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ASSESSING THE IMPACT OF LAND USE TYPES ON SOIL ORGANIC CARBON, BULK DENSITY, MOISTURE CONTENT AND CARBON STOCK IN THE SAVANNA REGION OF KANO STATE, NIGERIA

ABDULRAHMAN, B.L.,[1], JAZULI, B.L.,[2*] AND ABUBAKAR, K.S.[1]

[1]Bayero University Kano, Department of Soil Science, Kano, Nigeria

[*2]Federal University Dutsin-ma, Department of Soil Science, Katsina, Nigeria

Corresponding Author: Tel: 08080354808, Email: basirulabs@gmail.com

ABSTRACT
This study evaluated the effects of land use types on key soil properties, including soil organic carbon (SOC), bulk density, moisture content and carbon stock in the Sudan Savanna region of Kano State, Nigeria. Soil samples were collected from forested and non-forested areas across three locations in Gwale, Kano Municipal, and Kura local governments, using a simple random sampling technique at a depth of 0–20 cm, yielding a total of 18 samples. Standard laboratory procedures were employed to analyse the samples, and data were subjected to analysis of variance (ANOVA). The results revealed that forested areas had significantly higher SOC (1.45%) compared to non-forested areas (0.49%). Similarly, moisture content and carbon stock were higher in forested sites, with values of 13.04% and 4,617,933 g/kg, respectively, compared to 10.42% and 1,639,156 g/kg in non-forested areas. Bulk density showed no significant variation between the land use types. The study concludes that forested land significantly enhances soil quality and carbon storage, emphasising the importance of forest conservation and sustainable land management in maintaining soil health and mitigating climate change impacts in the region.
Key Words: Carbon dynamics, Eco

system service, Environmental sustainability, Land management, Soil health.

INTRODUCTION

The continuous increase in atmospheric greenhouse gas (GHG) concentrations, particularly carbon dioxide (CO2), is widely recognised as a major driver of global climate change. These changes pose significant threats to ecological stability, food security, water resources and overall agricultural productivity worldwide (Smith *et al*., 2020). Carbon dioxide, although fundamental to the photosynthetic process in plants, becomes harmful when present in excessive concentrations, intensifying the natural greenhouse effect and leading to the warming of the Earth's surface, disruption of climatic patterns and adverse environmental consequences. This anthropogenic alteration of the global carbon balance is primarily attributed to the burning of fossil fuels, deforestation, industrial processes, and unsustainable land-use changes (Olsen *et al*., 2019).
Historically, the atmospheric concentration of CO2 remained below 300 parts per million (ppm) for hundreds of thousands of years, ensuring climatic equilibrium. However, since the onset of industrialisation in the 18th and 19th centuries, and especially in recent decades, CO2 levels have risen dramatically, now exceeding 400 ppm (IPCC, 2007). This sharp escalation correlates with a recorded global temperature rise of approximately 0.88 °C since the late 19th century, and climate models predict further increases of between 1.5 °C and 5.8 °C by the end of the 21st century if emissions are not curbed (IPCC, 2001). Such warming is associated with a range of environmental disturbances, including polar ice melt, sea-level rise, increased frequency of extreme weather events, disruption of growing seasons, biodiversity loss and shifts in ecosystem structure and function.

Forests are among the most effective natural systems for sequestering carbon dioxide from the atmosphere. They serve as critical carbon sinks, absorbing carbon dioxide from the atmosphere and storing it in plant biomass (leaves, stems and roots) and in soil organic carbon (SOC) pools (Pan *et al*., 2011). The importance of forest ecosystems in the global carbon cycle cannot be overstated, as they sequester a substantial proportion of terrestrial carbon, helping to reduce the net CO2 flux into the atmosphere. The potential of forests to act as long-term carbon reservoirs depends on various factors, including tree species composition, stand density and soil characteristics. Notably, soils under forest cover tend to contain significantly higher SOC than those under other land uses such as croplands or grassland (Lal, 2020).

