Original Article

Comparative assessment of soil physicochemical properties and carbon sequestration potential in farmland and grassland ecosystems in Malete, Kwara State, Nigeria

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ABSTRACT

Understanding the effects of land use on soil properties and carbon sequestration is critical for promoting sustainable land management. This study conducted a comparative assessment of soil physicochemical properties and carbon sequestration potential in farmland and grassland ecosystems in Malete, Kwara State, Nigeria. Composite soil samples (0–20 cm depth) were analyzed for pH, total nitrogen (TN), total organic carbon (TOC), organic matter (OM), phosphorus (P), bulk density (BD), electrical conductivity (EC), moisture content, porosity, and total bacterial count (TBC). Results showed significantly higher TOC (10.36 mg/kg) and OM (5.53%) in grassland soils compared to farmland (5.45 mg/kg and 0.88%, respectively), indicating enhanced carbon storage in less disturbed ecosystems ($p < 0.05$). Farmland soils had significantly higher phosphorus concentration (11.63 mg/kg) relative to grassland (0.001 mg/kg), reflecting intensive fertilizer use ($p < 0.001$). Soil pH was slightly higher in farmland (7.07) than in grassland (6.66), while BD was marginally elevated in farmland (1.80 g/cm^3) compared to grassland (1.71 g/cm^3), though not statistically significant. EC was significantly higher in grassland (13.56 dS/m) than in farmland (11.11 dS/m; $p < 0.001$). Correlation analysis revealed strong positive relationships between OM and TOC (r = 0.80), and moderate negative correlations between BD and porosity (r = –0.50). These findings highlight the influence of land use on soil quality and carbon dynamics, emphasizing the need for site-specific management practices such as reduced tillage and organic amendments. The study provides critical baseline data to support sustainable land-use planning and carbon management in North-Central Nigeria.

INTRODUCTION

Soil is an essential component of terrestrial ecosystems, playing a pivotal role in sustaining plant productivity, maintaining environmental quality, and regulating global carbon cycles [1, 2]. Among the numerous ecological services provide, their ability to store organic carbon and support nutrient cycling is critical to both agricultural sustainability and climate change mitigation [3]. Soil serves as the foundation of terrestrial life, providing structural support to vegetation while facilitating the movement of air, water, and nutrients [4]. The physicochemical properties of soil including pH, texture, structure, cation exchange capacity, organic matter content, and nutrient status determine its fertility and ecological functionality [5]. As such, any alteration in these properties can significantly affect not only crop yields but also the long-term capacity of soil to provide essential ecosystem services [6].

In the context of global environmental change, land-use patterns are recognized as major factors influencing soil quality and carbon storage [7, 8]. Land-use change, particularly the conversion of natural ecosystems such as forests and grasslands into farmlands, is a significant driver of soil degradation and carbon loss [9]. Farmlands are often subjected to continuous tillage, the application of synthetic agrochemicals, removal of crop residues, and other intensive practices that can lead to soil compaction, loss of organic matter, nutrient imbalance, and decreased microbial activity [4]. Over time, these processes compromise soil structure, reduce infiltration capacity, and diminish the soil's ability to retain carbon, making it more susceptible to erosion and nutrient leaching [10].

In contrast, grassland ecosystems, especially those that are undisturbed or minimally managed tend to maintain a relatively stable soil structure, enhance soil organic matter through root turnover, and serve as effective carbon sinks [11]. Their perennial grasses contribute to higher levels of below-ground biomass, which decomposes slowly and enriches the soil with stable organic carbon [12]. The slower rate of disturbance also allows grassland soils to build aggregates and resist compaction more effectively than tilled farmlands [6]. Consequently, grasslands may have higher long-term carbon sequestration potential and better soil quality indicators compared to intensively cultivated systems [2].

Despite the increasing recognition of the role land use plays in shaping soil health and carbon dynamics, there remains a significant gap in site-specific, ecosystem-based assessments, especially in developing countries [7]. In Nigeria, and particularly in the North Central region, the challenge of balancing food security with environmental sustainability is becoming increasingly urgent [13]. This is especially relevant in communities such as Malete in Kwara State, where both agricultural expansion and population pressure are altering natural landscapes [14]. As these transformations take place, there is a need for comprehensive, empirical evaluations of how different land-use types such as farmland and grassland affect critical soil functions and their capacity to sequester carbon [15, 7].

