FUDMA Journal of Agriculture and Agricultural Technology
ISSN: 2504-9496
Vol. 12 No.1, March 2026: Pp.82-102

https://doi.org/10.33003/jaat.2026.1201.11

TREE SPECIES DIVERSITY, SOIL PHYSICOCHEMICAL, BIOMASS AND CARBON STOCK ASSESSMENT IN GUYAKU GRAZING RESERVE, GOMBI LGA, ADAMAWA STATE.

Umar M.R[1], Adedeji E.T[2] and Folayan B.O[3]

[1] Department of Forestry and Wildlife Management, Faculty of Agriculture, Modibbo Adama University P.M.B. 2076. Yola, Adamawa State, Nigeria.

[2&3]Department of Forestry and Wood Technology, School of Agriculture and Agricultural Technology, Federal University of Technology P.M.B. 704, Akure, Ondo State, Nigeria

Corresponding author: Email: *Mumar@mau.edu.ng* . Phone No. +2348038719318.

ABSTRACT

Forests provide a variety of products and services to human societies, sustain diverse flora and fauna, and, through their interception and processing of solar energy and precipitation, influence climate and the composition of the atmosphere. Deforestation and degradation of forests lead to the emission of carbon dioxide through the burning of forest biomass and the decomposition of plant parts, soil carbon, which accelerates and contributes to a long-term rise in atmospheric carbon dioxide levels. This research aimed at determining tree species diversity, soil physicochemical, biomass and carbon stock assessment in Guyaku grazing reserve. Systematic line transects were employed in the laying of the plots. Two parallel transects of 1500m in length with a distance of 500m between the two parallel transects in the grazing reserves. Sample plots of 50m x 50m in size were laid in alternate rows along each transect at 100m intervals, with 4 sample plots per 1500m transect, totalling 8 sample plots. In each sample plot, all living trees with dbh ≥10cm were identified and measured for diameter at the base, middle and top and total height. Diameter tape/girth and Spiegel relaskop were used for tree height and diameter at the base, middle, top and dbh measurement. 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). One-way analysis of variance (ANOVA) and Student t-test of significance was used to determine the difference in each soil nutrient according to depth, tree density, species diversity and richness, basal area and bio – volume of the six grazing reserves. Results show that 13 species, 6 families, 86 species/plot and 43 nha-1. Total Ba/ha 0.38cm and 4.39m^3 vol/ha. The Fabaceae family has the highest frequency 30 while unknown and moraceae lowest with 7 and 8, respectively. Dbh and height class range 0-10 to 41-50 and <11 to 21-30, respectively. Total biomass, carbon stock and CO_2 (5.70ton/ha, 2.85ton/ha and 10.45kg) respectively. Textural classes are sandy loam and sandy clay loam. Physical properties revealed sand 65.58±8.55% higher than silt and clay. Total bulk density 1.52±0.08g/cm^{3,} lower than particle density 2.63±0.23glcm^3. Porosity at 41.39±8.05%, while WHC at 19.74±3.08% moderate. Chemical properties showed that P^H 6.52±0.33 is slightly alkaline, EC at 0.07±0.05ds/m. Organic matter 2.15±0.24% higher than OC and TN. Av-p at 9.10±0.74mg/kg. ECEC at 7.64±1.47cmol/kg is higher than Ca, Mg, Na, K, H, AI, TEB, TEA. PBS at 83.52±3.97% higher than ESP at 7.57±2.68%. The findings revealed that porous soils slightly improve growth, with soil structure and mineral density playing roles in dominant tree development. Furthermore, growth traits are moderate to strong and positive, showing good structural consistency. It is recommended that strengthening protection and sustainable management of forest and grazing reserves minimise biodiversity loss and implement comprehensive soil protection strategies.