Land use change, particularly the conversion of forest lands to agricultural or urban areas, has been identified as a significant contributor to SOC depletion. The removal of vegetation covers and subsequent soil disturbance often leads to increased rates of organic matter decomposition and the release of carbon into the atmosphere. Additionally, such changes alter vital soil physical properties, such as bulk density, porosity, and moisture retention capacity, which are closely linked to soil fertility, productivity, and resistance to erosion and degradation (Zhang *et al*., 2023). Decreases in SOC content negatively affect soil structure, microbial activity and nutrient cycling, thereby undermining the ecological functions of soil and its capacity to provide ecosystem services such as water regulation, food production and carbon sequestration (Smith *et al*., 2020).

Given the rapid land-use transformations occurring in many parts of sub-Saharan Africa, including Nigeria, there is an urgent need to assess how different land-use types affect soil quality and carbon storage potential. Forested lands, if managed sustainably, could play a key role in enhancing SOC stocks and mitigating the adverse impacts of land degradation and climate change. Conversely, non-forested land areas, such as fallow or cultivated lands, may be more vulnerable to carbon loss, nutrient depletion, and reduced resilience to environmental stressors.

This study, therefore, evaluated the effects of contrasting land use types, specifically forested and non-forested areas, on soil organic carbon, bulk density, moisture content and overall carbon stock in the Sudan Savanna ecological zone of Kano State, Nigeria. The region represents an important agricultural and environmental landscape where land use decisions have profound implications for soil health, farm sustainability and climate change mitigation. By elucidating the relationship between land cover, soil quality parameters and carbon storage potential, this research aims to provide valuable insights that can inform sustainable land management practices targeted at improving soil productivity while contributing to global carbon balance efforts.

MATERIALS AND METHODS

Study Location and Description

The study was conducted in the Sudan Savanna region of Nigeria, specifically in three local governments of Kano State: Gwale, Kano Municipal, and Kura. Geographically, the study areas are situated within the following coordinates: Gwale (Latitudes 11o56'56" N and 12o00'12" N, and Longitudes 8o28'23" E and 8o32'06" E), Kano Municipal (Latitudes 11o55'07" N and 11o59'09" N, and Longitudes 8o30'25" E and 8o34'25" E), and Kura (Latitudes 11o43'17" N and 11o49'17" N, and Longitudes 8o22'49" E and 8o28'49" E). The total area of each local government is approximately 18 km², 17 km², and 206 km² for Gwale, Kano Municipal, and Kura, respectively. Kano State is characterised by a tropical climate, with an average monthly rainfall of 696.4 mm and an annual evaporation rate of approximately 1600 mm (Umar, 2006). The mean daily temperature ranges from 29°C to 30°C (Kawal *et al*., 1972). The vegetation in the study area is primarily composed of shrubs, grasses, and scattered trees, including species of Neem and Acacia.

Soil Sampling Procedure

Soil samples were collected from three forest areas and three non-forest areas, resulting in a total of eighteen samples. Sampling was conducted at a depth of 0-20 cm, using a combination of pipe auger and core sampler to ensure representative and undisturbed samples. Three replicate samples were collected from each area to account for spatial variability.

Sample Preparation for Analytical Measurement

Soil samples were prepared and processed using the air-drying method, where they were dried at room temperature and low humidity to prevent degradation of organic carbon. High-temperature drying was avoided due to its potential to alter organic carbon content. Dried samples were crushed and ground using a jaw crusher and a grinder, respectively. The resulting material was then sieved through a 2 mm mesh.

