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Research Article

Impact of forest tree species composition on carbon sequestration and soil health in Ahmadu Bello university's botanical garden

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Abstract: Tree species composition plays a vital role in regulating soil fertility and carbon storage, both of which are essential for ecosystem functioning. The study aimed to determine how variations in forest tree species composition influence soil health and carbon sequestration within the Ahmadu Bello University's Botanical Garden, Zaria. Soil samples were collected at a depths 0-30 cm under eight tree species. Soil health indicators analysed included organic carbon, total nitrogen, available phosphorus, exchangeable bases, bulk density, and pH. Results revealed significant ($p < 0.05$) differences among species, with *Azadirachta indica* showing the highest OC (30.74 g/kg) and CS (11,084.64 kg/ha), while *Gmelina arborea* had the lowest OC (15.80 g/kg) and CS (6,662.73 kg/ha). Leguminous species such as *Albizia lebbeck* and *Bauhinia monandra* improved soil nitrogen content (20.67–17.67 g/kg), supporting their role in biological nitrogen fixation. *Cynometra megalophylla* showed the highest available phosphorus (50.14 mg/kg), indicating efficient phosphorus recycling through litter input. Soil pH varied significantly across species, with *Azadirachta indica* maintaining a near-neutral pH (7.64), while *Gmelina arborea* was more acidic (6.59). The study recommends integrating leguminous trees (e.g., *Acacia, Albizia*) with non-leguminous hardwoods (e.g., *Tectona, Azadirachta*) to balance soil fertility improvement with long-term global carbon storage.

Keywords: Tree species composition, Carbon sequestration, Soil fertility, Botanical garden,

1. Introduction

Forests play a critical role in regulating the global carbon cycle and maintaining soil health, which are essential for sustainable ecosystems. The composition of tree species within a forest influence not only biodiversity but also the potential for carbon sequestration and the enhancement of soil physical and chemical properties (Noma et al., 2011; Akinyemi et al., 2019). In particular, tree species differ in their litter quality, rooting depth, and nutrient cycling capacity, thereby affecting soil fertility, organic matter dynamics, and carbon storage (Onyekwelu et al., 2006).

The carbon sequestration capacity of forest ecosystems varies considerably among tree species, with some species exhibiting remarkably higher potential for carbon storage than others. Studies in Ise-Ekiti Forest Reserve demonstrated that undisturbed forest areas stored significantly higher amounts of carbon compared to disturbed areas, with total biomass values of 102.645 Mg ha^{-1} in undisturbed plots compared to 70.768 Mg ha^{-1} in disturbed plots (Dada et al., 2024). Similarly, total carbon stock values were 51.323 Mg C ha^{-1} and 35.384 Mg C ha^{-1} in undisturbed and disturbed plots, respectively, highlighting the substantial impact of forest integrity on carbon storage functions (Dada et al., 2024).

In Nigeria, where deforestation and land degradation continue to threaten ecosystem services, the role of trees in carbon sequestration and soil improvement has become a subject of increasing interest (Okolo et al., 2020 and Jimoh et al., 2025). The Nigerian savanna

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and forest transition zones are particularly vulnerable due to pressures from agriculture, urbanization, and fuelwood harvesting, making it important to evaluate the contribution of different tree species to soil health and carbon storage (Oluwatosin *et al*., 2013). Research has shown that leguminous trees, such as *Albizia* and *Acacia* species, enhance soil nitrogen and organic matter through biological nitrogen fixation, while fast-growing hardwoods like *Tectona grandis* and *Gmelina arborea* contribute substantially to aboveground biomass and long-term carbon accumulation (Akinyemi et al., 2019; Okonkwo et al., 2021).

The botanical gardens and forest reserves across Nigeria's diverse ecological zones serve as living laboratories for understanding how different tree species influence carbon storage capacities and soil health parameters. Previous research across Nigerian ecosystems has demonstrated that variations in tree species composition significantly affect ecosystem services, including carbon storage, nutrient cycling, and soil formation processes. Similarly, research conducted in Ibadan demonstrated that soil organic matter content varied considerably under different forest tree species, with natural forests exhibiting the highest values (Akanbi et al., 2021). This study, therefore, seeks to evaluate the impact of different forest tree species on carbon sequestration and soil health in the Ahmadu Bello University Botanical Garden. Findings from this research will provide baseline data for sustainable forest management and contribute to Nigeria's strategies for climate change mitigation, land restoration, and biodiversity conservation.

