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Research Article

Phytosociological, Soil Physicochemical, and Carbon Stock Assessment in Jibiro Grazing Reserve Girie Local Government Area, Adamawa State, Nigeria

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ABSTRACT
This study assessed the phytosociological characteristics, soil physicochemical properties, and carbon stock of Jibiro Grazing Reserve. A systematic line transect design was used, consisting of two parallel transects (1500 m each) spaced 500 m apart. Along each transect, four 50 m × 50 m sample plots were established alternately at 100 m intervals, resulting in eight plots. All living trees with diameter at breast height (DBH) ≥10 cm were identified and measured for DBH, basal diameter, and total height. Soil samples were collected from three points per plot at depths of 0–15, 16–30, 31–45, and 46–60 cm. Data were analysed using one-way ANOVA and Student's t-test. A total of 12 tree species belonging to 7 families and 68 individuals were recorded, with a stand density of 34 trees ha^{-1}. Phyllanthaceae had the highest frequency, while Sapotaceae was least represented. Total basal area and tree volume were 0.22 m^2 ha^{-1} and 1.63 m^3 ha^{-1}, respectively. Diameter classes ranged from 0–50 cm, and height classes ranged from <11 m to 20 m. Estimated biomass, carbon stock, and CO_2 equivalents were 3.10 t ha^{-1}, 1.55 t ha^{-1}, and 5.68 kg, respectively. Soils were predominantly sandy loam to sandy clay loam, with high sand content (67.25%). Bulk density was lower than particle density, while porosity (39.10%) and water-holding capacity (13.00%) were low. The soil was slightly acidic (pH 7.14), with moderate organic matter and available phosphorus, and high base saturation (79.25%), indicating nutrient limitations affecting vegetation growth.

Keywords: Biomass; Carbon stock; CO_2; Phytosociological; Soil physicochemical

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INTRODUCTION

Tree species diversity refers to the variety and relative abundance of different tree species within a forest ecosystem (Magurran, 2004). It is often expressed in terms of species richness and species evenness, which together reflect both the number of species present and how evenly individuals are distributed among them (Magurran, 2013). Tree diversity plays a crucial role in maintaining ecosystem stability, productivity, and resilience. Forests with higher species diversity are more capable of withstanding environmental stresses such as pest outbreaks, drought, and climate change (Tilman *et al.*, 2014). Diverse tree communities contribute to enhanced nutrient cycling, improved soil fertility, and greater carbon sequestration capacity due to complementary resource use and varied canopy structures (Mensah *et al.*, 2017). Several factors influence tree species diversity, including climatic variables (temperature, rainfall, humidity), topography (elevation, slope, aspect), and edaphic conditions such as soil fertility and pH (Chazdon, 2016). Anthropogenic activities such as logging, overgrazing, and agricultural expansion have also been reported to reduce species richness and disrupt forest regeneration (Feyisa *et al*., 2022). In tropical ecosystems, particularly in Africa, soil fertility gradients and moisture availability are key determinants of species composition and distribution (Lawrence *et al*., 2020). According to Adekunle et al., (2013), forests in southwestern Nigeria with high soil nutrient content exhibit greater tree species richness and basal area compared to nutrient-poor sites. This supports the hypothesis that soil quality directly influences forest structure and diversity. Moreover, maintaining high species diversity is essential for promoting ecosystem services such as carbon storage, timber production, and biodiversity conservation (Chazdon, 2016).

Soil physicochemical properties determine the fertility, structure, and productivity of forest ecosystems and are among the most critical factors affecting tree growth and diversity (Brady and Weil, 2016). These properties are broadly categorized into physical (texture, bulk density, porosity, moisture content) and chemical (pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases, and cation exchange capacity) characteristics. Soil texture influences aeration, water retention, and root penetration, thereby affecting tree establishment and growth (Lal, 2019). Soils with balanced proportions of sand, silt, and clay (loam soils) are often associated with higher tree species diversity due to their favorable nutrient and moisture conditions. Soil pH affects nutrient solubility and microbial activity, with neutral to slightly acidic soils generally supporting higher vegetation diversity (Tellen and Yerima, 2018). Organic carbon serves as an indicator of soil fertility and is a major driver of microbial activity, nutrient cycling, and forest productivity (Brady and Weil, 2016). Tellen and Yerima (2018) reported that variations in soil organic carbon, nitrogen, and phosphorus significantly influenced vegetation composition in the Bamenda Highlands of Cameroon. Similarly, Lawrence et al. (2020) found that soil nutrient status and moisture gradients play a major role in shaping tropical forest diversity in Ghana. In Ethiopia, Feyisa et al. (2022) found that soil organic carbon and total nitrogen were positively correlated with tree species richness and basal area in dry Afromontane forests.

In Nigerian forest ecosystems, the influence of soil properties on tree diversity has been reported across different vegetation zones. Adekunle et al. (2013) and Akinyemi, Adedeji, and Adebayo (2021) found that sites with high soil organic matter and exchangeable cations tend to support richer tree communities than degraded soils with low fertility.

Grazing reserves in Nigeria are increasingly threatened by climate variability, overgrazing, deforestation, bush burning, and unsustainable land-use practices, leading to severe degradation of vegetation and soil resources. The Jibiro Grazing is a vital rangeland that supports pastoral livelihoods, livestock production, and ecosystem services such as carbon sequestration. However, its present ecological condition remains poorly documented. Phytosociological qualities, including species composition, diversity, and vegetation structure, are key indicators of rangeland health. In Jibiro Grazing Reserve, increasing grazing pressure and human activities are alleged to have changed plant communities, reduced biodiversity, and stimulated the dominance of invasive or unpleasant species. Similarly, continuous livestock trampling, erosion, and nutrient depletion may have degraded soil physicochemical properties, yet the extent and spatial variability of soil degradation are largely unquantified.

Rangelands also play a key role in climate change mitigation through carbon storage in vegetation and soils. Degradation can significantly reduce this carbon stock potential, but data on aboveground, belowground, and soil carbon stocks in Jibiro Grazing Reserve are scarce. The lack of integrated studies combining vegetation, soil, and carbon assessments creates a major knowledge gap, limiting evidence-based management and restoration planning. Therefore, a comprehensive assessment of phytosociological characteristics, soil physicochemical properties, and carbon stocks is essential to support sustainable rangeland management and climate-smart interventions in Adamawa State and Nigeria.

MATERIALS AND METHODS

The Study Area

Adamawa State is located at the North-Eastern part of Nigeria. It lies between latitude 7° and 11° N of the equator and between longitude 12° and 13° E of the Greenwich meridian E in the Upper Benue catchment (Figure 7). Girei LGA lies 9.4265° N and 12.4809° E. The population Girei is approximately 200,200 (projected for 2022). Jibiro grazing reserve is located in Jabbi Lamba (Girei LGA), gazette and has an area of 2,866.36 hectares. it serves as a key area for livestock production, featuring pastoral resources, grass biomass, facilities such as boreholes and veterinary outposts provided by the state government with varying grass/trees above-ground biomass (GAB) production, with peak production occurring around September. The State covers a land area of about 38,741 km^2. It is divided into 21 Local Government Areas. It has a population of 3,168,101 (National Bureau for Statistics, 2007 and National Population Commission, 2006).