Field Observations and Laboratory Analysis

The laboratory analysis was conducted to evaluate the following parameters using standard analytical techniques:

Bulk Density

Bulk density was determined using the core method (Blake and Hartge, 1986). Undisturbed soil cores were collected from the field and oven-dried at 105 °C for 24 hours. The oven-dried weight was recorded and used to calculate the bulk density, expressed as the ratio of the dry soil mass to the total soil volume (including pores). This measurement provides an estimate of soil compactness as follows:

$$BD = \frac{Ms}{Vt}\ (gcm^{-3})$$

Where: BD = bulk density, Ms = mass of oven-dried soil (g), Vt = volume of soil, equivalent to volume of core (cm3).

Organic Carbon Content

The organic carbon content was determined using the Walkley and Black (1934) wet oxidation method. A 1-g air-dried soil sample was weighed into a 500 mL conical flask. Then, 5 ml of K2Cr2O7 solution was added, followed by gentle swirling to disperse the soil. Subsequently, 10 mL of H2SO4 was rapidly added, and the mixture was gently swirled until the soil and reagents were well mixed. After 30 minutes, 100 ml of distilled water was added, and 4 drops of phenolphthalein indicator were added. The solution was then titrated against 0.5 M ferrous solution until the endpoint was reached, indicated by a light green colour. A blank sample, consisting of all reagents but without soil, was titrated first for comparison before the soil-containing solution was titrated

$$\%OC = \frac{(B - T) \times N \times 0.003 \times 1.33}{W.S} \times 100$$

Where: B= Blank Titer value, T= Sample Titer Value, N= Normality of $FeSO_4$, 1.33= organic carbon correction, 0.003= Milli equivalent weight of carbon.

Soil Moisture Content

Soil moisture content was determined using the direct method. In this study, the direct method was employed, utilising thermo-gravimetric analysis through oven drying. The collected soil samples in the core were initially weighed and recorded. The samples were then dried in an oven at 105 °C until a constant weight was achieved. The dry weight of each sample was subsequently recorded, allowing for the calculation of the moisture content.

$$Moisture\ content\ (on\ weight\ basis) = \frac{Wet\ weight - Dry\ weight}{Dry\ weight} \times 100$$

Soil Carbon Stock Estimation

Soil carbon stocks were estimated using baseline and end-line soil data. The carbon was calculated using the relationship developed by Rodrigo-Comino and Artemi (2018), which integrates soil depth (D), bulk density (BD), and carbon concentration (CC). The carbon stock is estimated using the following equation:

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$$Carbon\ Stock\ (gkg^{-1}) = D \times BD \times CC \times 10000$$

This approach allows for the quantification of soil carbon stocks, providing a valuable metric for assessing soil carbon sequestration.

Statistical Analysis

The collected data were analysed using one-way analysis of variance (ANOVA) to examine the effect of land use on the measured soil properties. Where significant differences were detected ($p \leq 0.05$), means were separated using the Least Significant Difference (LSD) test to determine which land use types differed significantly from each other. All statistical analyses were performed using GENSTAT version 17 statistical software.

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RESULTS AND DISCUSSION

Results

Impact of Land Use Types on Bulk Density

Bulk density values across the different land use types and study locations did not differ significantly (Table 1). Both forested and non-forested areas exhibited moderate bulk density, ranging from 1.58 g/cm³ to 1.71 g/cm³. Forest soils exhibited slightly lower bulk density (1.58 g/cm3) than non-forested soils (1.71 g/cm3), but the differences were statistically insignificant.

Table 1: Impact of Land Use Types on Bulk Density

Parameters	Bulk Density (g/cm^3)
Location	
BUK	1.758
Kura	1.697
Kano Zoo	1.578
S.E.D	0.0729
F/Value	NS
Land Use	
Non-Forest	1.706
Forest	1.583
S.E.D	0.0959
F/Value	NS
Interaction	
Location x Land Use	NS

NS= Non-significant, S.E.D= Standard Error of Difference

Impact of Land Use Types on Organic Carbon Content

Soil organic carbon (SOC) varied significantly among locations and between land use types (Table 2). Forested areas showed markedly higher SOC content (1.45%) compared to non-forested areas (0.48%). Among the locations, BUK and Kano Zoo displayed higher SOC values (1.14% and 1.09%, respectively), while Kura recorded the lowest (0.67%). However, there was no significant interaction between location and land use type for SOC.