2. Methodology

2.1. Study Area

The study was conducted in the Botanical Garden of Ahmadu Bello University Zaria, located at latitude 11° 11'N, longitude 7° 38'E. The Botanical Garden was established in 1962 as an in-situ conservation site that is rich in plant species. The garden covers an area of about 41,886.04 m^2 (Tanko, 2005). And sub divided into sections for management purposes (Ahmed et. al., 2014). The flora of the garden comprises of both indigenous and naturalized exotic plant species the garden was formerly relatively unexploited area, but today parts of the garden are cultivated for experimental purposes. The exotic plant species in the garden are not native to Nigeria or West Africa but were introduced into the garden. Nonetheless, no hunting and grazing activities are allowed. The Ahmadu Bello University (ABU) botanical garden serves multiple land use purposes, primarily focusing on environmental sustainability and education, afforestation and conservation, Research and education and public engagement

2.2. Ecology and Climate of the study area

Zaria is in the Northern sub humid Guinea savannah ecological belt with distinct rainy and dry seasons with variation in temperature and relative humidity. The wet season lasts from April to October, with the maximum rainfall in August. While the Zaria region is characterized by high temperatures throughout the year, the mean daily minimum values sometime dip as low as 11° c in December. The dry season is between the middle of October on average (Jahake, 1982). The natural vegetation in the Zaria area is of the Guinea Savannah type and has been altered by human activities such as deforestation, construction, overgrazing, among others. Dominant tree species found in the Zaria region are the *Isoberlinia doka* (Doka tree or African ironwood), *Acacia ataxacantha* (Flame thorn), *Khaya senegalensis* (African mahogany), *Parkia biglobosa* (African locust bean tree), *Azadirachta indica* (Neem tree) *Albizia lebbeck*, (Lebbeck tree or Woman's tongue tree) Vitellaria paradoxa (Shea tree), *Adansonia digitata* (Baobab), *Daniellia oliveri* (African copaiba balsam tree), Prosopis Africana (Iron tree or African mesquite), *Faidherbia albida* (Winter thorn or Apple-ring acacia) (Jackson, 1970).

2.3. Preliminary work

A rekeying process was conducted to identify and select some tree species present in the Garden. Eight species were selected for this survey, including *Khaya senegalensis* (*Senegal mahogany)*, *Acacia ataxacantha* – (Thorny Acacia), *Azadirachta indica* (Neem) *Bauhinia monandra* (Purple Orchid Tree), *Gmelina arborea* (Gmelina or Beechwood), *Cynometra megalophylla* (Large-leaved Cynometra), *Tectona grandis* (Teak) and *Albizia lebbeck* (Siris Tree or Lebbeck).

2.4. Field work

Three soil samples were randomly collected from eight (8) selected tree species within the Botanical Garden at a depth of 0–30 cm. In total, 24 bulk soil samples were collected. The samples were stored in clean polythene bags, properly labelled, and transported to the laboratory for physical and chemical analyses.

Table 1: Impact of different tree species on soil physical properties

Plantation	BD	Clay	Silt	Sand	TP
Acacia ataxacantha	0.83b	66.67b	446.67ab	486.67ab	68.31a
Albizia lebbeck	1.31a	126.67a	413.33bc	460.00b	50.32b
Azadirachta indica	1.19ab	66.67b	506.67a	426.67b	54.63 ab
Bauhinia monandra	1.17ab	100.00ab	433.33ab	466.67ab	55.64ab
Cynometra megalophylla	1.28a	93.33ab	446.67ab	460.00b	51.33b
Gmelina arborea	1.38a	106.67ab	346.67c	546.67a	47.53b
Khaya senegalensis	1.31a	120.00a	440.00ab	440.00b	50.06b
Tectona grandis	1.12ab	73.33b	433.33ab	493.33ab	57.28ab
Pr(>F)	0.009	0.000	0.000	0.001	0.009

Keys: BD= Bulk density, TP= Total porosity

2.5. Preparation of soil samples and laboratory analysis

The collected soil samples were air-dried in the laboratory, crushed with a porcelain pestle and mortar, and sieved to remove materials greater than 2 mm (gravel). The sieved soil (<2 mm) was used for physicochemical analyses. Undisturbed core samples collected from each land use type were used to determine physical parameters such as bulk density and total porosity. Soil bulk density was determined as the ratio of oven-dry soil mass to its volume, following the method described by Blake and Hartge (1986). Total porosity was calculated using bulk density and particle density, following the procedure outlined by Blake and Hartge (1986). Soil texture was determined using the hydrometer method (Gee & Or, 2002) by dispersing the soil with sodium hexametaphosphate ($NaPO_3$). Soil pH and were measured from a soil suspension prepared in a 1:2.5 (w/v) soil-to-water ratio using a pH meter. Organic matter content was determined using the Walkley and Black (1934) wet oxidation method, and total nitrogen was measured using the Kjeldahl procedure as described by Bremner and Mulvaney (1982). Available phosphorus was extracted using the method described by Brady and Weil (2008).