Keywords: Tree species, soil physicochemical, biomass, carbon stock and grazing reserve

INTRODUCTION

Biological diversity (biodiversity) is described as the diversity of life in a given ecosystem. It includes the totality of species in a region, ranging from organisms present in the soil (microfauna, mesofauna, microflora, and mesoflora) to the large trees in a particular ecological community or system, and how they relate with one another and support the ecosystem. These can be measured by the number and types of different species, or genetic variation within and between species. It was reported that over-exploitation of the existing forest resource and disappearance of economic and other important hardwood species are threats to global biodiversity, conservation and abundance of microbes and it is an issue of great concern (Adeduntan *et al*., 2007). Deforestation and degradation of forests lead to the emission of carbon dioxide through the burning of forest biomass and the decomposition of plant parts and soil carbon. These human activities have significantly contributed to a long-term rise in atmospheric carbon dioxide level (Jerome *et al.,* 2014).

Soil physical properties also influence the natural distribution of forest tree species, growth, and consequently forest biomass production. However, soil physical properties are largely controlled by the size, distribution, and arrangement of soil particles (Speir, 2010). Trees depend on soil for stability, nutrients and water. Most nutrient cycling takes place in the top 60cm of soil, where suppliers of air, water and food allow microorganisms to thrive (Rumpel *et al*., 2001).

The global carbon cycle during geological history, the emergence of plants on earth has led to the conversion of carbon dioxide (CO_2) in the atmosphere and oceans into innumerable inorganic and organic compounds on land and in water. The natural exchange of carbon (C) compounds between the atmosphere, the oceans and terrestrial ecosystems is now being modified by human activities that release CO_2 from fossilised organic compounds (fossil fuel) and through land use changes. The earth is returned to a less-vegetated stage of its history, with more CO_2 in its atmosphere and a stronger greenhouse gas effects trapping solar energy (Tropical Forest group 2011, U.S Energy Information, 2010). According to the IPCC (2006), carbon pools in forest ecosystems comprise carbon stored in the living trees aboveground and dead matter, including standing dead trees, down woody debris and litter; in non-tree understory vegetation and in the soil organic matter.

Umar et al., (2025) noted that, the enhancement of biodiversity conservation is achieved through strengthening protection and sustainable management of forest and grazing reserves to minimise biodiversity loss, which directly affects biomass, carbon stock, and ecosystem stability. The regulation of land through degradation processes promotes soil restoration through sustainable agricultural practices, erosion control, organic matter management, and soil fertility enhancement yield growth traits in forest and grazing reserves (Umar and Adekunle, 2025). The study aimed to establish the current status and development of their management plan.

The present status of the Guyaku grazing reserve of the savannah ecological zone of Adamawa State, Nigeria in terms of tree species diversity and abundance. Soil physicochemical properties of the grazing reserve. Aboveground/belowground biomass, carbon stock and CO_2 sequestration potentials of the selected grazing reserves, and evaluate/compare the diversity, tree growth variables and bio-volume of the grazing reserve. The tree biomass from forest ecosystems plays a key role in the sustainable management of natural resources and also for the contribution of forests to the global carbon cycle. Sustainable management, planting, and rehabilitation of forests conserve or increase forest carbon stocks, while deforestation, degradation, and poor forest management reduce them.

MATERIALS AND METHODS

The Study Area

Adamawa State is located at the North-Eastern part of Nigeria. It lies between latitude 7° N and 11° N of the equator and between longitude 11° E and 14° E of the Greenwich meridian E in the Upper Benue catchment (Figure 7). Gombi LGA lies between latitude 9° 59′ and 10° 27′ N and longitudes 12° 14′ and2° 50′ E. The population of 147,787 at 2006 population census, with a recent estimate of 243,300 (projection 2025). Guyaku grazing reserve lies between latitude 8^0 32’ 48’’ N longitude 12^0 34’ 28’’ E is located in Gombi LGA, gazetted and has an area of 18,100 hectares. Adamawa State shares a boundary with Taraba State in the South and West, Gombe State in its Northwest and Borno State to the North. Adamawa State has an international boundary with the Republic of Cameroon along its eastern border. 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 of Statistics, 2007 and National Population Commission, 2006).