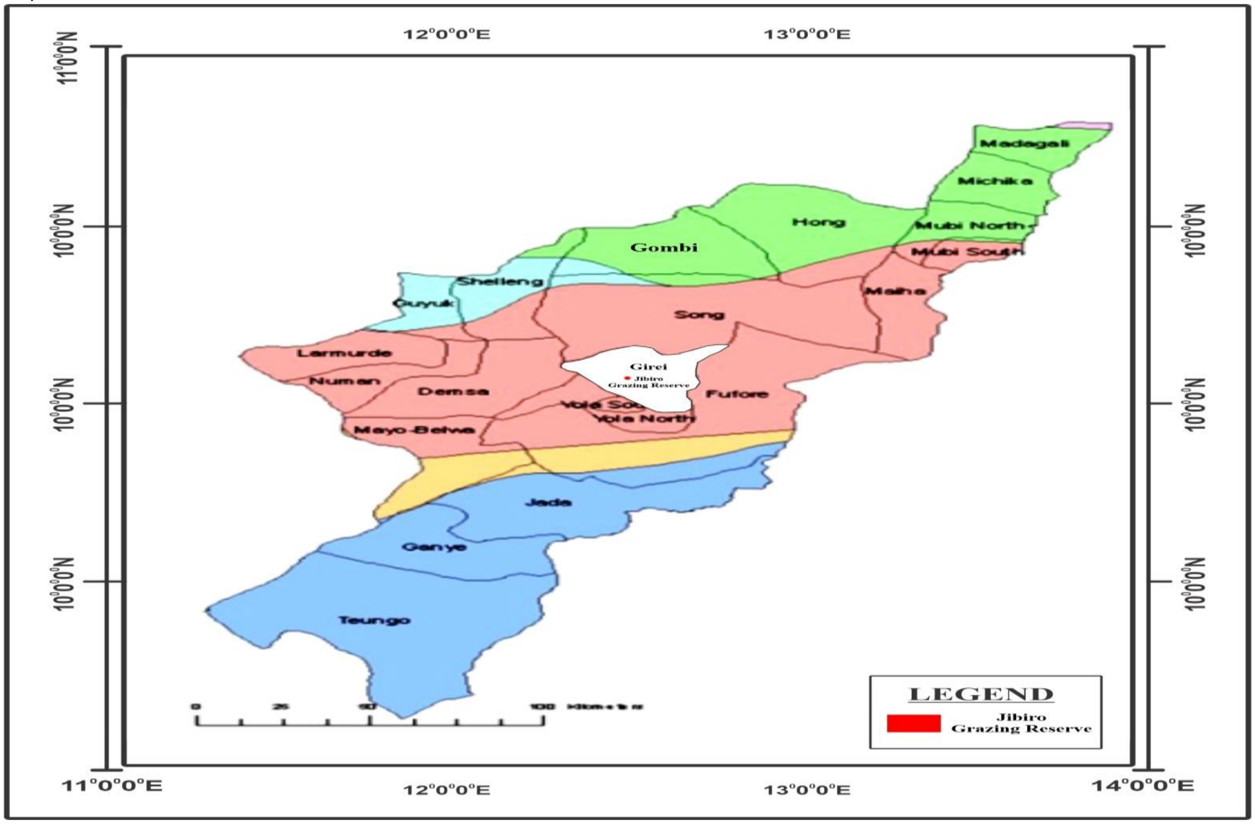

Figure 1: **Map of Adamawa State indicating Jibiro Grazing Reserve in Girei LGA (Source: Umar *et al*., 2025, in Adebayo and Nwagboso, 1999)**

Sampling Procedure and Plot Demarcation

The study employed systematic sampling techniques, where two lines transects were systematically laid. Two parallel transects, 1500m in length, with a distance of 500m between them, were used. Sample plots of 50m x 50m in size were laid in alternate along each transect at 100m interval and thus summing up to 4 sample plots per 1500m transect and a total of 8 sample plots in the Jibiro grazing reserve.

Method of Data Collection

Tree species identification

The identification of plant samples was carried out using flora Field guides (Keay, 1989). A taxonomist was engaged to identify the plants in the field. Those that could not be identified in the field were preserved in a wooden press and taken to the Department of Forestry and Wildlife Management Harbarium of Modibbo Adama University, Yola Herbarium, for proper identification.

Tree growth variable measurement

In each sample plot, all living trees with dbh ≥10cm were identified and measured for dbh, diameter at the base, middle and top and total height. Diameter tape and spiegel relaskop were used for tree height and diameter at the base, middle and top, while diameter/girth tape was used for dbh measurement.

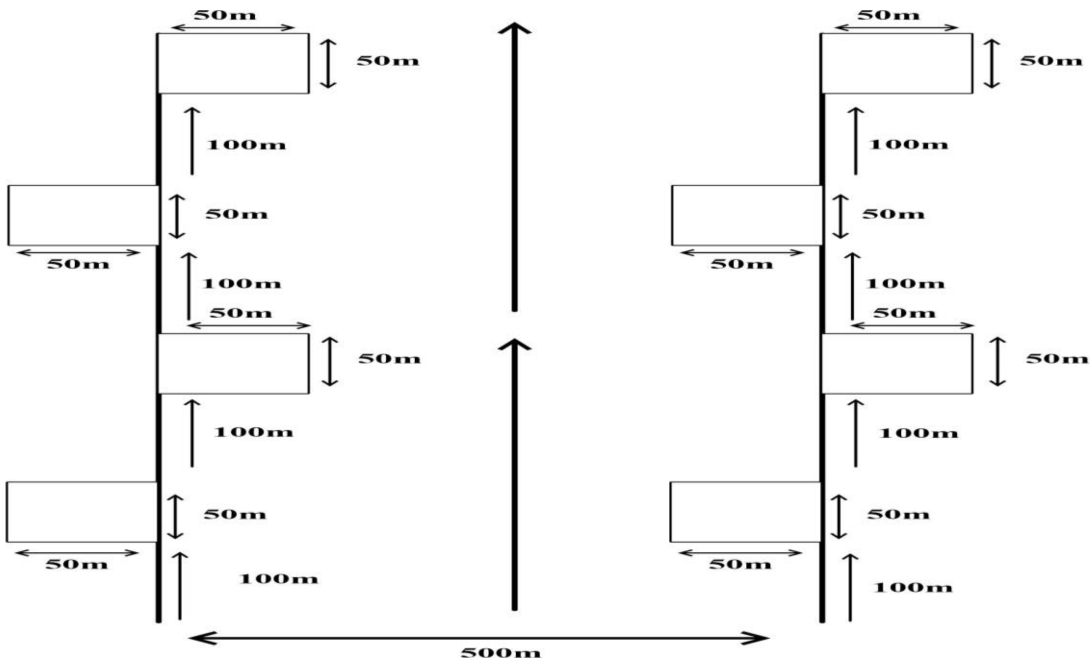

Figure 2. Plot Layout with systematic line transect sampling technique (Source: Umar *et al.*, 2025)

Soil sample collection

A diagonal line was laid within the sample plot for soil sample collection. Soil samples were taken from four soil depths of 0 – 15cm, 16 – 30cm, 31 – 45cm and 46 – 60cm at three points (i.e. at the two edges and middle of the line). Soil samples from the same depths and from the same plot were thoroughly mixed to form a composite soil sample, from which samples were taken for laboratory analysis.

Method of Data Analysis

Basal area estimation

The Basal areas of all trees in the sample plots in the selected study area were calculated using the formula:

$$BA = \frac{\pi D^2}{4} \quad \text{.......} \quad (1)$$

Where BA – Basal area (m^2), D – Diameter at breast height (cm) and π – Pie (3.142).

The total basal area for each of the sample plots were obtained by summing of the BA of all trees in the plot. While mean basal area per hectare was obtained by multiplying mean basal area per plot with the number of 50 x 50m plots in the grazing reserves.

$$BA_{ha} = BA_p = \frac{\Sigma BA}{n} \quad \text{.......} \quad (2)$$

Where BA_{ha}= Basal area per hectare.

BA_P= Mean basal area per plot

n= number of all possible sample plot

Stem volume estimation

The volume of individual trees was estimated using the formula of Newton's formula of (Husch *et. al*., 2003). The equation is expressed as follows:

$$V = \frac{\pi h}{24}(D_b^2 + 4D_m^2 + D_t^2) \quad \text{.......} \quad (3)$$

Where:

V = Volume of tree (m^3)

D_b = Diameter at the base (m^3)

D_m = Diameter at the middle (m^3)

D_t = Diameter at the top (m^3)

h = height (m)

Total plot volume was obtained by adding the volume of individual trees encountered in the plots. Mean volume for sample plots were calculated by dividing the total plot volume by the number of sample plots (4 plots) in the grazing reserves.