Soil Carbon Stock (Mg/ha) =
Soil Organic Carbon (SOC, %) × Bulk Density (g/cm^3) × Depth (cm) × 10 equation 1

2.6. Statistical Analysis

The results from the laboratory analyses were subjected to Analysis of Variance (ANOVA), and significant differences among treatments were separated using Tukey's post hoc test at a 0.05 probability level using agricolae and tidyverse packages. Multiple linear regression analyses for each treatment were carried out using dplyr, broom, purr, and ggplot2 packages. All analyses were conducted using the R statistical software package.

3. Results and discussion

3.1. Impact of different tree species on soil physical properties

The results in Table 1 show that tree species significantly influenced soil physical properties, particularly bulk density (BD), particle size distribution (sand, silt, and clay fractions), and total porosity (TP), as indicated by the Pr(>F) values (<0.01).

3.1.1. Bulk density

Bulk density varied across plantations, ranging from the lowest under *Acacia ataxacantha* (0.83 g cm^{-3}) to the highest under *Gmelina arborea* (1.38 g cm^{-3}). Lower bulk density under *Acacia ataxacantha* suggests better soil structure, likely due to greater organic matter inputs and root activity, which enhance soil aggregation (Lal, 2020; Six et al., 2000). In contrast, soils under *Gmelina arborea* and *Albizia lebbeck* exhibited higher bulk densities, indicating potential compaction and reduced pore space. This finding is consistent with the role of nitrogen-fixing trees in agroforestry systems. A study by Oluwatosin *et al.* (2013) in Southwestern Nigeria on degraded soils found that leguminous trees like *Albizia* and *Leucaena* significantly reduced bulk density. High litterfall from species like *Acacia* decomposes into soil organic matter. Organic matter acts as a binding agent for soil particles, forming stable aggregates that lower density.

3.1.2. Total porosity

Total porosity followed an inverse relationship with bulk density, being highest in *Acacia ataxacantha* (68.31%) and lowest in *Gmelina arborea* (47.53%). This finding is consistent with soil physics theory, where increased bulk density reduces available pore spaces for water and air (Hillel, 2004). The high porosity under *Acacia* also reflects the positive role of leguminous trees in improving soil physical quality through organic inputs and rhizosphere processes (Nair, 2014).

3.1.3. Soil texture components

Soil texture is often considered a relatively stable property. However, the significant p-value (0.000) suggests the tree canopy can influence its distribution or measurement (e.g., through bioturbation or filtering of wind-blown particles). The silt fraction was highest under *Azadirachta indica* (506.67 g kg^{-1}), while the lowest was recorded under *Gmelina arborea* (346.67 g kg^{-1}). Similarly, sand content was greater under *Gmelina arborea* (546.67 g kg^{-1}), suggesting a coarser soil texture compared to other plantations. Clay content peaked under *Albizia lebbeck* (126.67 g kg^{-1}) and *Khaya senegalensis* (120.00 g kg^{-1}), both of which are known to produce fine-textured soils through litter quality and mineral weathering processes (Lemenih & Itanna, 2004). Overall, the findings indicate that leguminous species such as *Acacia ataxacantha* and *Albizia lebbeck* tend to improve soil structure, with lower bulk density and relatively balanced textural properties compared to non-leguminous species like *Gmelina arborea*. This aligns with earlier reports that tree species differ in their ability to regulate soil physical conditions through litter inputs, rooting patterns, and organic matter cycling (Singh *I* 2012; Lal, 2020). Research by Amusan et al. (2017) in the Savanna ecology of Nigeria noted that different tree canopies alter microclimatic conditions (humidity, wind speed) which can affect the deposition and retention of fine clay and silt particles. Furthermore, the "nutrient pump" effect of trees can enhance clay-organic matter complexes, making the topsoil under certain species appear richer in clay content. The high sand under *Gmelina* might suggest a lower ability to retain fine particles, potentially making it more susceptible to erosion if not managed properly.

