The Influence of Different Land Use Practices on Specific Physical Characteristics of Soil in Gaya, a Region within the Savanna Ecosystem in Nigeria

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Abstract:- This study examines the impact of various land use types on specific physical properties of soil at the Kano University of Science and Technology Research Farm in Gaya, Gaya L.G.A., Kano State, Nigeria. The four agricultural land uses investigated are cropland, forest, grazing, and plantation land. Soil samples were randomly collected from two depths (0-15 cm and 15-30 cm), with five samples from each depth per land use type, resulting in 40 samples. Bulk densities were measured using the core method. The results indicated no significant effect (Fpr > 0.05) of land use on bulk density and porosity. However, bulk density values exhibited an increasing trend: cropland (1.602 g/cm³) < forest land (1.667 g/cm³) < plantation land (1.669 g/cm³) < grazing land (1.69 g/cm³). Grazing land had the highest mean bulk density, while cropland had the lowest. At 0-15 cm depth, plantation land had the highest mean bulk density (1.698 g/cm³), and cropland had the lowest (1.547 g/cm³). At a depth of 15-30 cm, forest land had the highest mean bulk density (1.767 g/cm³), while plantation land had the lowest (1.641 g/cm³). Total porosity showed an increasing trend from grazing land (30.8%) to plantation land (33.6%), cropland (34.3%), and forest land (37.7%). Factors such as organic matter content, aggregate size, and soil depth influenced the bulk density and porosity characteristics. Overall, bulk density was higher than standard values, indicating compaction: sandy soils were too compact, loamy soils were very compact, and clay soils were highly compact. Total porosity generally fell within the moderate range, and particle density was within the normal acceptable range of 2.65 g/cm³.

Keywords:- *Cropland, Grazing Land, Plantation Land, Forest Land and Bulk density.*

I. INTRODUCTION

Land use encompasses the arrangements, actions, and inputs individuals implement to produce, alter, or maintain a particular type of land cover (Ufot et al., 2016). Sustainable management of soil resources is crucial for successful agriculture because soil quality and quantity can rapidly deteriorate due to factors such as intensive farming, leaching, and soil erosion (Kiflu and Beyene, 2013). A comprehensive understanding of sustainable land use is essential for agricultural operations (Takele et al., 2014). Recognizing soil's long-term response to agricultural practices is vital for effective soil management that preserves soil quality (Duguma et al., 2010). High soil quality is the foundation of sustainable agricultural growth, as it is crucial for sustaining agriculture and enhancing crop output (Liu et al., 2010). Soil resources have significantly contributed to food and fiber production and the maintenance of environmental quality at local, regional, and global levels (Bore and Bedadi, 2015).

Anthropogenic activities have dramatically altered livelihoods over the past century by rapidly changing land-use patterns (Liu et al., 2005a, 2005b; Hurtt et al., 2006; Liu and Tian, 2010; Tian et al., 2014). Deforestation converts forest land (FL) into various land use (LU) systems, such as cultivated land (CL), grassland (GL), horticultural land (HL), plantation land (PL), and barren land (BL), at an annual rate of 13 million hectares (FAO, 2006). This conversion often leads to soil quality degradation, reducing soil productivity potential (Wei et al., 2014; Nath et al., 2018). International studies report that intensive land use, uneven terrain, and changing climatic conditions combined with land-use changes (LUC) lead to soil degradation (Palni et al., 1998; Abera and Wolde-Meskel, 2013; Kumar et al., 2017, 2021). These LUCs also alter the system's carbon sequestration capacity (Abera and Wolde-Meskel, 2013; De Blécourt et al., 2013; Guillaume et al., 2015; Fan et al., 2016; Iqbal and Tiwari, 2016). The transformation of FL into various LUs results in biodiversity loss and reduced soil organic carbon (SOC) (De Blécourt et al., 2013; Ahrends et al., 2015; Guillaume et al., 2015; Nath et al., 2018).