Sampling Procedure and Plot Demarcation

The study covered the savannah ecosystem types in the Adamawa State (Southern Guinean Savannah). One grazing reserve was randomly selected from these savannah ecological zones of the State. Systematic line transect was employed in the laying of the plots. Two parallel transects of 1500m in length with a distance of 500m between the two parallel transects was used. Sample plots of 50m x 50m in size was 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 Guyaku grazing reserve.

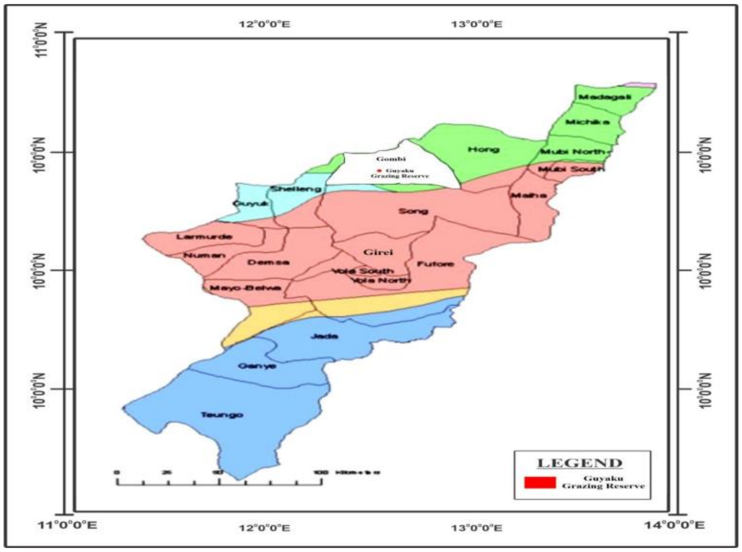

Figure 1: Map of Adamawa State showing Guyaku Grazing Reserve Gombi LGA
Source: Umar M. R, (2025) in Adebayo and Nwagboso, (1999)

Method of Data Collection

Tree species identification

The botanical name of every living tree encountered in each sample plot was recorded for each of the study site. When a tree's botanical name is not known immediately, it is identified by its commercial or local name. Such commercial or local names were translated to the correct botanical name using Keay (1989).

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. Spiegel relaskop was used for tree height, while diameter tape was used to measure diameter at the base, middle and top (Bitterlich relascope).

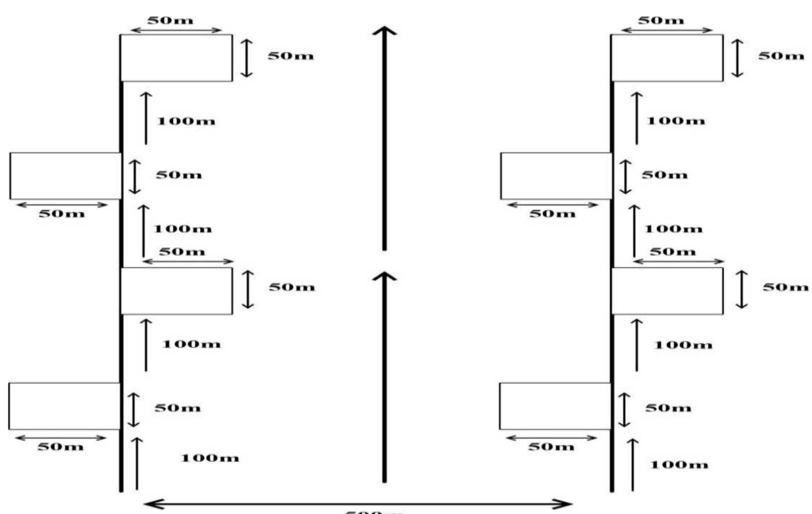

Figure 2. Plot Layout with systematic line transect sampling technique

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 each along the diagonal line (i.e. at the two edges and middle of the diagonal 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:

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

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 50m by 50m plots size in Guyaku grazing reserves.

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

Where BA_{ha}= Basal area per hectare.

$\overline{BA_P}$= Mean basal area per plot

n= number of all possible sample plot

Stem Volume Estimation

The volume of individual trees was estimated using Umar and Adekunle (2025), who adopted Newton's formula. The equation is expressed as follows:

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

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 = Total 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 (8 plots) in the grazing reserves.