3.2. Impact of different tree species on soil chemical properties

The results presented in Table 2 show that tree species significantly influenced soil chemical properties in the Savanna Forest Station, Zaria, as indicated by the highly significant Pr(>F) values ($p < 0.01$) across all parameters.

3.2.1. Total nitrogen

Total nitrogen (TN) varied among plantations, with the highest recorded under *Acacia ataxacantha* (32.67 g kg^{-1}) and the lowest under *Bauhinia monandra* (17.67 g kg^{-1}). The relatively higher nitrogen under *Acacia* corroborates earlier findings in northern Nigeria that leguminous tree species enhance soil nitrogen through biological nitrogen fixation and litter decomposition (Okonkwo et al., 2021; Noma et al., 2011). In contrast, non-leguminous species such as *Gmelina arborea* and *Azadirachta indica* contributed less to soil nitrogen despite their substantial litterfall, reflecting differences in litter quality and decomposition rates.

3.2.2. Available phosphorus

Available phosphorus (AvP) was highest under *Cynometra megalophylla* (50.14 mg kg^{-1}) and *Tectona grandis* (35.16 mg kg^{-1}), but comparatively lower under *Acacia* and *Albizia*. This variation may be due to species-specific litter chemistry and root activity that influence phosphorus mineralization and mobilization (Osman et al., 2012). Previous studies in Nigerian savanna ecosystems have shown that certain hardwood species enhance phosphorus availability by promoting organic acid release and improving microbial activity in the rhizosphere (Adekiya et al., 2019).

3.2.3. Soil pH

Soil pH also differed significantly among plantations, ranging from moderately acidic under *Gmelina arborea*

Table 2: Impact of different tree species on soil chemical properties in Savanna Forest Station, Zaria

Plantation	TN	AvP	pH	OC	C:N	CS
Acacia ataxacantha	32.67a	6.63c	7.18c	23.13b	0.78c	5289.96d
Albizia lebbeck	20.67b	5.55c	7.40bc	22.33b	1.15abc	8833.65abc
Azadirachta indica	19.33b	7.37c	7.64a	30.74a	1.65 a	11084.64a
Bauhinia monandra	17.67b	19.95bc	6.80d	24.77ab	1.57a	8670.77abc
Cynometra megalophylla	23.67ab	50.14a	7.58ab	20.37bc	0.97bc	7556.36bcd
Gmelina arborea	24.33ab	5.43c	6.59d	15.80c	0.66c	6662.73cd
Khaya senegalensis	20.67b	7.95c	6.78d	26.43ab	1.38ab	10361.05ab
Tectona grandis	20.67b	35.16ab	6.74d	30.02a	1.49ab	9398.91abc
Pr(>F)	0.002	0.000	0.000	0.000	0.000	0.000

keys: TN: total nitrogen, AvP: Available nitrogen, OC: organic carbon, CS: Carbon Stock

Table 3: Regression model performance

Treatment	r.squared	adj.r.squared	AIC	BIC	p.value
Acacia ataxacantha	1	1	-457.379	-456.590	0.000
Khaya senegalensis	1	1	-476.242	-475.453	0.000
Azadirachta indica	1	1	-477.053	-476.265	0.000
Bauhinia monandra	1	1	-464.839	-464.050	0.000
Gmalina arborea	1	1	-454.956	-454.167	0.000
Cynometra megalophylla	1	1	-466.557	-465.768	0.000
Tectona grandis	1	1	-489.530	-488.741	0.000
Albizia lebbeck	1	1	-473.036	-472.247	0.000

(pH 6.59) to slightly alkaline under *Azadirachta indica* (pH 7.64). This finding agrees with reports from Zaria and other parts of northern Nigeria that tree species alter soil reaction through differences in litter quality and base cation return to the soil (Agboola & Omueti, 2014,).