Evaluating the effects of LUC is crucial for developing government policies and understanding the interrelationships between ecosystems, climate systems, and human activities (Houghton and Hackler, 2003; Tian et al., 2003; Arora and Boer, 2010). The United Nations Department of Economic and Social Affairs predicts that by 2025, India will surpass China as the world's most populous country (Population

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Division, 2019). Between 1980 and 2020, India's population grew from 200 million to 1.4 billion, significantly altering land use (Tian et al., 2014; United Nations Population Division, 2020). In regions like central Ethiopia, with high population density and heavy reliance on land resources, this population increase poses significant challenges. Such pressures lead to soil degradation and impair the sustainability of soil resources (Yimer and Abdulkadir, 2011). Overgrazing, deforestation, irregular and intense rainfall patterns, cultivation of steep soils, and poor soil conservation management are the main causes of land degradation in Ethiopia (Aytenew and Kibret, 2016). Additionally, land topography and cultivation methods significantly influence soil quality and depth (Pavlu et al., 2007).

Therefore, addressing resource degradation, enhancing agricultural productivity, reducing poverty, and achieving food security are the main challenges facing tropical African nations (Qadir et al., 2014). Efforts should focus on the sustainable use of natural resources to maintain the physical, biological, and socioeconomic environment necessary for the production of food crops, livestock, timber, and other products (Adeyemo and Agele, 2010). Increasing populations and livestock numbers have intensified the expansion of grazing grounds and croplands, altering soil characteristics (Mustapha, 2007). This has led to the conversion of forest lands into agricultural and grazing areas, driven by population growth (Chemada et al., 2017). In Ethiopia, for instance, forest cover has decreased from 40% to less than 3% due to rapid population growth, with the population nearly doubling every 26 years (MOFED, 2007).

A. *Problem Statement*

This research delves into a noteworthy research gap concerning the influence of different land management approaches on fundamental soil properties. Despite the extensive body of research in soil science and land utilization, there exists a scarcity of precise data on the effects of various land uses such as forestry, agriculture, urban expansion, and grazing on soil attributes like bulk density, porosity, aggregate stability, and infiltration rate. It is widely acknowledged that intensive agricultural practices, deforestation, and urban development are key contributors to soil deterioration, leading to heightened erosion rates, declining organic content, and increased compaction. Nevertheless, the specific impacts of individual land use categories on these transformations remain inadequately understood.

Changes in soil physical properties significantly influence the infiltration and retention of water, both of which play a crucial role in agricultural productivity and the management of water resources. Insufficient water infiltration, heightened surface runoff, and erosion resulting from inappropriate land utilization worsen the challenges associated with water scarcity and quality. Furthermore, soil physical properties are essential for the processes of carbon sequestration. It is imperative to comprehend how different land uses impact the structure of soil and organic material to create land management strategies that alleviate the effects of climate change. The primary objective of this research is to methodically examine the impacts of various types of land use on the essential physical properties of soil to address this knowledge gap.

B. *Justification for the Study*

Investigating the "Impact of Various Land Use Practices on Select Physical Properties of Soil in Gaya, Savanna Region, Nigeria" is imperative for the advancement of sustainable agricultural methodologies and ecological conservation. The savanna region, which constitutes a significant component of Nigeria's agricultural topography, necessitates a comprehensive comprehension of the influence of diverse land use practices on soil physical attributes. This comprehension is paramount for the amelioration of agricultural efficiency, preservation of environmental well-being, and maintenance of sustainable land utilization.

The rationale behind this study is substantiated by a myriad of critical exigencies and advantages:

Addressing Soil Degradation: Improper land use techniques contribute to the ubiquitous dilemma of soil degradation, culminating in escalated erosion rates, diminished agricultural output, and depletion of soil fertility. This investigation will expound on the repercussions of forestry, urbanization, agriculture, and grazing on soil physical properties that are fundamental for soil vitality. Grasping these ramifications is essential for formulating measures to avert soil degradation and safeguard agricultural territories.

Enhancing Agricultural Productivity: The condition of the soil plays a pivotal role in the productivity of agricultural activities. Alterations in soil physical characteristics, such as bulk density, porosity, aggregate stability, and infiltration rates, due to land use practices, have a direct influence on the quality and quantity of crops produced. This study aims to contribute to food security and sustainable agricultural development through a thorough examination of these effects, offering guidance on improved land management strategies to enhance soil conditions for agricultural purposes.