Volume per hectare was obtained by multiplying mean volume per plot Vp with the number of 50 x 50m plots in a hectare (8 plot) (Adekunle, 2007; Adekunle *et al.*, 2013; Umar *et al.*, 2025).

$$V_{ha} = \bar{V}_p \times 8 \quad \text{.......} \quad (4)$$

Where V_{ha}= Volume per hectare

$\bar{V}_p$ = Mean Volume per plot

Tree Species Classification and Biodiversity indices

(i) The relative density of the species was computed as:

$$RD = \frac{n_i}{N} \times 100 \quad \text{.......} \quad (5)$$

Where:

RD = species relative density

n_i = number of individual of species i

N = total number of all tree species in the community.

(ii) Species relative dominance (RD_o (%)) was computed using the equation:

$$RD_o = \frac{\sum Ba_i \times 100}{\sum Ba_n} \quad (6)$$

Where:

Ba_i = Basal area of individual tree belonging to species i

Ba_n = Stand basal area

(iii) Species diversity index was calculated using the Shannon – Weiner diversity index (Kent and Coker, 1992)

$$H' = -\sum_{i=I}^{S} P_i \ln(P_i) \quad (7)$$

Where:

H'= Shannon – Weiner Diversity index

S = Total number of species in the community

Pi = Proportion of S made up of the i^{th} species

In = natural logarithm

(iv) Shannon's maximum diversity index was calculated using the relationship:

$$H_{max} = \ln(S) \quad (8)$$

Where:

H_{max} = Shannon's maximum diversity

S = Total number of species in the community

(v) Species evenness in each community was determined using Shannon's equitability (Eh).

$$E_H = \frac{H'}{H_{max}} = \frac{\sum_{i=I} P_i \ln(P_i)}{\ln(S)} \quad (9)$$

(vi) Mangelaf's index was calculated using the equation below:

$$D = \frac{S-1}{\ln N} \quad (10)$$

Where:

D = Mangelaf's index

S = Number of species

N = Number of individuals

(vii) Simpson's index

$$D = 1 - \sum \left(\frac{n_i}{N}\right)^2 \quad (11)$$

Where

D = Simpson's index

ni= number of individual of species

N = Total number of all tree species in the entire community

(viii) Family Importance Valve (FIV)

The family importance Valve (FIV) was used to understand a family's share in the tree community. FIV is defined as the sum of its relative dominance (RDm), it relative density (RD) and its relative frequency (RF), which is

Calculated as follows:

$$RD_m = \frac{\text{Total basal area for a family}}{\text{Total basal area for all families}} \times 100 \quad (12)$$

$$RD = \frac{\text{Number of individuals of a family}}{\text{Total number of all individual}} \times 100 \quad (13)$$

$$RF = \frac{\text{Frequency of a family}}{\text{Sum of frequencies of all families}} \times 100 \quad (14)$$

Thus, Family importance Value = RDm + RD + RF ...(15)

Number 1 of Hill Diversity Index

N1: as the exponent of Shannon – Wiener Diversity index given as;

$$N1 = \exp(-\sum pi (\ln pi) \quad (16)$$

$$Pi = ni / N \quad (17)$$

Where: pi: is the proportional abundance of ith species,

ni: number of individuals of ith species

N: total number of individuals

Number 2 of Hill diversity index

N2: species evenness index as a reciprocal of Simpson's dominance index;

$$N2 = 1/\sum pi^2 \quad (18)$$

Biomass equation

To estimate the above – ground live biomass, the equation of Brown (1997) for tropical wet climate zone was adopted. The equation is given as

$$Y = 21.297 - 6.953 (D) + 0.740 (D^2) \quad (19)$$

Where:

Y is biomass per tree in kg

D is diameter at breast height (dbh) in cm.

Estimation of above and below-ground biomass

Estimation of the above–ground live biomass was carried out by multiplying the volume of each tree by its respective wood density or using biomass equation ($Y = 21.297 - 6.953 (D) + 0.740 (D^2)/1000$).

Below-ground biomass was estimated as 15% of the above-ground biomass (Mac Dicken, 1997).

Carbon Stock estimation

Carbon stock of trees was calculated by dividing the total biomass value or by converted to carbon stocks using 0.5 carbon fractions as default values (Mac Dicken, 1997, Penman, 2003 and IPCC, 2006) and expressed in t/ha.

Carbon Stock (ton) = Total biomass /2 or Total biomass x 0.5 (Sharma *et al.*, 2014)...(20)

Estimation of CO_2 Sequestration

The estimation of CO_2 sequestration in the trees was calculated by multiplying the carbon stock in the trees by 3.66673 or 44/12 as adopted by (Pascua *et al*., 2021)

CO_2 sequestration in trees = Atomic weight of CO_2 x Carbon stock……………………………………………………(21)

Where CO_2 = Carbon dioxide (tons/ha)

Laboratory Analysis

Soil physical and chemical properties were determined using standard laboratory analysis.

Data Analysis

One-way ANOVA was employed to assess differences in soil nutrients, tree density, species diversity and richness, basal area, and bio-volume in Jibiro grazing reserve. Student's t-test was used to evaluate significant differences in soil characteristics at varying depths in Jibiro grazing reserve. Where significant differences were found ($p < 0.05$), Duncan's New Multiple Range Test (DMRT) was applied to separate and compare the means.

Tree Species Composition in Jibiro Grazing Reserve

A total of 12 tree species, comprising 68 individuals across 7 families, were recorded in the Jibiro grazing reserve (Tables 1 & 2). The distribution of individuals per hectare varied among species, with Bridelia mollis having the highest density (11 trees ha^{-1}), indicating that it is the most abundant species in the study area. Most other species had relatively low densities ranging between 1–4 trees ha^{-1}, suggesting uneven distribution within the vegetation stand. The relative density (RD) further confirms the dominance of Bridelia mollis, which accounted for 32.35% of the total tree population. In terms of tree size structure, the mean diameter at breast height (MDBH) varied across species, with Philenoptera violacea (27.84 cm) and Burkea africana (27.74 cm) recording the largest diameters, indicating relatively mature trees. The mean basal area (MBA) values ranged from 0.01 to 0.07 m^2, with the highest basal area observed in Burkea africana and Philenoptera violacea, suggesting their greater contribution to stand structure and biomass.The mean volume (MVOL) also varied among species, with Burkea africana (0.81 m^3) and Philenoptera violacea (0.70 m^3) recording the highest tree volumes, reflecting their larger size and potential timber value. Tree height also differed among species, with Burkea africana having the highest mean height (13.20 m), followed by Philenoptera violacea (12.20 m) and Combretum zeyheri (11.90 m).

Families Important Index (FIV) for Jibiro Grazing Reserve

A total of 68 individual trees belonging to seven plant families were recorded in the study area, with a total basal area of 0.22 m^2/ha and total volume of 1.63 m^3/ha (Table 2). The results reveal clear variation in the structural contribution and ecological importance of the families. The Fabaceae family showed the highest ecological dominance, recording 18 individuals with 26.47% relative frequency (RF) and 26.47% relative density (RD). It also had the highest relative dominance (40.46%), resulting in the highest Family Importance Value (FIV) of 66.43, indicating that species in this family contribute significantly to the stand structure. Similarly, Phyllanthaceae recorded the highest frequency (22 individuals) and highest RF and RD (32.35%), reflecting wide distribution across the plots. However, it had a very low basal area and relative dominance (2.19%), suggesting that the species are generally small-sized trees or shrubs, though the family still maintained a high FIV of 65.44 due to its abundance (Table 2).

Biodiversity Indices

These indices were used to assess tree species diversity in the grazing reserves. The total number of trees/ha is 34, found within 7 families and 12 species. Shannon-Wiener (H^1), was 2.17, Species evenness index J= 0.51, Simpson's concentration (λ) = 0.11, N1 of hill diversity (N1),= 8.76, N2, and Margalef's index of Spp richness (M)= 2.61.