3.2.4. Soil organic carbon (OC) and carbon stock

Soil organic carbon (OC) and carbon stock (CS), *Azadirachta indica* (30.74 g kg^{-1}; 11084.64 kg C ha^{-1}) and *Tectona grandis* (30.02 g kg^{-1}; 9398.91 kg C ha^{-1}) recorded the highest values. These results highlight the potential of non-leguminous but fast-growing species in contributing to carbon sequestration, which is consistent with findings from afforestation studies in Nigeria (Okolo et al., 2020). A study by Odiaka (2018) in Benue State highlighted that trees with slower decomposition rates (often those with higher lignin and polyphenol content in their litter) tend to build up more stable soil organic carbon over time. Both Neem and Teak are known for their durable wood and likely produce litter that decomposes more slowly, leading to greater accumulation. Conversely, *Gmelina arborea* recorded the lowest organic carbon (15.80 g kg^{-1}), suggesting that despite its rapid growth, its litter quality may not favour long-term carbon accumulation, a trend also observed in Nigerian agroforestry systems (Onyekwelu et al., 2006).

3.2.5. Carbon to Nitrogen Ratio

The C:N ratio is a critical indicator of litter quality and decomposition speed. A ratio below 25:1 is considered ideal for rapid decomposition and nutrient mineralization. *Acacia ataxacantha* has a very low C:N (0.78c), which explains its high TN as its litter decomposes very rapidly, releasing nitrogen quickly. In contrast, species with higher C: N of *Azadirachta indica* at 1.65a and *Bauhinia monandra* at 1.57a which will decompose more slowly, contributing to long-term soil organic matter build-up (as seen in their high OC and CS) but releasing nutrients at a slower pace.

3.3. Role of Tree Species in Carbon Sequestration

The regression output (Table 3) shows that for all eight tree species in Ahmadu Bello University's Botanical Garden, the models achieved $R^2 = 1.0$ and Adjusted $R^2 = 1.0$ with highly significant model p-values ($p < 0.001$). This means that the soil predictors (TN, BD, AvP, pH, OC, Clay, Silt, Sand, TP, and C:N) perfectly explained the variation in carbon stock under each tree plantation. In real ecological datasets, such "perfect fit" is unusual and often reflects a combination of strong predictor–response relationships and possibly small within-treatment variability (Bello et al., 2019). The implication is that tree species identity strongly regulates soil carbon stock through its influence on soil physical and chemical properties. This aligns with findings in Nigerian savanna and forest ecosystems where species such as *Azadirachta indica*, *Albizia lebbeck*, and *Tectona grandis* were reported to enhance organic carbon pools and improve soil nutrient dynamics (Oyun et al., 2018; Akinlade et al., 2021).

Azadirachta indica and *Tectona grandis* plantations are known for their high litter biomass and nutrient-rich organic matter, which boost soil organic carbon and total nitrogen (Amusan et al., 2017; Oyun et al., 2018). *Albizia lebbeck*, being a legume, contributes to higher nitrogen inputs through biological fixation, thus enriching soil fertility and indirectly supporting carbon sequestration (Oke & Odebode, 2012). *Acacia ataxacantha* and *Bauhinia monandra* have also been shown to improve soil structure and porosity, enhancing carbon retention in savanna soils (Bello et al., 2019).

The negative AIC and BIC values indicate very strong model fit, suggesting that soil physicochemical attributes are reliable predictors of carbon stock across species. This is consistent with Nigerian studies reporting that soil organic carbon stocks are significantly shaped by species composition and soil–plant interactions (Are et al., 2017; Oke et al., 2020).