Several studies in Nigeria have examined soil fertility, organic matter dynamics, and nutrient availability under various land-use systems, but there is a notable lack of integrated investigations that assess both soil physicochemical properties and

carbon sequestration potential within the same ecological and geographical context [14]. Most existing studies tend to focus on agricultural productivity or isolated soil parameters without considering the broader ecological implications of land-use conversion [1]. Furthermore, available research often generalizes findings across agroecological zones, overlooking the micro-regional variations that significantly influence soil responses to land use [16].

Specifically, there is no detailed study currently for Malete, Kwara State, that provides a comparative analysis of farmland and grassland ecosystems in terms of soil quality and carbon storage capacity [17]. This knowledge gap hinders the ability of land managers, environmentalists, and policymakers to implement site-appropriate practices that promote soil conservation and climate mitigation [6]. Without such localized data, recommendations for sustainable land use may lack scientific credibility and practical relevance for the target community [7].

This study therefore seeks to fill this critical research gap by conducting a comparative assessment of key soil parameters and carbon sequestration indicators across farmland and grassland ecosystems within Malete. By generating reliable, site-specific data, this research aims to inform sustainable agricultural planning, guide ecosystem restoration initiatives, and contribute to the broader understanding of land-use impacts on soil health in West African landscapes.

The aim of this study is to comparatively assess the soil physicochemical properties and carbon sequestration potential of farmland and grassland ecosystems in

Malete, Kwara State, Nigeria. This will involve a detailed evaluation of essential soil attributes, including but not limited to soil texture, pH, organic carbon, bulk density, total nitrogen, available phosphorus, and cation exchange capacity. By analyzing and contrasting these indicators across the two land-use types, the study seeks to identify patterns, differences, and potential trade-offs in soil quality and carbon storage between intensively managed agricultural lands and naturally occurring grasslands.

The outcomes of this study are expected to provide a scientific foundation for promoting land-use strategies that enhance soil fertility, maintain ecological integrity, and support climate change adaptation through improved carbon management. Ultimately, the research aims to contribute to the formulation of sustainable land-use policies and community-level interventions that balance agricultural productivity with environmental stewardship.

MATERIALS AND METHODS

Soil samples were collected using a stratified random sampling approach from the top 0–20 cm of the soil profile. Samples were obtained using a stainless-steel auger and stored in sterile polyethylene bags before being transported to the laboratory for analysis. All equipment was cleaned between collections to prevent cross-contamination [18].

Bulk density was assessed using the core method. Undisturbed cores were dried at 105°C for 24 hours, and bulk density was calculated by dividing the dry weight by the volume of the core [19].

Available nitrogen was determined by extracting soil with 2 M KCl and analyzing the extract through Kjeldahl digestion followed by titration [20].

Soil pH was measured by preparing a 1:2.5 soil-to-distilled water suspension and reading the pH using a calibrated pH meter [21].

Total organic matter content was determined through the Loss on Ignition method. Soil samples were heated at 550°C for 4 hours in a muffle furnace, and organic matter was calculated based on the weight loss [22].

Available phosphorus was analyzed using the Bray I method for acidic soils and the Olsen method for alkaline soils. Extracts were read with a spectrophotometer [23].

Electrical conductivity was measured using a 1:5 soil-to-water extract. The conductivity was recorded using a calibrated EC meter to evaluate soluble salt concentration [24].

Moisture content was determined gravimetrically by drying fresh soil samples at 105°C for 24 hours and calculating water loss as a percentage of fresh weight [25].

Soil porosity was calculated using the relationship:

Porosity (%) = [1 - (Bulk Density / Particle Density)] × 100, assuming a particle density of 2.65 g/cm^3 [26].

Bacterial count was estimated using the serial dilution and plate count method. Diluted samples were plated on nutrient agar and incubated at 28°C for 48 hours,

after which colony-forming units (CFU) were counted [27].

Organic carbon was analyzed using the Walkley-Black wet oxidation method, which involves oxidation with potassium dichromate and sulfuric acid followed by titration [28].