Optimizing Water Resource Management: The management of water resources is significantly impacted by land use practices, particularly in terms of water infiltration and retention. Inadequate land management practices can result in decreased infiltration, heightened surface runoff, soil erosion, and water scarcity. This research seeks to identify the most effective land use approaches to mitigate the negative consequences of flooding, drought, and water contamination.

Mitigating the Impacts of Climate Change: Carbon sequestration, a vital process in combating climate change, is heavily influenced by soil properties. The variation in land use

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types can affect soil organic carbon levels and the overall structure of soil. This investigation is designed to offer insights into the ways different land use patterns impact soil carbon dynamics, aiding in the formulation of land management strategies that promote carbon sequestration and reduce emissions of greenhouse gases.

Conserving Ecosystem Services and Biodiversity: The physical attributes of soil are crucial for nurturing plant growth and providing a habitat for soil-dwelling organisms, which ultimately contribute to biodiversity above ground. Analyzing the effects of diverse land use patterns on these soil properties will bolster conservation initiatives aimed at preserving biodiversity, and fostering the resilience of ecosystems to withstand environmental fluctuations.

The importance of this research is highlighted by its potential to enhance agricultural productivity, address climate change, conserve biodiversity, manage water resources efficiently, and influence policymaking. Through the analysis of the influence of diverse land use patterns on the physical characteristics of soil, this investigation will tackle crucial agricultural and environmental obstacles, enriching the enduring productivity and well-being of terrains.

C. Aim and Objectives

The principal aim of this research is to ascertain the impact of different land uses at the KUST Research Farm in Gaya on specific physical soil properties. The precise objectives are:

- To evaluate the influence of various land management strategies (such as forest, agriculture, plantation, and grazing land) on soil physical properties.
- To assess the impact of different land uses on soil compaction.

II. MATERIALS AND METHODS

A. Description of the Study Area

The investigation took place within the confines of the Gaya Local Government Area situated in Kano State, Nigeria. This particular geographic region is entirely situated in the Sudan Savannah, falling within the latitudes 11°N to 14°N and longitudes 7°38'E to 8°38'E. An average annual precipitation of 773.4 mm characterizes the area, with the predominant soil type being sandy loam, possessing a dark brown hue and a notable silt composition. The research site was segregated into distinct zones for land use management.

B. Method of Sampling

Samples of soil were gathered from four distinct categories of land use management: grazing land, plantation land, cropland, and forested land. Within each sampling area, five representative samples were procured using core samplers at depths of 0-15 cm and 15-30 cm, resulting in a total of 40 core samples for the assessment of soil bulk density. Furthermore, soil specimens were obtained through an auger at the same depths and from identical land use categories, thereby adding another collection of 40 samples. These samples were meticulously stored in appropriately labelled polyethene bags, air-dried in shaded conditions, and subsequently ground using a pestle and mortar before being sifted through a 2 mm mesh for laboratory scrutiny.

- *Collection of Soil Samples Using the Core Method*

The acquisition of soil samples was executed employing core samplers, whereby metal cylinders were delicately inserted into the soil using a sharpened cutting edge without altering the core's height. Subsequently, the cylinder housing the soil specimen was extracted and weighed while still moist. Following the moisture weight recording, the sample underwent a drying process in an oven at 105°C before being reweighed.

C. Laboratory Analysis

- *Bulk Density*

Bulk density measurements were conducted utilizing the core method as outlined by Anderson and Ingram (1993). The essential apparatus encompassed a metal ring, cylinder, wooden block, hammer, and an oven. Before sampling, any loose surface material was eliminated. In the case of subsurface layers, a pit was excavated to the desired depth. The cylinder was carefully driven into the soil aided by a wooden block and hammer, ensuring minimal soil compaction. Upon core extraction, the soil was meticulously trimmed and weighed, with the soil weight alone determined by deducting the cylinder's weight. A segment of the soil was utilized for moisture content determination, enabling the subsequent calculation of the oven-dry weight. The calculation of Bulk Density (BD) was computed according to specific formulae.

