainforest ecosystems in southwestern Nigeria. However, the calcium value (0.96–1.24 Cmol/kg) in this study is higher than the calcium value (0.67–0.91 Cmol/kg) reported by Onyekwelu *et al.* (2008).

Furthermore, the results of this study on chemical properties are contrary to the findings of Abdulrashid *et al.* (2024), who assessed soil physicochemical properties in the parklands of northern Nigeria. They reported higher Ca (1.86-2.21 Cmol/kg), P (3.83 - 5.73 Cmol/kg) and K (0.19-0.25 Cmol/kg) while OC (0.49-0.51 %), N (0.04-0.05%), Mg (0.55-0.71 Cmol/kg) and Na (0.80-0.9 Cmol/kg) were lower for Bauchi, Jigawa, and Kano States than what is recorded in this study.

The Mg, N, P, K, and Ca values in this study are lower than the values reported by Watanabe *et al.* (2020) for a Teak plantation in Ghana which contained total N content of 1.3 ± 0.5 g kg^{-1}, P content of 3.69 ± 1.86 mg kg^{-1}, exchangeable Ca content of 6.17 ± 4.61 Cmol/kg, Mg content of 1.23 ± 0.81 Cmol/kg, and exchangeable K of 0.15 ± 0.07 Cmol/kg. Kerenku *et al*. (2010) opined that low nutrients values (Mg, N, P, K, Ca, among other nutrients) are characteristics of most Nigerian soils, which they attributed to leaching losses by the high tropical rainfall as well as low content in the parent rock. From the result of this study, it can be deduced that the contents of Ca, K, Mg, Na, N, and P were low across the studied forest management soils when compared with results of other studies (Onyekwelu *et al.*, 2008; Onyekwelu *et al.*, 2014; Dachung *et al*., 2019; Akinde *et al*., 2020; Egwunatum *et al.*, 2020; Watanabe *et al.*, 2020).

The effects of land management on soil properties vary depending on several factors (Negasa e*t al.*, 2016; Kebebew *et al.*, 2022). Adapting land management practices to the unique soil conditions of each forest type can enhance sustainability and mitigate potentials. The observed differences in soil chemical properties among the three forest management types can be attributed to various factors, including soil composition, land management practices, and environmental conditions (Selassie *et al*., 2015; Akinde *et al.*, 2020; Haile *et al*., 2022).

Soil Organic and Carbon Storage

The OC content, which ranged from 1.80 % to 1.83 % across the three forest managemnt types, indicates that the soils in these forests have relatively low organic carbon contents. However, the organic carbon our forests is higher than the values (0.1 to 0.16%) in Wassaniya forest reserve (Atiku and Noma, 2011). However, Akpa et al. (2016) reported a higher mean soil organic carbon (OC) concentration of 1.41% (ranging from 0.42% to 2.4%) in the top 30 cm across agro-ecological zones of Nigeria, compared to the values recorded in this study. Our result does not align with those reported by Egwunatum *et al.* (2020) who worked in Ogwashi-Uku Forest Reserve, Delta State, Nigeria, and reported a higher soil organic carbon of 3.02% for Bamboo plantation and lower organic carbon of 1.66% from Gmelina plantation compared to the results of this study.

The OM levels observed in this research are comparatively lower than those documented in the Igbo-Ile and Igbo-Oba sacred groves (Oyelowo et al., 2021). According to Oyelowo *et al.* (2021), the soil OM at 0-15 cm depth ranged from 5.24% to 6.0%, and 4.5% to 4.6% at the depth of 15-30 cm. However, the value of OM across the forest types in this study is higher than the OM contents of 0.17 to 0.24 % reported by Atiku and Noma (2011).

The p-values for both OC and OM are greater than 0.05 (0.391 and 0.528, respectively), indicating that there are no significant differences in OC and OM contents of the three forest management types. This finding indicates that the three forest types have comparable effects on soil OC and OM contents. This similarity in OC and OM contents of the forest management types may be attributed to various factors, including the presence of similar soil types (characterized by high sand content), uniform climate conditions, and identical ecological zones.

Also, the result of this study indicates that the three forest management types have similar effects on soil properties and carbon storage. This comparable OM and OC results of the three forest types in this study could imply similar organic matter inputs, decomposition rates, and carbon cycling processes within these ecosystem, which was the views of Pérez-Cruzado *et al.* (2014), Lu *et al.* (2019), and Giweta (2020).

5. CONCLUSION

This study examined the physical and chemical characteristics of soils of three different forest management types (CFA, FR and SG) in Benue State, Nigeria. The physical properties (sand, clay and silt) of the soils of the forests differed significantly, with SG having the highest clay content (34.6%) and the lowest sand and silt contents (60.0% and 5.4%). Some soil chemical properties (e.g Mg and Ca) differed significantly ($p<0.05$) across the management types, with SG having the highest values while others (e.g. N, P, Na soil OC and OM Were statistically similar.

The soils in the CFA and FR were primarily sandy loam, whereas the soils in SG contained a higher percentage of clay loam. These findings indicated that forest management practices influenced soil physical and chemical properties, which in turn affects soil fertility, soil organic carbon, and ecosystem health.

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