Statistical analyses were conducted using paired t-tests to compare soil properties between farmland and grassland sites. Pearson's correlation analysis was also performed to examine the relationships among measured variables. All analyses were carried out at a 95% confidence level ($p < 0.05$) using SPSS version 25 software

RESULTS

Physical and Chemical Properties of Soils in Farmland and Grassland

The comparative physical and chemical properties of soils from farmland and grassland environments in selected areas of Malete, Moro Local Government Area, Kwara State is presented in Table 1. The parameters analyzed include soil pH, total nitrogen (TN), total organic carbon (TOC), organic matter (OM), phosphorus (P), bulk density (BD), electrical conductivity (EC), moisture content (MC), total bacterial count (TBC), and porosity. The mean soil pH was 7.07 in farmland and 6.66 in grassland, with a t-statistic of 2.34 (p = 0.05), indicating a statistically significant borderline difference. Total nitrogen levels were similar in both environments (0.13% in farmland vs. 0.14% in grassland; t = -0.818, p = 0.43), with no significant difference. Total organic carbon was significantly higher in grassland (10.36 mg/kg) than in farmland (5.45 mg/kg), with t = -2.57 and p = 0.03. Similarly, organic matter content was

significantly greater in grassland (5.53%) compared to farmland (0.88%), as shown by t = -7.493 and p < 0.001.

Phosphorus concentration was markedly higher in farmland (11.63 mg/kg) than in grassland (0.001 mg/kg), with a significant difference (t = 11.63, p < 0.001). Bulk density was slightly higher in farmland (1.80 g/cm^3) than in grassland (1.71 g/cm^3), but the difference was not statistically significant (t = 1.79, p = 0.11). Electrical conductivity was significantly higher in grassland (13.56 dS/m) than in
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farmland (11.11 dS/m), with t = -3.65 and p < 0.001.

Moisture content was 0.19% in farmland and 0.72% in grassland (t = -0.369, p = 0.72), showing no significant difference. Total bacterial count was similar in both environments (58.44 cfu/g in farmland and 59.11 cfu/g in grassland; t = -0.045, p = 0.97). Porosity was slightly higher in grassland (33.63%) than in farmland (32.00%), with t = -1.31 and p = 0.23, indicating no significant variation

Table 1: Paired t-test Results for Physical and Chemical Properties of Soils in Farmland and Grassland of Malete, Kwara State

Variable	t-statistic	Farmland (Mean)	Grassland (Mean)	p-value
pH	2.34	7.07	6.66	0.05
Total Nitrogen (%)	-0.818	0.13	0.14	0.43
Total Organic Carbon (mg/kg)	-2.57	5.45	10.36	0.03*
Organic Matter (%)	-7.493	0.88	5.53	0.00*
Phosphorus (mg/kg)	11.63	11.63	0.001	0.00*
Bulk Density (g/cm^3)	1.79	1.80	1.71	0.11
Electrical Conductivity (dS/m)	-3.65	11.11	13.56	0.00*
Moisture Content (%)	-0.369	0.19	0.72	0.72
Total Bacterial Count (cfu/g)	-0.045	58.44	59.11	0.97
Porosity (%)	-1.31	32.00	33.63	0.23

*Significant at p < 0.05

Correlation Analysis of Soil Parameters

Table 2 displays the Pearson correlation matrix for the soil parameters measured across farmland and grassland ecosystems. Notable relationships include a weak negative correlation between pH and total nitrogen (r = -0.40), and a moderate positive correlation between total nitrogen and total organic carbon (r = 0.55). A strong positive correlation was observed between organic matter and total organic carbon (r = 0.80).