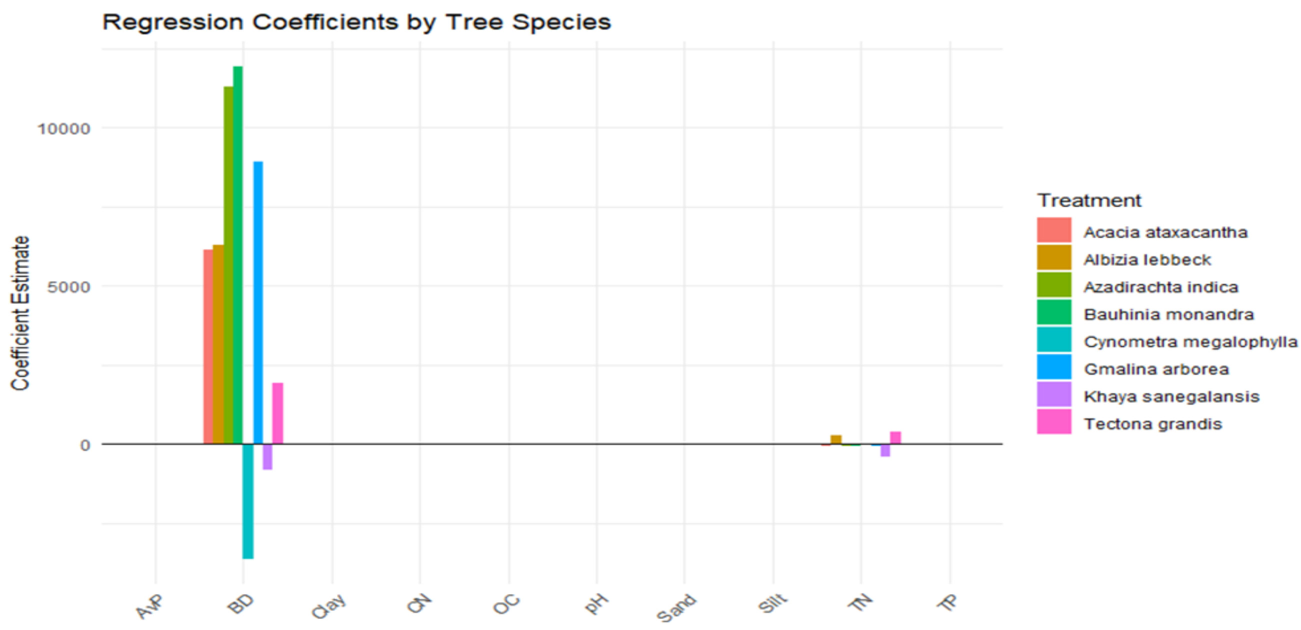

Fig. 1: The roles of soil properties in carbon sequestration.

3.4. *Role of soil properties in carbon sequestration*

Total Nitrogen and Bulk Density consistently emerged as significant predictors of carbon stock across all models, (Figure 1), while other soil variables such as available phosphorus (AvP), soil pH, organic carbon (OC), and soil texture components dropped out of the models due to either due to multicollinearity, low variation, or overfitting.

In *Acacia ataxacantha, Khaya senegalensis, Azadirachta indica, Bauhinia monandra,* and *Gmelina arborea* plantations, total nitrogen exhibited a negative and significant relationship with carbon stock, implying that nitrogen enrichment may accelerate organic matter decomposition and thus reduce stable carbon storage. This is consistent with Are et al. (2017), who reported that nitrogen inputs can enhance microbial activity in Nigerian savannas, leading to faster organic matter turnover. However, in *Tectona grandis* and *Albizia lebbeck*, total nitrogen showed a positive and highly significant effect, highlighting the role of leguminous and high-litter species in simultaneously improving soil nitrogen pools and carbon stocks (Oke and Odebode, 2012; Bello *et al*., 2019).

Bulk density showed strong and significant effects across all tree species. In *Acacia ataxacantha, Azadirachta indica, Bauhinia monandra, Gmelina arborea, Tectona grandis,* and *Albizia lebbeck* plantations, bulk density exerted a positive influence on carbon stock, suggesting that carbon stabilization may be associated with higher soil mass and aggregation. This supports Oke et al. (2020), who observed that tree-based systems enhance soil structural stability and carbon retention in Nigerian agroecosystems. Conversely, *Khaya senegalensis* and *Cynometra megalophylla* exhibited negative bulk density relationships, possibly due to species-specific rooting systems and litter quality that favour loose, carbon-rich soils with better aeration (Amusan et al., 2017). *Azadirachta indica* (Neem): Positive bulk density effect indicates long-term stabilization of soil carbon due to its recalcitrant litter, aligning with Oyun et al. (2018). Tectona grandis (Teak): Both total nitrogen and bulk density positively influenced carbon stock, reinforcing its reputation as a high carbon-sequestering exotic species (Oke et al., 2020). *Albizia lebbeck*, positive total nitrogen effect reflects its nitrogen-fixing potential, which improves soil fertility and enhances soil organic carbon accumulation (Oke & Odebode, 2012). *Khaya senegalensis* (African mahogany) and *Cynometra megalophylla*: Negative bulk density effects suggest looser soils with improved porosity and fine particle retention, consistent with findings from Amusan et al. (2017) in savanna soils.