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

$$V_{ha} = \overline{V_p} \times 8 \quad \ldots\ldots\ldots(4)$$

Where V_{ha}= Volume per hectare

$\overline{V_p}$ = Mean Volume per plot

Tree Species Classification and Biodiversity indices

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

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

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:

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

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)

$$H' = -\sum_{i=I}^{s} P_i \ In (P_i) \quad \ldots(7)$$

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:

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

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).

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

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

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

Where

D = Mangelef's index
S = Number of species
N = Number of individual

(vii) Simpson's index

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

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:

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

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

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

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;

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

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

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;

$N2 = 1/\sum pi^2$ ……………………………………………………………………………(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

$Y = 21.297 - 6.953 (D) + 0.740 (D^2)$………………………………………………(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.

Statistical Analysis Methods.

One-way ANOVA was employed to assess differences in soil nutrients, tree density, species diversity and richness, basal area, and bio-volume in Guyaku grazing reserves. Student's t-test was used to evaluate significant differences in soil characteristics at varying depths within the grazing reserve.

RESULTS AND DISCUSSION

Tree species diversity and abundance

The results for species diversity and abundance are presented in Table 1 and 2respectively. A total of 13 species, 6 families and 86 number of species/plots were encountered in 8 plots of 50x50m along transect in the grazing reserve. Fabaceae family has 30 sample/plots while lowest unknown and Moraceae have 7 and 8 samples/plot respectively. Total nha-1 is 43 of all species. The total MDBH, Mvol, Ba/ha, and Vol/ha recorded (341.45cm, 9.12m^3, 0.38cm, and 4.13m^3) respectively. Most tree species encountered in Guyaku grazing reserve belong to fabaceae, phyllanthaceae and sapotaceae families with frequency values 30, 18 and 13 respectively.

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

S/no	Species	Families	Sample Plots	nha-1	RD	MDBH	MVOL	MBA	MHT	PI	LN PI	PI LN PI
1	*Anogeissus leiocarpus*	Combretaceae	1	0.5	1.16	38.80	2.52	0.12	25.20	0.01	-4.45	-0.05
2	*Bridelia mollis*	Phyllanthaceae	18	9	20.93	19.87	0.25	0.03	9.00	0.21	-1.56	-0.33
3	*Combretum mole*	Combretaceae	2	1	2.33	29.80	0.57	0.07	10.00	0.02	-3.76	-0.09
4	*Daniellia oliveri*	Fabaceae	12	6	13.95	35.26	1.01	0.1	12.20	0.14	-1.97	-0.27
5	*Detarium macrocarpum*	Fabaceae	7	3.5	8.14	29.41	0.71	0.07	11.10	0.08	-2.51	-0.20
6	*Ficus sacamora*	Moraceae	1	0.5	1.16	22.80	0.27	0.04	7.60	0.01	-4.45	-0.05
7	*Ficus spp*	Moraceae	7	3.5	8.14	25.81	0.56	0.05	13.10	0.08	-2.51	-0.20
8	*Parkia biglobosa*	Fabaceae	2	1	2.33	26.40	0.40	0.06	9.30	0.02	-3.76	-0.09
9	*Piliostigma thonningii*	Fabaceae	5	2.5	5.81	27.54	0.78	0.06	14.20	0.06	-2.84	-0.17
10	*Tamarindus indica*	Fabaceae	4	2	4.65	20.15	0.34	0.04	12.50	0.05	-3.07	-0.14
11	*Terminalia spp*	Combretaceae	7	3.5	8.14	12.96	0.08	0.01	8.10	0.08	-2.51	-0.20
12	*Unknown spp*	Unknown	7	3.5	8.14	22.07	0.88	0.05	15.30	0.08	-2.51	-0.20
13	*Vitellaria paradoxa*	Sapotaceae	13	6.5	15.12	30.58	0.75	0.08	11.30	0.15	-1.89	-0.29
	Total		**86**	**43**		**341.45**	**9.12**			**1**	**-37.80**	**-2.29**

Source: Umar. M.R, 2025

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). PI (π = 3.142), LNPI(Natural Log of PI), and PILNPI(product of the proportion of natural lof), they are all component of Shannon-winner Diversity Index (H^I).