Table 1: Tree Species Abundance/ha, Diversity Indices and Tree Growth Variables in Jibiro Grazing Reserve

S/No	Species	Families	Freq	nha-1	RD	MDBH	MVOL	MBA	MHT	PI	LN PI	PI LN PI
1	*Burkea africana Hook. (1843)*	Fabaceae	5	2.5	7.35	27.74	0.81	0.07	13.20	0.10	-2.61	-0.19
2	*Combretum zeyheri Sound.*	Combretacea	5	2.5	7.35	17.78	0.32	0.03	11.90	0.10	-2.61	-0.19
3	*Detarium macrocarpum Guill & Perr*	Fabaceae	2	1	2.94	27.74	0.13	0.04	5.40	0.01	-3.53	-0.10
4	*Tamarindus indica L.1753*	Fabaceae	3	1.5	4.41	20.17	0.42	0.04	10.70	0.01	-3.12	-0.14
5	*Bridelia mollis Hutch*	Phyllanthaceae	22	11	32.35	9.95	0.06	0.01	7.10	0.30	-1.13	-0.37
6	*Hexalobus monopelatus (A.Rich.) Engl.& Diels*	Anacardiaceae	8	4	11.76	14.14	0.09	0.02	6.40	0.10	-2.14	-0.25
7	*Sterculia setigera Delile*	Malvaceae	8	4	11.76	26.49	0.39	0.06	6.30	0.10	-2.14	-0.25
8	*Balanite aegyptiaca (L.) Delile*	Zygophyllaceae	3	1.5	4.41	19.83	0.12	0.03	4.50	0.01	-3.12	-0.14
9	*Phileneptera violacea (Klotzsch) Schrire*	Fabaceae	5	2.5	7.35	27.84	0.70	0.07	12.20	0.10	-2.61	-0.19
10	*Sclerocarya birrea (A.Rich.) Hochst.*	Anacardiaceae	2	1	2.94	21.55	0.33	0.04	11.60	0.01	-3.53	-0.10
11	*Prosopis africana (Guill. & Perr.) Taub.*	Fabaceae	3	1.5	4.41	17.63	0.14	0.03	5.70	0.01	-3.12	-0.14
12	*Vitelaria paradoxa C.F Gaertn.*	Sapotaceae	2	1	2.94	21.45	0.17	0.04	5.80	0.01	-3.53	-0.10
	Total		**68**	**34**		**252.30**				**1**	**-33.18**	**-2.17**

nha^{-1} – number of species per hectare, RD- Species Relative density, MDbh- Mean Diameter at breast height (cm), MVol- Mean Volume per hectare(cm^3), MBa- Mean Basal area (m^2), MHt- Mean Height (m)

Table 2: Families Important Index (FIV) for Jibiro Grazing Reserve.

S/No	Families	Frequency	Ba/ha	Vol/ha	RF	RD	RDo	FIV
1	Anacardiaceae	10	0.03	0.21	14.71	14.71	13.49	33.91
2	Combretacea	5	0.01	0.06	7.35	7.35	6.24	16.79
3	Fabaceae	18	0.09	0.9	26.47	26.47	40.46	66.43
4	Malvaceae	8	0.03	0.19	11.76	11.76	14.23	28.27
5	Phyllanthaceae	22	0.00	0.03	32.35	32.35	2.19	65.44
6	Sapotaceae	2	0.04	0.17	2.94	2.94	16.41	11.35
7	Zygophyllaceae	3	0.02	0.06	4.41	4.41	6.98	11.15
	Total	**68**	**0.22**	**1.63**				

Source: Umar et al., 2025

Table 3: **Biodiversity Indices**

Variables	Jibiro Grazing Reserve
No of individual trees/ha	34
No of families	7
No of species	12
Shanno-Wienner (H^1)	2.17
Species evenness index	0.51
Simpson's concentration (λ)	0.11
N1 of hill diversity (N1)	8.76
Margalef's index of Spp richness (M)	2.61

Source: Umar *et al.* (2025)

Diameter at Breast Class and Height Class Distribution in Jibiro Grazing Reserve

Results from tables 4 and 5 show biodiversity indices and tree growth variables in terms of diameter and height classes, showing Dbh range from 0-10 to 41-50. Total number of species 68, number of families 25 and number of individual species 30. The total volume/ha is 11.07m^3 and 1.12cm Ba/ha. Dbh class 11-20 has NS, NF, and Ni (29, 7 and 7). The lowest values were found between 41-50 with 1 NS, NF and Ni, respectively. Height class result shows that the <11 to 11-20 ranges. Total NS, NF, and Ni (68, 11 and 19), respectively. The total volume/ha 11.07m^3 and 1.12cm Ba/ha. Height class <11 highest in NS, NF and Ni (54, 6 and 11), respectively, and the lowest range is 11-20, with NS 14, 5, NF and 8 Ni.

Biomass, Carbon Stock and Carbon dioxide (CO_2) in Jibiro Grazing Reserve

Results from table 6 below show biomass, carbon stock and CO_2 of all tree species encountered in Jibiro grazing reserve. A total mean height of 100.80m, 3.10tons/ha of biomass, carbon stock 1.55ton/ha, and a total of 5.68kg carbon dioxide. *Burkea africana, Detarium macrocarpum* and *Phileneptera violaceae* had the highest with 0.46tons/ha of biomass, 0.23 tons/ha of carbon stock in the same species while *Burkea africana* and *Detarium macrocarpum* 0.84kg both and *Phileneptera violaceae* 0.85kg. Lowest biomass was obtained in *Bridelia mollis* at 0.03ton/ha, 0.01ton/ha and 0.05kg of biomass, carbon stock and carbon dioxide, respectively.

Physical Properties of Soil in Jibiro Grazing Reserve

The soil analysis shows variation in texture and physical properties among grazing reserves as shown in Table 7 below. The soils of Jibiro Grazing Reserve are predominantly sandy (67.25%) across the 0–60 cm profile, indicating a coarse texture, rapid drainage, and high infiltration, but low water retention capacity (12.54–13.48%). Bulk density was moderately high (1.54 g/cm³), particularly in the topsoil, suggesting slight compaction from grazing pressure, while particle density remained stable (2.49–2.57 g/cm³), reflecting mineral-dominated soils typical of savanna reserves. Total porosity was moderate (39.10%) total, inversely related to compaction trends but insufficient to offset the limited moisture storage. Collectively, these properties classify Jibiro soils as well-aerated but drought-sensitive, potentially constraining seedling establishment and biomass-carbon accumulation during dry seasons unless supported by organic amendments or moisture-conserving practices.

Duncan's Multiple Range Tests for Soil Physical Properties

Jibiro soils are predominantly sandy (67.25%, group b), with high silt (15.50%, group a) and moderate clay (14.25%, group ab), indicating coarse texture and rapid drainage. Bulk density was moderate (1.53 g/cm³, group bc), reflecting mild compaction from grazing influence, while particle density was uniformly high (2.52 g/cm³, group a), confirming mineral-dominated soils. Total porosity was moderate (39.09%, group ab) but water holding capacity remained low (12.99%, group c), classifying the reserve soils as well-aerated yet moisture-limited, which may seasonally constrain vegetation biomass and carbon storage potential.

Chemical Properties of Soils in Jibiro Grazing Reserve

Results were found in table 9, which shows that the chemical properties of the reserve include: The reserve soils are neutral to slightly alkaline (pH 7.14) and non-saline (EC 0.16 dS/m), providing a chemically suitable medium for vegetation growth. Organic carbon (1.20%) and organic matter are moderate, supporting soil structural aggregation, yet total nitrogen is low, reflecting limited inherent soil fertility. Exchangeable bases are moderate (TEB 8.88 cmol/kg, PBS 79.25%) with high base saturation and low exchangeable sodium percentage, indicating chemical stability with minimal sodicity risk (ESP 5.26%). The Jibiro soils are well-aerated and chemically stable but constrained by moisture and nutrient availability, conditions that may limit biomass productivity and carbon accumulation unless supported by organic amendments or moisture-conserving practices.