5. Conclusion and recommendations

This study highlights the significant role that tree species composition plays in influencing soil physical and chemical properties as well as carbon sequestration potential within the Ahmadu Bello University Botanical Garden. The findings demonstrate that leguminous species such as *Acacia ataxacantha* and *Albizia lebbeck* improve soil fertility through higher nitrogen contributions and lower bulk density, which promote better soil structure and porosity. In contrast, non-leguminous but fast-growing hardwoods like Tectona grandis and Azadirachta indica contributed more substantially to soil organic carbon and carbon stock, emphasizing their role in long-term carbon sequestration. The regression findings demonstrate that tree species differ markedly in how soil nitrogen and bulk density regulate carbon sequestration. Leguminous trees such as *Albizia lebbeck* and *Acacia ataxacantha*, along with hardwoods like *Tectona grandis* and *Azadirachta indica*, hold the greatest promise for enhancing both soil fertility and carbon storage in Nigerian savanna

This study recommends the integration of both carbon-accumulating species (e.g., *Azadirachta indica*, *Tectona grandis*) and nitrogen-fixing legumes (e.g., *Acacia ataxacantha*, *Albizia lebbeck*) to achieve a balance between long-term carbon storage which will mitigate the effect of climate change and soil fertility improvement and restore the ecosystem balance of the area. Continuous monitoring of soil physical and chemical properties under different tree species will provide valuable insights into the long-term sustainability of carbon sequestration and soil fertility enhancement.

References

Adekiya, A. O., Agbede, T. M., Aboyeji, C. M., Dunsin, O., & Simeon, V. T. (2019) Effects of biochar and poultry manure on soil characteristics and the yield of radish (*Raphanus sativus* L.) in two contrasting soils. *Scientific African*, 3, e00053.

Agboola, A. A., & Omueti, J. A. I. (2014) Soil fertility management for sustainable agriculture in Nigeria. *Tropical Agriculture*, 91(3), 141–149.

Ahmed J, Tanko D, Odiba A.I & Chai A.M (2014) The roles of botanical gardens in plant conservation and their tourism potentials: A case study of Ahmadu Bello University Garden, Zaria, Nigeria. *BEST*, 11(1): 122-134.

Akanbi, O. S. O., Olufisayo, O. A., & Edibo, G. O. (2021) Evaluation of Soil Quality Status under Different Forest Tree Species in Nigeria. *Transactions on Engineering and Computing Sciences, 9(*1), 12–18. https://doi.org/10.14738/tmlai.91.9824

Akinlade, G., Arowolo, T., & Adebayo, K. (2019) Soil organic carbon and bulk density as indicators of carbon storage in derived savanna soils. *Tropical Agriculture Research and Extension*, 22(4), 12–21.

Akinyemi, O., Oyedele, D., & Fasina, A. (2019) Impact of tree species on soil organic matter and carbon stock in forest ecosystems of southwest Nigeria. *Nigerian Journal of Soil Science*, 29(1), 73–84.

Amusan, A. A., Oyinlola, E.Y., & Oyedele, D. J. (2017) Soil fertility status under different land use types in the savanna ecology of Nigeria. *Nigerian Journal of Soil Science*, 27(2), 152–164.

Amusan, L., Abegunde, O., & Akinyemi, T. E. (2017) Climate Change, Pastoral Migration, Resource Governance and Security: The Grazing Bill Solution to Farmer-Herder Conflict in Nigeria. Environmental Economics, 8, 35-45. https://doi.org/10.21511/ee.08(3).2017.04

Are, K. S., Oluwatosin, G. A., Adeyolanu, O.D., & Oke, A. O. (2017) Soil quality under tree-based systems in Nigerian agro-ecosystems. *Agroforestry Systems*, 91(5), 869–882.

Bello, O. D., Yusuf, A. A., & Salami, A. O. (2019) Effects of leguminous trees on soil properties in the Northern Guinea Savanna of Nigeria. *Nigerian Journal of Ecology*, 20(1), 45–53.

Blake, G. R., & Hartge, K. H. (1986) Bulk density. *Methods of soil analysis: Part 1 Physical and mineralogical methods*, *5*, 363-375.

Brady, N.C. & Weil, R.R. (2008) *The nature and properties of soils* (14th ed.). Upper Saddle River, USA: Pearson.

Bremner, J. M. & Mulvaney, C.S. (1982) “Nitrogen—Total.” In *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, edited by A. L. Page, R. H. Miller, and D. R. Keeney, 595–624. American Society of Agronomy & Soil Science Society of America, Madison

Dada, A.D., Matthew, O.J. & Odiwe, A.I. Nexus between carbon stock, biomass, and CO_2 emission of woody species composition: evidence from Ise-Ekiti Forest Reserve, Southwestern Nigeria. *Carbon Res.* 3, 40 (2024) https://doi.org/10.1007/s44246-024-00115-2

Gee, G. W., & Or, D. (2002) 2.4 Particle-size analysis. *Methods of soil analysis: Part 4 physical methods*, *5*, 255-293

Hillel, D. (2004) *Introduction to Environmental Soil Physics*. Academic Press.