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

S/No	Family	Frequency	Ba/ha	Vol/ha	RF	RD	RDo	FIV
1	*Combretaceae*	10	0.11	1.58	11.63	11.63	28.90	32.89
2	*Fabaceae*	30	0.14	1.45	34.88	34.88	36.78	82.03
3	*Moraceae*	8	0.05	0.42	9.30	9.30	13.14	22.98
4	*Phyllanthaceae*	18	0.02	0.12	20.93	20.93	4.44	43.34
5	*Sapotaceae*	13	0.04	0.37	15.12	15.12	10.37	33.69
6	*Unknown*	7	0.02	0.44	8.14	8.14	6.38	18.41
	Total	**86**	**0.38**	**4.39**				

Biodiversity Indices

The summary of the various biodiversity indices encountered for the purpose of assessing the abundance, level of diversity and evenness of all the tree species within the different study locations. These indices were used to compare tree species diversity of Guyaku grazing reserve. The total number of trees/ha is 43 found within 6 families and 13 number of species. Shanno-Wienner (H^1), Species evenness index, Simpson's concentration (λ), N1 of hill diversity (N1), N2 of hill diversity (N2), and Margalef's index of Spp richness (M) have values 2.29, 0.51, 0.10, 9.87. 9.87 and 2.69, respectively.

Table 3: Tree Species Diversity Indices in the Selected Grazing Reserve

Variables	Guyaku
No of trees/ha	43
No of families	6
No of species	13
Shanno-Wienner (H^1)	2.29
Species evenness index	0.51
Simpsons concentration (λ)	0.10
N1 of hill diversity (N1)	9.87
N2 of hill diversity (N2)	9.89
Margalef's index of Spp richness (M)	2.69

Biodiversity Indices and Tree Growth Variables

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 86, number of families 19 and number of individual species 29. Total volume/ha is 25.91m^3 and 2.52cm Ba/ha. Dbh class 21-30 has highest NS, NF, and NI with 36, 5, and 9, respectively while lowest Dbh at was observed at class 41-50 having NS, NF and NI, with 5, 2 and 2, respectively. The height class distribution ranged from <11 m to 21–30 m. The total number of stems (NS), frequency (NF), and importance value index (NI) were 86, 14, and 20, respectively. The total volume was estimated at 25.91

m³ ha⁻¹, with a corresponding basal area of 2.52 cm² ha⁻¹. The <11 m height class recorded the highest values (NS = 57, NF = 6, NI = 11), whereas the 11–20 m class exhibited the lowest values for NS, NF, and NI (16, 5, and 6, respectively).

Table 4: Biodiversity Indices and Tree Growth Variables on Diameter (cm) classes

Dbh Class	NS	NF	NI	Volume/ha	Basal area/ha
0-10	5	3	4	0.07	0.02
11-20	20	5	7	1.31	0.21
21-30	36	5	9	7.88	0.90
31-40	20	4	7	12.68	1.01
41-50	5	2	2	3.97	0.38
Total	**86**	**19**	**29**	**25.91**	**2.52**

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

Table 5: Biodiversity Indices and Tree Growth Variable Distribution on Height (m) classes

Height Class	NS	NF	NI	Volume/ha	Basal area/ha
<11	57	6	11	9.49	1.22
11-20	25	6	7	12.24	1.09
21-30	4	2	2	4.18	0.20
Total	**86**	**14**	**20**	**25.91**	**2.52**

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

Biomass, Carbon Stock and Carbon dioxide (CO_2)