Table 4: Diameter at Breast Height distribution in Jibiro Grazing Reserve

Dbh Class	NS	NF	NI	Volume/ha	Ba/ha
0-10	17	6	7	0.17	0.07
11-20	29	7	7	4.15	0.30
21-30	13	8	9	2.35	0.30
31-40	8	3	6	3.32	0.37
41-50	1	1	1	1.09	0.08
Total	**68**	**25**	**30**	**11.07**	**1.12**

NS: Number of species, NF: Number of families, NI: Number of individual species

Table 5: Height Class Distribution in Jibiro Grazing Reserves

Height Class	NS	NF	NI	Volume/ha	Basal area/ha
<11	54	6	11	5.93	0.69
11-20	14	5	8	5.14	0.43
Total	**68**	**11**	**19**	**11.07**	**1.12**

NS: Number of species, NF: Number of families, NI: Number of individual species

Table 6: Biomass, Carbon Stock and Carbon dioxide (CO_2) in Jibiro Grazing Reserve

JIBIRO G.R	Species	MDBH (cm)	MHT (m)	Above Ground Biomass ton/ha	Below Ground Biomass ton/ha	Total Biomass ton/ha	Carbon Stock ton/ha	CO_2 kg
1	*Burkea africana*	27.74	13.20	0.40	0.06	0.46	0.23	0.84
2	*Combretum zeyheri*	17.78	11.90	0.13	0.02	0.15	0.08	0.28
3	*Detarium macrocarpum*	27.74	5.40	0.40	0.06	0.46	0.23	0.84
4	*Tamarindus indica*	20.17	10.70	0.18	0.03	0.21	0.10	0.38
5	*Bridelia mollis*	9.95	7.10	0.03	0.00	0.03	0.01	0.05
6	*Hexalobus monopelatus*	14.14	6.40	0.07	0.01	0.08	0.04	0.15
7	*Sterculia setigera*	26.49	6.30	0.36	0.05	0.41	0.20	0.75
8	*Balanite aegyptiaca*	19.83	4.50	0.17	0.03	0.20	0.10	0.37
9	*Phileneptera violacea*	27.84	12.20	0.40	0.06	0.46	0.23	0.85
10	*Sclerocarya birrea*	21.55	11.60	0.22	0.03	0.25	0.12	0.45
11	*Prosopis africana*	17.63	5.70	0.13	0.02	0.15	0.07	0.27
12	*Vitelaria paradoxa*	21.45	5.80	0.21	0.03	0.24	0.12	0.45
	Total		**100.80**			**3.10**	**1.55**	**5.68**

Source: Umar (2025)

Table 7: Soil Physical Properties in Jibiro Grazing Reserve

Grazing Reserves	Soil Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g/cm^3)	Particle Density (g/cm^3)	Total Porosity (%)	Water Holding Capacity (%)
Jibiro	0-15	69.00±5.57	18.00±2.00	13.00±6.56	1.58±0.05	2.54±0.05	37.76±1.30	13.48±1.77
	16-30	71.33±0.58	13.33±1.15	15.33±0.58	1.51±0.01	2.57±0.10	41.31±2.02	13.13±0.83
	31-45	61.33±11.85	25.33±10.07	13.33±7.51	1.52±0.09	2.49±0.03	38.90±2.88	12.83±0.50
	46-60	67.33±6.66	17.33±4.16	15.33±4.51	1.55±0.07	2.52±0.08	38.42±2.26	12.54±1.13
	Total	**67.25±7.36**	**18.50±6.56**	**14.25±4.81**	**1.54±0.06**	**2.53±0.07**	**39.10±2.33**	**13.00±1.05**

Source: Laboratory Analysis (Umar M.R., 2025)

Table 8: Duncan's Multiple Range Tests for Soil Physical Properties

Grazing Reserves	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g/cm^3)	Particle Density (g/cm^3)	Total Porosity (%)	Water Holding Capacity (%)
Jibiro	67.25^{b}	15.50^{a}	14.25^{ab}	1.53^{bc}	2.52^{a}	39.09^{ab}	12.99^{c}

Alphabets with the same letter show that there is no significant difference; Alphabets with different letter show that there is significant difference along the row.

Note

- DMRT is a post-hoc test used after ANOVA to compare means.
- Means that share the same letter are not significantly different from each other.
- Means with different letters are significantly different at the chosen probability level (usually $p < 0.05$).

Soil Depth (cm)	Particle Density (g/cm^3)
31-45	2.46^{b}
46-60	2.51^{ab}
16-30	2.54^{a}
0-15	2.55^{a}

Table 9: Chemical Properties of Soils in Jibiro Grazing reserve

Grazing Reserves	Soil Depth (cm)	PH (1:2)	EC (dS/m)	Organic carbon (%)	Organic Matter (%)	TN (%)	Av-P (mg/kg)	Ca (cmol/kg)	Mg (cmol/kg)	Na (cmol/kg)
Jibiro	0-15	7.14±0.34	0.13±0.02	1.29±0.07	2.22±0.12	0.12±0.01	12.58±2.64	3.89±2.87	1.93±0.65	0.43±0.26
	16-30	7.27±0.44	0.14±0.03	1.29±0.17	2.22±0.29	0.12±0.02	10.90±2.81	2.77±1.41	1.74±0.88	0.48±0.12
	31-45	7.06±0.54	0.21±0.09	1.15±0.15	1.98±0.27	0.11±0.02	10.95±1.01	4.67±0.49	2.07±0.45	0.34±0.15
	46-60	7.10±0.28	0.16±0.12	1.06±0.16	1.83±0.28	0.10±0.02	10.44±1.45	5.74±4.33	2.08±1.24	0.42±0.20
	Total	**7.14±0.36**	**0.16±0.07**	**1.20±0.16**	**2.06±0.28**	**0.11±0.02**	**11.22±2.00**	**4.27±2.57**	**1.96±0.74**	**0.42±0.17**
	Soil Depth (cm)	**K (cmol/kg)**	**H (cmol/kg)**	**Al (cmol/kg)**	**TEB (cmol/kg)**	**TEA (cmol/kg)**	**ECEC (cmol/kg)**	**PBS (%)**	**ESP (%)**	
	0-15	0.38±0.18	0.82±0.07	0.83±0.25	6.63±1.88	1.65±0.21	8.28±1.86	79.40±4.71	5.71±4.62	
	16-30	0.53±0.13	0.74±0.17	0.88±0.21	5.53±1.41	1.61±0.36	7.14±1.76	77.23±1.50	7.13±3.23	
	31-45	0.42±0.16	0.89±0.20	0.96±0.24	7.50±0.75	1.86±0.26	9.35±0.68	80.10±3.37	3.64±1.49	
	46-60	0.44±0.21	0.95±0.24	1.14±0.40	8.68±2.72	2.09±0.45	10.77±3.12	80.27±2.30	4.57±3.19	
	Total	**0.44±0.16**	**0.85±0.18**	**0.95±0.27**	**7.08±1.98**	**1.80±0.35**	**8.88±2.24**	**79.25±3.01**	**5.26±3.14**	

Values are means±SD

Duncan's Multiple Range Tests for Soil Chemical Properties in Jibiro Grazing Reserve

Jibiro Grazing Reserve soils are neutral to slightly alkaline (top Duncan group), showing no acidity limitation. Soil salinity is non-limiting and statistically uniform across reserves, indicating stable conductivity conditions. Organic carbon and organic matter occur in moderate but comparatively lower significance groups, reflecting reduced organic buildup. Nitrogen status shows relatively low distinction from other reserves, while available phosphorus aligns with the highest statistical class, suggesting it is not limiting. Low exchangeable sodium and low sodicity grouping indicate minimal chemical degradation risk. Overall, Jibiro soils are chemically stable for vegetation growth but may require organic and nitrogen enrichment to optimise biomass and carbon sequestration potential.