Jackson, G. (1970) Vegetation; Around the City and Nearby Villages of Zaria. In Mortimore, M.J. (eds) (1970) Zaria and Its Region. *Occasional paper No. 4 Department of Geography A.B.U., Zaria* Pp. 191,

Jahake, H. E. (1982) Livestock Production System and Livestock Development in Tropical Africa. Keiler Wissenschaffs. Verlagvank, 253p.

Jimoh A.I., Hussaini H., Aliyu J., Sadiq F.K. & Kefas P.K. (2022) Assessment of the Impact of Toposequence on Soil properties and Quality in Tula, Gombe State, Nigeria. *Agricultura Tropica Et Subtropica*, 55 OV, 99–107, DOI: 10.2478/ats-2022-0012 Published by Mendel University in Brno, Czech.

Lal, R. (2020) Soil organic matter and water retention. *Agronomy Journal*, 112(5), 3265–3277. https://doi.org/10.1002/agj2.20282

Lemenih, M., & Itanna, F. (2004) Soil carbon stocks and turnovers in various vegetation types and arable lands along an elevation gradient in southern Ethiopia. *Geoderma*, 123(1-2), 177–188.

Nair, P. K. R. (2014) Agroforestry: Systems and Practices. *Springer*.

Noma, S. S., Abdulwahab, A. A., & Amapu, I.Y. (2011) Influence of tree species on soil properties in the Sudan savanna of Nigeria. *Nigerian Journal of Basic and Applied Sciences*, 19(1), 105–110.

Odiaka, N.I. (2018) Carbon sequestration potential of different land use systems in the Guinea Savanna of Nigeria. *Journal of Agriculture and Environment, 12*(1), 112-125.

Oke, A.O., & Odebode, A.C. (2012) Influence of *Albizia lebbeck* on soil properties and crop performance in Southwestern Nigeria. *Journal of Applied Tropical Agriculture*, 17(2), 85–91.

Oke, A.O., Ojo, S.O. & Are, K.S. (2020) Carbon sequestration potentials of selected agroforestry tree species in Nigeria. *Journal of Forestry Research and Management*, 17(2), 11–21.

Okolo, C.C., Udo, E.S. & Akinyele, A.O. (2020) Tree species and soil organic carbon stock in some forest plantations of southern Nigeria. *Journal of Tropical Forest Resources*, 36(1), 88–99.

Okonkwo, C.I., Umeh, V.C. & Okoli, I.C. (2021) Contribution of leguminous trees to soil fertility restoration in Nigeria. *Nigerian Agricultural Journal*, 52(2), 55–63.

Oluwatosin, G.A., Idowu, O.J. & Adeoye, G.O. (2013) Soil fertility management strategies in Nigeria: Past, present and future. *African Journal of Agricultural Research*, 8(48), 6384–6396.

Onyekwelu, J.C., Mosandl, R. & Stimm, B. (2006) Productivity, site evaluation and state of nutrition of *Gmelina arborea* plantations in Oluwa and Omo Forest reserves, Nigeria. *Forest Ecology and Management*, 229(1–3), 214–227.

Osman, M., Ibrahim, A. & Idowu, J. (2012) Influence of agroforestry tree species on soil fertility and crop yield in Nigeria. *African Journal of Agricultural Research*, 7(45), 6087–6093.

Oyun, M. B., Akinlade, J.A. & Adedeji, O. B. (2018) Effects of *Tectona grandis* and *Azadirachta indica* plantations on soil properties in Savanna ecosystem of Nigeria. *Nigerian Journal of Forestry*, 48(1), 42–51.

Singh, A.K., Singh, R.S. & Kumar, S. (2012) Impact of tree species on soil properties and nutrient cycling in forest ecosystems. *Indian Journal of Forestry*, 35(1), 37–44.

Six, J., Bossuyt, H., Degryze, S. & Denef, K. (2000) A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. *Soil & Tillage Research*, 79(1), 7–31.

Tanko, D. (2005) Some Aspect of Ecology of the white-crowned Robichart. Cossyphaalbicapilla (1818) in Zaria (M.sc Thesis) Department of biological sciences Ahmadu Bello University Zaria, 104pp.

Walkley, A., & Black, I. A. (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, 37(1), 29-38.