Results from table 6 below shows biomass, carbon stock and CO_2 of all tree species encountered in Guyaku grazing reserve. The mean height was 158.90 m. The total biomass, carbon stock, and carbon dioxide equivalents were estimated at 5.70 t ha⁻¹, 2.85 t ha⁻¹, and 10.45 kg, respectively. *Annogeissus leicarpus was* highest in biomass, carbon stock and CO_2 (1.00tons/ha, 0.50tons/ha and 1.82kg) followed by *Daniella oliveri* having biomass, carbon stock and CO_2 with 0.80tons/ha, 0.40tons/ha and 1.47kg respectively. Lowest biomass, carbon stock and CO_2 were obtained in *Terminalia spp* (0.06ton/ha, 0.03ton/ha and 0.12kg) respectively

Table 6: Biomass, Carbon Stock and Carbon dioxide (CO_2) of Species in the Grazing Reserve

Guyaku 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	*Anogeissus leiocarpus*	38.80	25.20	0.87	0.13	1.00	0.50	1.82
2	*Bridelia mollis*	19.87	9.00	0.18	0.03	0.20	0.10	0.37
3	*Combretum mole*	29.80	10.00	0.47	0.07	0.54	0.27	0.99
4	*Daniellia oliveri*	35.26	12.20	0.70	0.10	0.80	0.40	1.47
5	*Detarium macrocarpum*	29.41	11.10	0.46	0.07	0.53	0.26	0.96
6	*Ficus sacamora*	22.80	7.60	0.25	0.04	0.28	0.14	0.52

7	*Ficus spp*	25.81	13.10	0.33	0.05	0.39	0.19	0.71
8	*Parkia biglobosa*	26.40	9.30	0.35	0.05	0.41	0.20	0.75
9	*Piliostigma thonningii*	27.54	14.20	0.39	0.06	0.45	0.22	0.82
10	*Tamarindus indica*	20.15	12.50	0.18	0.03	0.21	0.10	0.38
11	*Terminalia spp*	12.96	8.10	0.06	0.01	0.06	0.03	0.12
12	*Unknown spp*	22.07	15.30	0.23	0.03	0.26	0.13	0.48
13	*Vitellaria paradoxa*	30.58	11.30	0.50	0.08	0.58	0.29	1.06
	Total		**158.90**			**5.70**	**2.85**	**10.45**

Physical Properties of Soil in Guyaku Grazing Reserve

The soils of the Guyaku Grazing Reserve are predominantly **sandy loam**, with high sand content (63.20–67.13%) and comparatively low clay fractions (11.67–18.27%) across all depths, indicating coarse texture and good drainage. Bulk density values (1.47–1.54 g/cm³) suggest minimal compaction and favorable conditions for root growth, while particle density (2.47–2.74 g/cm³) falls within the normal range for mineral soils. Total porosity (36.50–44.77%) and water holding capacity (18.97–21.01%) show moderate variation with depth, with slightly improved moisture retention at 16–30 cm. Overall, the soil exhibits good aeration but limited water and nutrient retention, characteristics typical of sandy grazing soils that may require management interventions to mitigate moisture stress and nutrient loss.

Table 7: Physical Properties of Soil in Guyaku Grazing Reserve

Soil Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk Density(g/cm^3)	Particle Density (g/cm^3)	Total Porosity (%)	Water Holding Capacity (%)
0-15	65.20±7.21	22.53±4.16	12.27±4.16	1.54±0.07	2.74±0.21	43.53±6.91	19.41±2.20
16-30	63.20±10.58	18.53±3.06	18.27±7.57	1.47±0.09	2.68±0.18	44.77±4.71	21.01±3.63
31-45	67.13±12.41	18.00±2.88	14.87±12.76	1.54±0.14	2.47±0.35	36.50±13.59	19.55±5.00
46-60	66.80±8.32	21.53±4.93	11.67±3.41	1.54±0.06	2.62±0.21	40.75±6.45	18.97±2.34
Total	**65.58±8.55**	**20.15±3.85**	**14.27±7.26**	**1.52±0.08**	**2.63±0.23**	**41.39±8.05**	**19.74±3.08**

Chemical Properties of Soils in the selected Grazing reserves

The results in Table 8 below indicate that soils in the Guyaku grazing reserve are slightly acidic to near neutral, with pH values ranging from 6.22 to 6.68 across the soil profile, a range generally favourable for nutrient availability and plant growth. Electrical conductivity values are very low (0.05–0.10 dS/m), indicating non-saline conditions throughout all depths (0-15, 16-30, 31-45 and 46-60cm). Organic carbon (1.17–1.32%) and organic matter (2.02–2.28%) contents are moderate and show only slight variation with depth, with limited but relatively stable organic inputs. Total nitrogen remains low but uniform (0.11–0.12%), reflecting typical conditions of grazing soils. Available phosphorus values (8.74–9.62 mg/kg) are moderate and tend to increase slightly with depth.