Correlation of Soil Physical Properties and Tree Growth Variables in Jibiro Grazing Reserve

Tree growth variables in Jibiro Grazing Reserve exhibited strong intrinsic relationships. Mean DBH was very strongly correlated with mean basal area ($r = 0.908$, $p < 0.01$), and mean basal area showed a strong positive relationship with mean volume ($r = 0.880$, $p < 0.01$). Mean height was strongly associated with mean volume ($r = 0.808$, $p < 0.01$). Dominant DBH and dominant height displayed an extremely strong positive correlation ($r = 0.965$, $p < 0.01$). Soil texture fractions showed a strong inverse relationship between sand and silt ($r = -0.767$, $p < 0.01$). Bulk density was strongly related to total porosity ($r = 0.773$, $p < 0.01$), while clay content showed a moderate negative relationship with bulk density ($r = -0.435$). Water holding capacity exhibited moderate positive correlations with dominant DBH ($r = 0.393$) and dominant height ($r = 0.403$). Collectively, Jibiro soils are structurally and chemically stable, as reflected by moderate porosity (39.10%), bulk density (1.57 g cm^{-3}) and high base saturation (79.25%), but remain moisture- and nitrogen-limited, indicated by the low water-holding capacity (13.00%), high sand content (67.25%), and only moderate organic matter levels, conditions that may seasonally constrain biomass productivity and carbon accumulation unless supported by organic matter addition and nitrogen enrichment strategies.

Correlation for Soil Chemical Properties and Tree Growth Variables in Jibiro Grazing Reserve

Tree growth attributes in Jibiro Grazing Reserve exhibited strong internal dependencies, with DBH strongly controlling basal area ($r = 0.908$, $p < 0.01$) and both basal area ($r = 0.880$, $p < 0.01$) and mean height ($r = 0.808$, $p < 0.01$) positively regulating stand volume. Dominant DBH and dominant height showed an extremely strong positive correlation ($r = 0.965$, $p < 0.01$). Soil chemical properties revealed negative associations between soil pH and dominant DBH ($r = -0.571$) and dominant height ($r = -0.628$, $p < 0.05$). Electrical conductivity exhibited strong negative relationships with mean height ($r = -0.703$, $p < 0.05$) and dominant DBH ($r = -0.655$, $p < 0.05$). Organic carbon, organic matter, and total nitrogen were highly intercorrelated ($r = 0.985$–0.987, $p < 0.01$) and showed moderate positive relationships with mean height ($r = 0.445$–0.552). Available phosphorus displayed very strong positive correlations with dominant DBH ($r = 0.871$, $p < 0.01$) and dominant height ($r = 0.922$, $p < 0.01$). Exchangeable acidity components showed generally negative associations with growth variables, while exchangeable sodium percentage was strongly related to EC ($r = 0.921$, $p < 0.01$) and negatively associated with effective cation exchange capacity ($r = -0.767$, $p < 0.01$). Collectively, Jibiro soils remain chemically suitable from a pH perspective (pH = 7.14) with high base saturation (79.25%), but exhibit growth limitations linked to moderate organic carbon and total nitrogen, low water-holding capacity (13.00%), and the negative influence of electrical conductivity on tree height ($r = -0.703$) and dominant DBH ($r = -0.655$). These conditions may moderate biomass productivity and carbon accumulation unless supported by organic matter enrichment and balanced nutrient management strategies.

Table 10: Duncan's Multiple Range Tests for Soil Chemical Properties in Jibiro Grazing Reserve

Grazing Reserves	PH (1:2)	EC (dS/m)	Organic Carbon (%)	Organic Matter (%)	TN (%)	Av-P (mg/kg)	Na (cmol/kg)	K (cmol/kg)	H (cmol/kg)	Al (cmol/kg)	TEA (cmol/kg)	PBS (%)	ESP (%)
Jibiro	7.14[a]	0.16[a]	1.19[bc]	2.06[bc]	0.11[b]	11.21[a]	0.41[b]	0.44[bc]	0.84[a]	0.95[bc]	1.80[ab]	79.25[a]	5.26[bc]

Alphabets with the same letter show that there is no significant difference; Alphabets with different letter show that there is significant difference.

Duncan's Multiple Range tests for Soil Chemical Properties for the Depth of the soil

Soil Depth (cm)	Organic Carbon (%)	Organic Matter (%)	TN (%)	Al (cmol/kg)
0-15	1.36[a]	2.36[a]	0.13[a]	0.80[b]
16-30	1.28[a]	2.22[a]	0.12[a]	0.89[b]
31-45	1.20[b]	2.07[b]	0.11[b]	0.90[b]
46-60	1.21[b]	2.10[b]	0.11[b]	1.14[a]

Alphabets with the same letter show that there is no significant difference; Alphabets with different letter show that there is significant difference along the column

Note

DMRT

- Values followed by different letters (a, b, c, etc.) are significantly different.
- Same letter(s) = no significant difference at the chosen probability level (usually $p < 0.05$)

Table 11: Correlation Matrix or Soil Physical Properties and Growth Variables in Jibiro Grazing Reserve

	Mean DBH (cm)	Mean Volume (m^3)	Mean Basal Area (m^2)	Mean Height (m)	Dominant DBH (cm)	Dominant Height (m)	Sand (%)	Silt (%)	Clay (%)	B.D (g/cm^3)	P.D (g/cm^3)	T.P (%)
Mean Volume	.663*											
Mean Ba	.908**	.880**										
Mean Height	0.275	.808**	0.496									
Dominant DBH	0.218	0.392	0.206	0.471								
Dominant Ht	0.173	0.278	0.13	0.298	.965**							
Sand (%)	-0.335	0.016	-0.153	0.124	0.043	-0.016						
Silt (%)	0.051	-0.191	-0.03	-0.369	-0.274	-0.142	-.767**					
Clay (%)	0.443	0.235	0.275	0.314	0.304	0.216	-0.485	-0.189				
B.D (g/cm3)	-0.25	0.158	0.065	0.098	-0.131	-0.221	0.225	0.065	-0.435			
P.D (g/cm3)	-0.398	-0.212	-0.269	-0.044	-0.26	-0.311	0.285	-0.072	-0.339	0.362		
T.P (%)	-0.023	-0.324	-0.261	-0.15	-0.045	0.011	-0.042	-0.106	0.209	.773**	0.311	
WHC (%)	-0.503	-0.22	-0.461	-0.041	0.393	0.403	0.348	-0.191	-0.273	0.043	0.141	0.054

** Correlation is significant at the 0.01 level (2-tailed)

Table 12: Correlation Matrix of Soil Chemical Properties and Growth Variables in Jibiro Grazing Reserve

	Mean DBH (cm)	Mean Volume (m^3)	Mean Basal Area (m^2)	Mean Height (m)	Dominant DBH (cm)	Dominant Height (m)	PH (1:2)	EC (dS/m)	Organic Carbon (%)	Organic Matter (%)	TN (%)	Av-P (mg/kg)
Mean Volume	.663*											
Mean Basal Area	.908**	.880**										
Mean Height	0.275	.808**	0.496									
Dominant DBH	0.218	0.392	0.206	0.471								
Dominant Ht	0.173	0.278	0.13	0.298	.965**							
PH (1:2)	-0.122	-0.059	-0.143	0.171	-0.571	-.628*						
EC (dS/m)	-0.182	-0.542	-0.311	-.703*	-.655*	-0.473	0.323					
Organic C (%)	0.00	0.333	0.176	0.546	-0.043	-0.131	0.378	0.026				
Organic M (%)	0.011	0.341	0.186	0.552	-0.037	-0.125	0.376	0.024	1.000**			
TN (%)	-0.068	0.232	0.091	0.445	-0.104	-0.172	0.397	0.121	.987**	.985**		
Av-P (mg/kg)	0.083	0.395	0.165	0.36	.871**	.922**	-0.528	-0.413	-0.08	-0.077	-0.119	
Ca (cmol/kg)	0.405	0.176	0.377	0.012	0.031	-0.03	-0.143	-0.004	0.071	0.084	0.028	-0.242