Table 2: Impact of Land Use Types on Organic Carbon Content

Parameters	Soil Organic Carbon
Location	
BUK	1.44a
Kura	0.67b
Kano Zoo	1.09a
S.E.D	0.0916
F/Value	**
Land Use	
Non-Forest	0.483b
Forest	1.450a
S.E.D	0.0748
F/Value	**
Interaction	
Location x Land Use	NS

- Means followed by the same letter(s) in a column are not significantly different from one another
- NS= non-significant, **= highly significant at <0.05, S.E.D= Standard Error of Difference

Impact of Land Use Types on Soil Moisture Content

A significant difference in moisture content was observed between land use types (Table 3). Forested areas maintained higher soil moisture (13.04%) compared to non-forested sites (10.42%). Across locations, Kura had the highest moisture content (12.47%), followed by BUK (11.91%) and Kano Zoo (10.87%). The interaction between location and land use type was statistically significant, indicating that both factors collectively influenced moisture content.

Table 3: Impact of Land Use Types on Soil Moisture Content

Parameters	Soil Moisture Content (%)
Location	
BUK	11.91
Kura	12.47
Kano Zoo	10.87
S.E.D	1.150
F/Value	NS
Land Use	
Non-Forest	10.42b
Forest	13.42a
S.E.D	0.939
F/Value	*
Interaction	
Location x Land Use	*

NS= non-significant, *= significant at <0.05, S.E.D= Standard Error of Difference

Impact of Land Use Types on Carbon Stock

The carbon stock across the study locations showed highly significant values, with mean values of 3,955,500 g kg-1 (BUK), 3,337,267 g kg-1 (Kano Zoo), and 2,092,867 g kg-1 (Kura) (Table 4). Kura recorded the lowest carbon stock, with a value of 2,092,867 g kg-1, while BUK exhibited the highest, with a value of 3,955,500 g kg-1. Kano Zoo presented an intermediate carbon stock with a value of 3,337,267 g kg-1. Carbon stock under land use types also displayed high significance (SED value: 202,283.0). Forested areas had a significantly higher carbon stock of 4,617,933 g kg-1 compared to non-forested areas, which recorded a much lower value of 1,639,156 g kg-1. However, the interaction between location and land use was statistically non-significant, indicating no notable variations in carbon stock due to their combined influence.

Table 4: Impact of Land Use Types on Carbon Stock

Parameters	Carbon Stock (g/kg)
Location	
BUK	3,955,500a
Kura	2,092,867b
Kano Zoo	3,337,267a
S.E.D	2,477,451
F/Value	**
Land Use	
Non-Forest	1,639,156b
Forest	4,617,933a
S.E.D	202,283.0
F/Value	**
Interaction	
Location x Land Use	NS

- Means followed by the same letter(s) in a column are not significantly different from one another

- NS= non-significant, **= highly significant at <0.05, S.E.D= Standard Error of Difference

DISCUSSION

Impact of Land Use Types on Bulk Density

The bulk density values observed in both forested and non-forested areas fall within the moderate range of 1.4–1.8 g cm-3, as suggested by Ray and Fred (2004). This indicates favourable conditions for plant root growth, as soil hardness and compaction, which hinder root development, typically occur at higher bulk density levels. The lower bulk density in forested areas could be attributed to the influence of organic matter accumulation and vegetation cover, which reduce soil compaction as reported by Blake and Hartge (1986). In contrast, non-forested areas showed slightly higher bulk density values, possibly due to reduced organic input and increased surface disturbances (Zhang *et al*., 2023). The interaction between location and land use was found to be non-significant, suggesting that the combined effects of these factors did not influence bulk density variation.