$$BD = \frac{\mathrm{Wts}}{\mathrm{V}}$$

Where:
BD = Bulk density
Wts = Weight of the oven-dried soil
V = Volume of the soil

- *Percentage Porosity*

Porosity represents the percentage of soil volume occupied by pore spaces. It is critical for plant growth, influencing aeration, permeability, drainage, and water retention. Total porosity was derived from the particle and bulk densities using the following formula:

$$\%\,Porosity = \left(1 - \frac{Bulk\ density}{Particle\ density}\right) \times 100$$

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- *Particle Density*

Particle density, also known as true density, is the weight per unit volume of the soil solids and is typically around 2.65 g/cm³ in normal soils. It was determined using the pycnometer method:

$$\rho p = \frac{dW \times W}{W1 - (W2 - W3)}$$

Where:
ρp = Particle density (g/cm³)
dW = Density of water at room temperature
W1 = Weight of oven-dried soil
W2 = Weight of pycnometer + soil + water
W3 = Weight of pycnometer + water

D. Statistical Analysis

The collected data were analyzed using analysis of variance (ANOVA) with Genstat 17th edition statistical software. Treatment means were separated using Tukey's 95% confidence intervals (HSD) at a 5% probability level.

III. RESULTS AND DISCUSSION

A. Effect of Land Use and Soil Depth on Soil Bulk Density

The impacts of land utilization and soil profundity on bulk density within the research area are delineated in Table 1. The data in the table reveals that there was no notable distinction in bulk density among the four categories of land utilization (Fpr > 0.05). Nevertheless, grazing land displayed the highest average bulk density figure (1.69 g/cm³), followed by plantation land and forest land, while cropland exhibited the lowest mean value (1.602 g/cm³).

Conversely, substantial variance in bulk density was noted across various soil depths (Fpr < 0.05). The bulk density peaked at the depth of 15-30 cm, with a mean of 1.689 g/cm³, in contrast to the 0-15 cm depth, which had an average of 1.626 g/cm³. Furthermore, there existed a statistically significant interplay between land utilization and soil depth (Fpr < 0.05), suggesting that the impact of land utilization on bulk density fluctuates with soil depth.

Table 1: Effect of Land use and Soil Depth on Bulk density

Treatment	**Bulk Density (g/cm3)**
Land use	
Cropland	1.602
Forest land	1.667
Grazing land	1.690
Plantation land	1.669
SE (±)	0.0385
F_{pr}	0.143
LSD	NS
Depth (cm)	
0-15	1.626
15-30	1.689
SE (±)	0.0272
F_{pr}	0.028
Land use × Soil depth	0.01
LSD	*

Key: * = Significant at 5% level of probability (≤0.05), NS = Not significant at 5% level of probability (>0.05), SE = Mean standard error of mean and LSD = Level of significance difference……….

- *Interaction of Land Use and Sampling Depth on Soil Bulk Density*

The impact of land utilization and sampling depth on soil bulk density resulted in a noteworthy distinction (Fpr<0.05) in bulk density across various land uses and depths, as outlined in Table 1. More specifically, within the 0-15 cm depth range, plantation land displayed the highest average bulk density (1.698 g/cm³), followed by grazing land and forest land, with cropland exhibiting the lowest average value (1.547 g/cm³). On the contrary, within the 15-30 cm depth range, forest land recorded the highest average bulk density (1.767 g/cm³), followed by grazing land and cropland, while plantation land demonstrated the lowest average value (1.641 g/cm³) (Table 2).

Table 2: Interaction of Land Use and Sampling Depth on Soil Bulk Density

Land use	**Bulk density (g/cm^3)**	
	(0-15cm)	(15-30cm)
Cropland	1.547b	1.657ab
Forest land	1.566b	1.767a
Grazing land	1.692ab	1.688ab
Plantation land	1.698ab	1.641ab
SE (±)	0.0544	

Key: * = Significant at 5% level of probability (≤0.05), NS = Not significant at 5% level of probability (>0.05), SE = Mean standard error of mean and LSD = Level of significance difference……….