Bulk density showed negative correlations with organic matter (r = -0.20) and porosity (r = -0.50). Moisture content was negatively correlated with pH (r = -0.50), while electrical conductivity exhibited a).

weak negative correlation with bulk density (r = -0.10) and a weak positive correlation with total bacterial count (r = 0.10

Table 2: Pearson Correlation Matrix for Soil Properties in Farmland and Grassland of Malete

Variable	pH	TN	TOC	OM	P	BD	EC	MC	TBC	POR
pH	1.00	-0.40	0.30	0.15	-0.10	-0.05	0.20	-0.50	0.10	-0.30
Total Nitrogen (TN)	-0.40	1.00	0.55	0.60	0.05	-0.30	0.15	-0.20	0.30	0.00
Total Organic Carbon	0.30	0.55	1.00	0.80	0.10	-0.10	0.40	-0.30	0.35	0.10
Organic Matter (OM)	0.15	0.60	0.80	1.00	0.15	-0.20	0.30	-0.25	0.25	0.20
Phosphorus (P)	-0.10	0.05	0.10	0.15	1.00	0.05	0.30	-0.40	0.20	0.15
Bulk Density (BD)	-0.05	-0.30	-0.10	-0.20	0.05	1.00	-0.10	0.40	-0.05	-0.50
Electrical Conductivity	0.20	0.15	0.40	0.30	0.30	-0.10	1.00	-0.15	0.10	-0.10
Moisture Content (MC)	-0.50	-0.20	-0.30	-0.25	-0.40	0.40	-0.15	1.00	-0.05	0.10
Total Bacterial Count	0.10	0.30	0.35	0.25	0.20	-0.05	0.10	-0.05	1.00	0.05
Porosity (POR)	-0.30	0.00	0.10	0.20	0.15	-0.50	-0.10	0.10	0.05	1.00

DISCUSSION

Soil pH

Farmland soils exhibited a slightly higher pH (7.07) than grassland soils (6.66), with a significant borderline difference (p = 0.05), suggesting a tendency toward neutrality or slight alkalinity in agricultural areas. This aligns with findings by [29], who attributed such patterns to practices like liming and fertilizer application. A near-neutral pH enhances nutrient availability and microbial activity, contributing to improved crop performance [30]. In contrast, the slightly acidic nature of grassland soils likely reflects minimal

anthropogenic influence and more natural soil-forming processes. While both systems fall within a range suitable for plant growth, continued monitoring of farmland pH is advisable to prevent excessive alkalinity, which may impair micronutrient availability.

Total Nitrogen

No significant difference was observed in total nitrogen levels between farmland and grassland soils (p = 0.43), indicating similar nitrogen statuses despite different land uses. This suggests that nitrogen inputs in farmland may either not exceed natural cycling in grasslands or are lost

rapidly through leaching or volatilization [31].

Total Organic Carbon (TOC)

Grassland soils had significantly higher TOC (10.36 mg/kg) compared to farmland soils (5.45 mg/kg; $p = 0.03$). This reflects the influence of continuous vegetation cover and minimal disturbance, which promote carbon accumulation through root biomass and litter deposition [32]. Conversely, reduced TOC in farmlands may indicate soil quality degradation due to cultivation. Adoption of conservation practices, such as reduced tillage and cover cropping, is recommended to restore carbon levels.

Organic Matter

Organic matter content was significantly higher in grasslands (5.53%) than in farmlands (0.88%), with strong statistical support ($p < 0.001$). This underscores the beneficial role of undisturbed vegetation in maintaining soil organic matter [33]. The sharp decline in agricultural soils indicates a deterioration of soil health, necessitating strategies such as organic amendments or compost in addition to improve soil structure, fertility, and water retention.

Phosphorus

Phosphorus concentration was markedly higher in farmland (11.63 mg/kg) than in grassland (0.001 mg/kg; $p < 0.001$), most likely due to fertilizer application in cropland. Similar trends have been reported in other studies [34], suggesting that residual phosphorus accumulation is a common outcome of intensive fertilization. While elevated phosphorus supports crop productivity, it also poses environmental risks such as runoff and eutrophication. This underscores the importance of balanced nutrient management to sustain yields and prevent ecological degradation.

Bulk Density

Although farmland soils showed slightly higher bulk density (1.80 g/cm^3) than grassland soils (1.71 g/cm^3), the difference was not statistically significant ($p = 0.11$). Slightly elevated bulk density in agricultural soils may result from repeated tillage and machinery use, potentially restricting root growth and water infiltration. Similar observations by [35] highlight the influence of land use on soil compaction. Despite the lack of statistical significance, minimizing soil compaction through reduced tillage and cover cropping remains advisable.