	Mg (cmol/kg)	**Na (cmol/kg)**	**K (cmol/kg)**	**H (cmol/kg)**	**Al (cmol/kg)**	**TEB (cmol/kg)**	**TEA (cmol/kg)**	**ECEC (cmol/kg)**	**PBS (%)**
Na (cmol/kg)	0.37								
K (cmol/kg)	0.413	.827**							
H (cmol/kg)	-0.30	-0.443	-0.529						
Al (cmol/kg)	-0.188	-0.341	0.017	0.162					
TEB (cmol/kg)	-0.391	-0.563	-0.523	0.569	0.534				
TEA (cmol/kg)	-0.297	-0.494	-0.258	.632*	.867**	.710**			
ECEC (cmol/kg)	-0.392	-0.573	-0.501	.601*	.606*	.994**	.782**		
PBS (%)	-0.142	-0.318	-0.446	0.182	-0.033	.738**	0.07	.664*	
ESP (%)	0.255	.921**	.698*	-0.493	-0.531	-.751**	-.668*	-.767**	-0.471

** Correlation is significant at the 0.01 level (2-tailed) *Correlation is significant at the 0.05 level (2-tailed)

DISCUSSION

The Jibiro grazing reserve shows low tree species richness (12 species) and stand density (34 trees ha^{-1}), typical of grazed savanna ecosystems under sustained anthropogenic pressure (Tellen and Yerima, 2018; Abdullahi *et al*., 2019). *Bridelia mollis* (Phyllanthaceae) dominated the stand, indicating strong tolerance to disturbance and prevailing site conditions (Lawrence *et al.*, 2020). The prominence of Phyllanthaceae and Fabaceae reflects their ecological advantage in savanna systems, with Fabaceae benefiting from their nitrogen-fixing ability, which enhances establishment in nutrient-limited soils (Mensah *et al.,* 2017; Feyisa *et al*., 2022). In contrast, the low abundance of *Detarium macrocarpum*, *Sclerocarya birrea*, *Vitellaria paradoxa*, *Tamarindus indica*, and *Balanites aegyptiaca* suggests selective exploitation and poor regeneration (Abdullahi *et al*., 2019). The low basal area (0.22 m² ha^{-1}) and volume (1.63 m³ ha^{-1}) indicate an open woodland structure dominated by few mature individuals, likely shaped by grazing pressure and resource extraction (Tellen and Yerima, 2018; Lawrence *et al*., 2020).

The biodiversity indices indicate moderate but reduced tree species diversity in the grazing reserve. The Shannon–Wiener index (H' = 2.17) and Margalef's richness (M = 2.61) reflect low–moderate diversity typical of disturbed savanna ecosystems (Tellen and Yerima, 2018; Abdullahi et al., 2019). Low evenness (J = 0.51) shows an uneven distribution of species, with few taxa dominating the stand. The low Simpson's index (λ = 0.11) suggests limited dominance but reduced heterogeneity. Hill diversity values (N1 = 8.76; N2 = 8.75) indicate that only a small number of species effectively contribute to stand structure. The indices confirm that grazing and anthropogenic pressure have constrained species richness and evenness, consistent with findings from similar West African savanna reserves (Mensah *et al*., 2017; Lawrence *et al.*, 2020).

The DBH and height class distributions show a stand dominated by small-sized trees, indicating a disturbed and uneven-aged structure typical of grazed savanna ecosystems. The highest species, family, and individual counts in the 11–20 cm DBH and <11 m height classes suggest ongoing recruitment but limited transition to larger size classes. The very low representation in the 41–50 cm DBH class explains the low basal area (1.12 m² ha^{-1}) and volume (11.07 m³ ha^{-1}). Similar patterns have been reported in Nigerian grazing reserves where selective harvesting and grazing suppress mature tree development (Tellen and Yerima, 2018; Abdullahi *et al.*, 2019). Overall, continuous anthropogenic pressure appears to constrain stand growth, canopy development, and biomass accumulation (Lawrence *et al*., 2020).

The low mean biomass (3.10 t ha^{-1}) and carbon stock (1.55 t ha^{-1}) in Jibiro grazing reserve reflect an open savanna system under continuous grazing and anthropogenic pressure. Higher biomass and carbon storage in *Burkea africana*, *Detarium macrocarpum*, and *Philenoptera violacea* are attributed to their larger size and wood density, which enhance carbon accumulation (Mensah *et al.*, 2017; Lawrence *et al*., 2020). In contrast, the low biomass and carbon values of *Bridelia mollis* reflect its smaller stature despite high abundance. Similar low carbon stocks have been reported in Nigerian grazing reserves and degraded savannas (Abdullahi *et al*., 2019; Tellen and Yerima, 2018). The selective removal of large trees and grazing pressure appear to limit biomass and CO_2 sequestration potential in the reserve. System dynamics and regional forest carbon models further emphasise that forest structure, fertility, and moisture regulation strongly determine biomass density and carbon outcomes across Africa's savanna belts (Kindermann *et al*., 2008; Martinez-Moyano and Richardson, 2013).

The predominantly sandy texture of Jibiro soils indicates rapid drainage and low water-holding capacity, a common characteristic of savanna grazing reserves that limits nutrient retention and seedling establishment (Tellen and Yerima, 2018). The moderately high bulk density suggests slight soil compaction from continuous grazing, which can restrict root penetration and reduce infiltration over time (Abdullahi *et al.*, 2019). Stable particle density reflects mineral-dominated parent materials typical of northern Nigerian savannas. Moderate porosity indicates adequate aeration but insufficient moisture storage to support sustained tree growth. Similar soil conditions have been reported to constrain biomass production and carbon accumulation in grazed savanna ecosystems (Lawrence *et al*., 2020).

The neutral to slightly alkaline pH and low electrical conductivity of Jibiro soils indicate a chemically favourable and non-saline environment for plant growth, consistent with savanna soils in northern Nigeria (Tellen and Yerima, 2018; Desheng, 2018; Yuzhuo *et al*., 2017). Moderate organic carbon and organic matter enhance soil structure but the low total nitrogen reflects limited nutrient availability, which can constrain vegetation productivity (Abdullahi *et al.,* 2019). The relatively high total exchangeable bases and base saturation indicate good nutrient retention and chemical stability. Low exchangeable sodium percentage suggests minimal sodicity risk and favourable soil physical conditions. Similar chemical limitations, particularly low nitrogen, have been reported to restrict biomass production and carbon sequestration in grazed savanna ecosystems (Lawrence *et al*., 2020).

The strong correlations among DBH, basal area, height, and volume confirm that tree size variables are intrinsically linked, with larger and taller trees contributing most to stand volume, as widely reported in savanna and woodland ecosystems (Mensah *et al*., 2017; Abdullahi *et al.*, 2019). The strong association between dominant DBH and dominant height indicates coordinated horizontal and vertical growth of canopy trees. The inverse relationship between sand and silt reflects typical textural trade-offs in savanna soils (Tellen and Yerima, 2018). Moderate positive correlations between water-holding capacity and dominant tree growth highlight the importance of soil moisture in regulating tree performance under sandy conditions (Mohammed and Hamid, 2019; Vahid *et al*., 2015). Similar studies have shown that moisture and nitrogen limitations strongly constrain biomass accumulation and carbon storage in grazed savanna reserves (Lawrence *et al*., 2020).

The strong correlations among DBH, basal area, height, and volume confirm that tree structural variables are tightly linked, with larger and taller trees contributing most to stand volume, consistent with savanna woodland studies (Mensah *et al*., 2017; Abdullahi *et al.*, 2019). The extremely strong association between dominant DBH and height reflects coordinated canopy development under favourable microsite conditions. Negative relationships between soil pH and tree growth suggest that slightly lower pH favours nutrient availability and dominant tree expression in savanna soils (Lawrence *et al*., 2020). The negative effects of electrical conductivity on height and DBH indicate sensitivity of tree growth to salinity stress, even at low EC levels. Positive relationships of organic carbon, nitrogen, and available phosphorus with tree growth highlight the importance of soil fertility in regulating productivity. Similar nutrient-driven growth patterns have been reported across grazed West African savanna ecosystems (Tellen and Yerima, 2018; Feyisa *et al*., 2022). Collectively, Jibiro soils are chemically suitable from a pH perspective but exhibit nitrogen- and moisture-linked productivity constraints, implying that biomass-carbon gains may require organic and nutrient-balancing strategies, a widely recommended restoration pathway in African afforestation and wood-energy transition landscapes (UNEP, 2011; Timilsina *et al*., 2014).