Impact of Land Use Types on Organic Carbon Content

The significant variation in organic carbon content among the study locations suggests that environmental and management practices have a substantial influence on soil carbon levels. The higher organic content observed in BUK and Kano Zoo could be attributed to better soil preservation and organic matter input compared to Kura, where carbon levels were notably lower. The significant difference between forested and non-forested areas, as supported by findings from Montagnini and Nair (2004) and Lal (2020), highlights the role of vegetation cover in enhancing soil organic matter. Forests contribute to organic accumulation through leaf litter and root biomass. In contrast, non-forested areas may experience higher organic matter degradation and reduced carbon sequestration due to exposure and anthropogenic activities (Olsen *et al*., 2019). The lack of significant interaction between location and land use indicates that organic carbon variation is primarily influenced by individual factors rather than their combined effect. This suggests that land cover type has a strong influence on the organic carbon dynamics of soils.

Impact of Land Use Types on Soil Moisture Content

The results align with the findings of Ray and Fred (2004), who reported that the optimal moisture content for loamy soil ranges from 15% to 30%. While the overall moisture content in the study area was slightly below this range, the higher moisture retention in forested areas can be attributed to the greater organic matter content and vegetation cover, which enhance the soil's water-holding capacity. In contrast, the lower moisture content in non-forested areas may result from increased surface evaporation and reduced organic inputs. Although no significant differences were found across locations, the higher moisture content in Kura might reflect better soil properties or lower levels of disturbance, while Kano Zoo's lower content could be due to factors such as compaction or limited vegetation. The influence of both location and land use on moisture content implies that microclimatic conditions, soil texture and organic matter levels collectively control moisture distribution (Marras *et al*., 2020; Zhang *et al*., 2023).

Impact of Land Use Types on Carbon Stocks

The significant variation in carbon stock among the locations highlights differences in soil management practices and environmental conditions. BUK's high carbon stock could be attributed to better organic matter accumulation and minimal disturbances, while Kura's lower stock may reflect reduced organic inputs and possible soil degradation. The intermediate values at Kano Zoo suggest mixed influences of natural and anthropogenic factors. Similarly, the higher carbon stock in forested areas underscores the role of vegetation cover in carbon sequestration. Forested soils often benefit from continuous organic matter input through litter and root biomass, which promotes carbon retention, corroborating earlier research that affirms forests as key carbon sinks in terrestrial ecosystems (Nair *et al*., 2010; Pan *et al*., 2011). Conversely, the low carbon stock in non-forested areas may result from reduced organic inputs and higher rates of carbon loss due to soil exposure and degradation. The non-significant interaction between location and land use suggests that the observed carbon stock differences are primarily driven by the individual effects of land use or location rather than their combined influence (Smith *et al*., 2020).

CONCLUSION

This study assessed soil organic carbon, bulk density, moisture content, and carbon stock across various locations and land-use types. The findings underscore the crucial role of forested areas in improving soil quality and enhancing carbon sequestration. Forested areas consistently exhibited higher organic carbon content, moisture retention, and carbon stock compared to non-forested areas. Bulk density values across locations and land uses fell within the moderate range, indicating favourable conditions for plant growth, although slight differences were observed between forested and non-forested soils. Moisture content varied significantly by land use, with forested areas retaining more moisture due to their dense vegetation cover and high input of organic matter. The carbon stock analysis revealed significant variations among the study locations and between land use types, with forests demonstrating a considerably higher capacity for carbon storage. However, the interaction between location and land use was non-significant for all parameters, suggesting that their effects on soil properties and carbon stock are independent of each other. These findings highlight the crucial role of forested ecosystems in preserving soil health and mitigating climate change through carbon sequestration. Land management practices that promote forest conservation and restoration can play a vital role in enhancing soil quality and carbon storage capacity. Further research should focus on long-term monitoring and the impact of specific land management strategies on soil carbon dynamics.

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