Electrical Conductivity (EC)

Grassland soils exhibited significantly higher EC (13.56 dS/m) than farmland soils (11.11 dS/m; $p = 0.00$), which may result from natural salt accumulation or reduced leaching due to higher organic matter content [36]. Elevated EC in grasslands could adversely affect salt-sensitive species and warrants monitoring, particularly in arid regions susceptible to salinization.

Moisture Content

No significant difference was detected in moisture content between the two systems ($p = 0.72$), although grasslands had a higher mean (0.72%) compared to farmland (0.19%). This trend likely stems from better soil structure and higher organic matter in grasslands, which enhance water retention. Improving

moisture retention in farmlands through organic amendments could enhance resilience under variable climatic conditions [37].

Total Bacterial Count

The microbial load showed no significant variation between farmland and grassland (p = 0.97), suggesting stability in total bacterial populations across land-use types. However, this does not preclude differences in microbial diversity or function, which may be shaped by land management practices. Strategies such as reduced agrochemical use or organic farming could support more diverse and resilient microbial communities [38].

Porosity

Porosity was slightly higher in grassland soils (33.63%) than in farmland (32.00%), though not statistically significant (p = 0.23). The trend likely reflects better aggregation and lower compaction in undisturbed grasslands [39]. Enhancing porosity in farmlands through practices like organic matter addition and minimal tillage is recommended [40].

Correlation Analysis of Soil Properties

The correlation matrix provided insight into the interactions among soil physicochemical and biological parameters.

pH and Organic Matter showed a weak positive correlation (r = 0.15), suggesting minimal influence of organic matter on pH within the studied context.

pH and Total Nitrogen were weakly negatively correlated (r = -0.40), indicating that nitrogen content may decrease with increasing pH, possibly due to reduced nitrogen fixation in more alkaline conditions.

Total Nitrogen and Total Organic Carbon were moderately positively correlated, indicating that soils with higher organic carbon also tend to have greater nitrogen reserves, due to the role of organic matter in nitrogen cycling.

Total Organic Carbon and Organic Matter had a strong positive correlation, as expected due to the carbon-rich composition of organic matter. This relationship reinforces the link between organic content and soil health.

Organic Matter and Phosphorus exhibited a weak positive correlation, indicating that while organic matter may aid phosphorus retention, availability is more heavily influenced by fertilizer inputs.

Bulk Density and Organic Matter were negatively correlated, suggesting that compaction reduces organic matter retention. Similarly, bulk density showed a moderate negative correlation with porosity, affirming that compaction lowers pore space.

Electrical Conductivity and Bulk Density had a weak negative correlation. EC in soils is influenced by factors like moisture and texture more than compaction alone.

Moisture Content and pH showed a moderate negative correlation, reflecting acidification trends in wetter soils due to cation leaching and microbial organic acid production.

Moisture Content and EC had a weak negative correlation, likely due to dilution of salts under wetter conditions.

EC and Total Bacterial Count were weakly positively correlated, suggesting that certain salt-tolerant bacteria may proliferate under higher EC conditions, and influencing microbial-mediated nutrient cycling.

Total Bacterial Count and pH showed a weak positive correlation (r = 0.10), consistent with previous studies indicating that near-neutral pH promotes microbial abundance.

Bulk Density and Porosity exhibited a moderate negative correlation, reaffirming that higher compounds reduce soil pore space and thus impacts aeration and water infiltration.

Porosity and pH showed a weak negative correlation, possibly due to increased leaching of basic cations in more porous soils, leading to lower pH.

CONCLUSION

This study provides a site-specific comparison of farmland and grassland soils in Malete, Kwara State, highlighting significant differences in key physicochemical properties and carbon sequestration potential. Grassland soils exhibited higher organic matter, total organic carbon, and porosity, reflecting minimal disturbance and better ecological function, while farmland soils showed elevated phosphorus levels due to fertilizer input but lower carbon content and signs of degradation. Correlation analysis revealed strong links between organic matter and carbon, and negative associations between bulk density and porosity, emphasizing the impact of land use on soil structure and fertility. These findings underscore the need for sustainable land management practices such as reduced tillage, organic amendments, and conservation of vegetative cover to enhance soil health and climate resilience. The study fills a critical data gap for the region and offers practical insights to guide environmentally sound agricultural policies and land-use planning in similar contexts.

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