- *Impact of Land Use and Sampling Depth on Total Porosity and Particle Density in the Study Area*

The outcomes concerning the impact of land utilization and sampling depth on overall porosity and particle density within the research area are displayed in Table 3. It was noted that there exists no notable distinction in overall porosity and particle density across the diverse land utilizations (Fpr > 0.05). Despite the absence of statistical significance, the forested land displayed the highest average overall porosity (37.7%), followed by cropland, plantation land, and grazing land, which exhibited the lowest average overall porosity (30.8%).

Likewise, the particle density reached its peak in forested land (2.708 g/cm³), succeeded by plantation land and grazing land, while cropland showcased the lowest mean particle density (2.464 g/cm³). Nonetheless, these variances did not attain statistical significance. Moreover, no significant

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interplay effects between land utilization and sampling depth on overall porosity and particle density were witnessed (Fpr > 0.05).

Table 3: Impact of Land Use and Sampling Depth on Total Porosity and Particle Density in the Study Area

Treatment	Porosity (%)	Particle Density (g/cm^3)
Land use		
Cropland	34.3	2.464
Forest land	37.7	2.708
Grazing land	30.8	2.475
Plantation land	33.6	2.558
SE (±)	3.34	0.1381
F_{pr}	0.246	0.284
LSD	NS	NS
Depth (cm)		
0-15	33.0	2.452
15-30	35.2	2.650
SE (±)	2.36	0.0977
F_{pr}	0.368	0.052
Land use × Soil Depth	NS	NS

Key: * = Significant at 5% level of probability (≤0.05), NS = Not significant at 5% level of probability (>0.05), SE = Mean standard error of mean and LSD = Level of significance difference……….

B. *Discussion*

➢ *Effect of Land Use on Soil Bulk Density*

The outcomes delineated in Table 1 suggest that there existed no statistically notable distinction (Fpr>0.05) in bulk density among the four distinct land uses. The average figures of bulk density varied from 1.602 g/cm³ to 1.69 g/cm³. As per Handreck and Black (1984), bulk density values ranging from 1.6 to 1.8 g/cm³ are generally too dense for sandy soils, exceedingly dense for loams, and extremely dense for clay soils. Furthermore, Hunt and Gilkes (1992) affirm that bulk densities between 1.6 and 1.9 g/cm³ are typically elevated. This implies that the soil in the research area displays a moderate level of compaction, as indicated by the marginally higher bulk density values observed.

Despite the absence of statistical importance, grazing land demonstrated the highest mean bulk density value of 1.69 g/cm³, while cropland exhibited the lowest mean value of 1.602 g/cm³. This divergence could be ascribed to varied management strategies impacting soil coverage, organic material, soil composition, and porosity, including manure application, tillage activities, and decomposition of crop residues. Table 1 also reveals that bulk density generally rises with soil depth. The average bulk density for the 0-15 cm depth was 1.626 g/cm³, whereas, for the 15-30 cm depth, it stood at 1.689 g/cm³, in alignment with conclusions by NLWRA (2001) and Cresswell and Hamilton (2002). Bulk density values surpassing 1.6 g/cm³ may hinder root expansion (McKenzie et al., 2004).

➢ *Interaction of Land Use by Sampling Depth on Soil Bulk Density*

Bulk density typically escalates with soil depth due to diminished organic material content, reduced aggregation, and diminished root penetration in deeper layers, resulting in decreased pore space. Table 2 exhibits a notable contrast (Fpr<0.05) in bulk density across sampling depths and land uses. In cropland, bulk density surged from 1.547 g/cm³ at 0-15 cm to 1.657 g/cm³ at 15-30 cm, indicating moderate to high bulk density (Handreck and Black, 1984). This could be attributed to management practices like manure application, tillage, and decomposition of crop residues.

Within forest land, bulk density escalated from 1.566 g/cm³ at 0-15 cm to 1.767 g/cm³ at 15-30 cm, also reflecting a moderate to high bulk density (Handreck and Black, 1984). The absence of management practices likely contributed to this rise, which may impede root growth and penetration at deeper levels (McKenzie et al., 2004). In grazing land, bulk density values were 1.692 g/cm³ at 0-15 cm and 1.688 g/cm³ at 15-30 cm, indicating a high bulk density rating. The slight reduction in bulk density with depth could be due to surface compaction induced by animal trampling (Batey, 2009). Plantation land displayed a decline in bulk density from 1.698 g/cm³ at 0-15 cm to 1.641 g/cm³ at 15-30 cm, possibly due to deep-rooted plants ameliorating soil structure and porosity, thereby reducing bulk density.