CONCLUSION

Jibiro Grazing Reserve possesses a stable but drought- and nitrogen-sensitive soil environment, and a woodland structure where dominant tree form regulates both stand productivity and carbon potential. While phosphorus availability enhances dominant tree performance, salinity and sodium imbalance suppress height growth and nutrient exchange, collectively constraining biomass productivity and carbon accumulation. Sustainable carbon gains in the reserve will likely require soil organic enhancement, nitrogen replenishment, and moisture-retention or conservation interventions, consistent with recommended restoration pathways for Africa's dry savanna and wood-energy dependent landscapes.

REFERENCES

Adebayo, A. A., & Nwagboso, N. K. (1999). Climate and agricultural planning in Adamawa State. In A. A. Adebayo & A. L. Tukur (Eds.), *Adamawa State in maps*. Paraclete Publishers. pp. 10–21.

Adekunle, V. A. J., Olagoke, A. O., & Ogundare, L. F. (2013). Logging impacts in tropical lowland humid forests on tree species diversity and environmental sustainability. *Forest Ecology and Management, 310*, 747–754.

Akindele, S. O., & LeMay, V. M. (2006). Development of tree allometric equations for estimating biomass in the savanna ecosystems of West Africa. *Forest Ecology and Management,* 226(1–3), 41–48.

Akinyemi, O. D., Adedeji, O. S., & Adebayo, O. A. (2021). Influence of soil physicochemical properties on tree species diversity in tropical forest ecosystems of southwestern Nigeria. *Tropical Ecology, 62*(4), 1–13.

Brady, N. C., & Weil, R. R. (2016). *The nature and properties of soils* (15th ed.). Pearson Education.pp. 245–260.

Brown, S. (1997). *Estimating biomass and biomass change of tropical forests: A primer*. (FAO Forestry Paper No. 134). Food and Agriculture Organisation.

Brown, S., & Lugo, A. E. (1990). Tropical secondary forests. *Journal of Tropical Ecology, 6*, 1–32.

Chazdon, R. L. (2016). Restoration of tropical forests: A global perspective. *Science Advances, 2*(5), e1501630.

Cochran, W. G. (1977). *Sampling techniques* (3rd ed.). John Wiley & Sons. Pp. 150–165.

Desheng, S. (2018). Forest biomass and carbon dynamics in the Sudan Sahel ecological belt. *Environmental Research Letters*, Volume 13, 055004. https://doi.org/10.1088/1748-9326/aacb3f

FAO. (2005). *Global forest resource assessment 2005: Progress towards sustainable forest management* (FAO Forestry Paper No. 146).

Feyisa, K., Mekonnen, K., & Hailu, B. (2022). Influence of soil properties on tree species diversity in dry Afromontane forests of Ethiopia. *Ecological Processes, 11*(3), 1–12.

Husch, B., Beers, T. W., & Kershaw, J. A. (2003). *Forest mensuration* (4th ed.). John Wiley & Sons, pp. 120–135

IPCC. (2006). Agriculture, forestry and other land use. In H. S. Eggleston et al. (Eds.), *IPCC guidelines for national greenhouse gas inventories*. (Vol. 4, Ch. 4, pp. 4.1–4.20). IGES.

Keay, R. W. J. (1989). *Trees of Nigeria*. Clarendon Press. pp. 120–135

Kent, M. (2012). *Vegetation description and data analysis: A practical approach* (2nd ed.). Wiley-Blackwell, pp. 210–225.

Kent, M., & Coker, P. (1992). *Vegetation description and analysis: A practical approach*. Belhaven Press. pp. 150–170.

Kindermann, G., McCallum, I., Fritz, S., & Obersteiner, M. (2008). A global forest growing stock, biomass and carbon map based on FAO statistics. *Silva Fennica*. *42*(3), 387–396.

Lal, R. (2019). Soil and Sustainable Development Goals. *Geoderma, 338*, 452–472.

Lawrence, D., Rieder, J., & Zuluaga, J. (2020). Soil fertility and tree diversity in tropical forests. *Forest Ecology and Management, 458*, 117710.

MacDicken, K. G. (1997). *A guide to monitoring carbon storage in forestry and agroforestry projects*. Winrock International. pp. 45–60.

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Publishing. pp. 102–115.

Magurran, A. E. (2013). *Measuring biological diversity* (2nd ed.). Wiley-Blackwell. pp. 85–100.

Martinez-Moyano, I. J., & Richardson, G. P. (2013). Best practices in system dynamics modelling. *System Dynamics Review*. *29*(2), 102–123.

Mensah, S., Veldtman, R., & Du Toit, B. (2017). Ecosystem services and biodiversity in managed forests. *Ecosystem Services, 27*, 160–169.

Mohammed, A., & Hamid, H. (2019). Energy transition and wood biomass dependence in African drylands. *Energy Policy*, *126*, 385–393.

Mohammed, Y. S., & Hamid, H. A. (2019). Wood fuel and energy reliance in dry savanna zones of Africa. *Energy Reports*, *5*, 357–366.

National Bureau of Statistics. (2007). *2006 population census official gazette* (Vol. 94, No. 24, pp. B175–B198). Federal Republic of Nigeria.

National Population Commission. (2006). *Annual population figures for Nigeria*. Abuja, Nigeria. Pp 23-30.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., & Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science, 333*(6045), 988–993. https://doi.org/10.1126/science.1201609

Pascua, J. G., Alfonso, G. P., & Calicia, R. S. (2021). Carbon sequestration potential of tree species. *Open Journal of Ecology, 11*(5), 462–473.

Penman, J. (2003). *Good practice guidance for land use, land-use change and forestry*. IPCC.

Sharma, R. P., Timilsina, Y. P., Bastola, A. P., & Gupta, M. K. (2014). Carbon stocks in forest types. *Indian Journal of Forestry, 37*(3), 259–266.

Tellen, V. A., & Yerima, B. P. K. (2018). Soil properties and vegetation relationships. Applied and Environmental Soil Science, Article 4181596, 1–9. https://doi.org/10.1155/2018/4181596.

Tilman, D., Isbell, F., & Cowles, J. M. (2014). Biodiversity and ecosystem functioning. *Annual Review of Ecology, Evolution, and Systematics, 45*, 471–493.

Timilsina, G. R., Abdullah, S. A., Mehta, P., & Shrestha, A. (2014). *Biomass energy consumption in Sub-Saharan Africa* (World Bank Policy Research Working Paper No. 7045). World Bank.

Umar, M. R., Adekunle, V. A. J., & Oyun, M. B. (2025). *Phytosociological, soil physicochemical, and carbon stock assessment of selected grazing reserves in Adamawa State, Nigeria* (Unpublished doctoral dissertation). Federal University of Technology Akure. Pp. 134-156.

UNEP. (2011). *Towards a green economy: Pathways to sustainable development and poverty eradication*. United Nations Environment Programme. pp. 245–260. https: //www. unep.org/ resources/report/towards-green-economy-pathways-sustainable-development-and-poverty-eradication

Vahid, N., Norouzi, N., & Ahmadi, A. (2015). Household energy consumption in Africa. *Renewable and Sustainable Energy Reviews,52*,146–154.https://doi.org/10.1016 /jrser. 2015.07.054

Wardle, D. A., Walker, L. R., & Bardgett, R. D. (2004). Ecosystem properties and forest decline. *Science, 305*, 509–512.

Zhang, Y., Li, X., & Wang, Z. (2017). Carbon sequestration potential in dry savanna ecosystems. *Journal of Arid Environments*, 145(2), 45–60.