➢ *Effect of Land Use and Sampling Depth on Total Porosity and Particle Density*

Table 3 illustrates the impact of land utilization and sampling depth on total porosity and particle density. No significant statistical contrast was observed in porosity and particle density among distinct land utilization types (Fpr>0.05). Nonetheless, forested land displayed the highest average porosity of 37.7% and the highest particle density of 2.708 g/cm³. This corresponds with FAO (2006), which suggests that total porosity exceeding 40% is considered very high. The recorded porosity values are marginally elevated, yet not significantly distinct.

Cropland exhibited an average porosity of 34.3% and a particle density of 2.464 g/cm³, indicating slightly improved aggregate stability and soil conditions for crop cultivation, potentially attributable to intensive farming and diminished organic matter content. Plantation land showcased an average porosity of 33.6% and a particle density of 2.558 g/cm³, conceivably due to reduced organic fertilization and limited soil management practices. Grazing land depicted the lowest porosity (30.8%) and a particle density of 2.474 g/cm³, possibly due to soil compaction from animal trampling (Batey, 2009). On the whole, total porosity values across land types fall within a moderate ranking (Cresswell and Hamilton,

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2002), and particle densities lie within the accepted normal range of 2.65 g/cm³.

IV. SUMMARY, CONCLUSION AND RECOMMENDATION

A. Summary

The primary objective of this investigation was to assess the influence of diverse land uses on specific physical characteristics of soil at the Research Farm of Kano University of Science and Technology, situated in the Gaya Savanna region of Kano State, Nigeria. The study area was segregated into four distinct land uses: cropland, forested land, grazing land, and plantation land. Five soil samples were collected at each land use location at depths of 0-15 cm and 15-30 cm, resulting in a total of ten samples per land use and forty samples overall. Soil samples were gathered utilizing the core method, involving the insertion of a metal cylinder into the soil, extraction, weighing, and subsequent drying in an oven at 105°C. Bulk density was determined through the core method (Anderson and Ingram, 1993), while porosity percentage and particle density were ascertained using the pycnometer method.

The amassed data underwent analysis through analysis of variance (ANOVA) employing Genstat 17th edition statistical software. Treatment means were segregated utilizing Turkey's 95% Confidence Intervals (HSD) at a 5% probability level. The outcomes revealed no notable effect (Fpr>0.05) of land use on bulk density and porosity. Nevertheless, a significant interaction effect (Fpr<0.05) of land use by sampling depth on soil bulk density was identified. This interaction revealed that cropland displayed the lowest mean bulk density value of 1.547 g/cm³ at a depth of 0-15 cm, while plantation land exhibited the highest mean value of 1.698 g/cm³. At a depth of 15-30 cm, plantation land recorded the lowest mean bulk density of 1.641 g/cm³, with forested land showing the highest mean value of 1.767 g/cm³.

B. Conclusion

The findings indicate that the bulk density of soil across the different land uses in the study area was generally high. The bulk density followed an increasing trend from cropland < forest land < plantation land < grazing land. According to Handreck and Black (1984) and Hunt and Gilkes (1992), bulk density values ranging from 1.6 to 1.9 g/cm³ are typically too compact for sandy soils, very compact for loams, and highly compact for clay soils. The total porosity was generally below the optimum level (<40%) as per the FAO (2006) rating and fell under the moderate rating value according to Cresswell and Hamilton (2002). The particle density was within the normal acceptable range of 2.65 g/cm³.

C. Recommendations

Based on the findings, the following recommendations are suggested:

- A sufficient amount of organic manure should be applied to improve soil organic matter (SOM), which would lower bulk density values and increase porosity due to better aggregate formation.
- Management practices that increase soil compaction in the study area should be avoided.

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