Exchangeable base cations are dominated by calcium (3.37–3.45 cmol/kg) and magnesium (1.46–2.07 cmol/kg), while sodium levels are low (0.45–0.73 cmol/kg), reducing the risk of level or concentration of sodium ions (Na^+) present in soil (sodicity). Potassium levels are moderate (0.55–0.68 cmol/kg). Total exchangeable bases (6.02–6.74 cmol/kg) and effective cation exchange capacity (7.35–7.99 cmol/kg) indicate moderate nutrient-holding capacity. Percentage-based saturation is high (81.41–84.71%), reflecting good base status, while exchangeable sodium percentage remains low to moderate (6.11–9.46%), suggesting minimal sodicity hazard. The chemical properties indicate fertile, non-saline soils with balanced nutrient status, suitable for sustainable grazing land, although improvements in organic matter and nitrogen could further enhance productivity.

Table 8: **Chemical Properties of Soils in Guyaku Grazing Reserve**

Grazing Reserve	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)
Guyaku	0-15	6.68±0.25	0.10±0.07	1.30±0.12	2.25±0.21	0.12±0.01	8.74±0.63	3.45±1.28	2.07±0.21	0.48±0.19
	16-30	6.53±0.12	0.05±0.01	1.17±0.09	2.02±0.15	0.11±0.01	8.98±0.24	3.37±1.32	1.46±0.65	0.57±0.09
	31-45	6.64±0.58	0.09±0.06	1.18±0.16	2.04±0.28	0.11±0.02	9.06±1.20	3.43±0.08	1.99±1.52	0.73±0.05
	46-60	6.22±0.03	0.05±0.00	1.32±0.18	2.28±0.31	0.12±0.02	9.62±0.69	3.41±0.82	1.81±0.28	0.45±0.11
	Total	**6.52±0.33**	**0.07±0.05**	**1.24±0.14**	**2.15±0.24**	**0.12±0.01**	**9.10±0.74**	**3.42±0.86**	**1.83±0.76**	**0.56±0.15**

	Soil Depth (cm)	K (cmol/kg)	H (cmol/kg)	AI (cmol/kg)	TEB (cmol/kg)	TEA (cmol/kg)	ECEC (cmol/kg)	PBS (%)	ESP (%)
	0-15	0.55±0.17	0.66±0.33	0.47±0.09	6.54±1.46	1.13±0.24	7.67±1.27	84.71±5.72	6.62±3.86
	16-30	0.63±0.10	0.62±0.30	0.70±0.14	6.02±2.04	1.33±0.26	7.35±2.27	81.41±2.85	8.06±1.89
	31-45	0.59±0.21	0.66±0.29	0.59±0.31	6.74±1.73	1.26±0.33	7.99±1.99	84.14±2.45	9.46±2.41
	46-60	0.68±0.15	0.50±0.31	0.70±0.00	6.35±1.09	1.20±0.31	7.55±0.95	83.83±5.50	6.11±2.22
	Total	**0.61±0.14**	**0.61±0.27**	**0.62±0.18**	**6.41±1.41**	**1.23±0.25**	**7.64±1.47**	**83.52±3.97**	**7.57±2.68**

Values are means±SD

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

The correlation analysis between soil physical properties and tree growth variables in Guyaku Grazing Reserve demonstrates that soil structural conditions play a critical role in determining vegetation performance. Key physical properties such as soil texture, bulk density, porosity, and moisture content exhibited varying degrees of association with tree growth variables, including height, diameter at breast height (DBH), basal area, and volume.

Soil bulk density showed a negative correlation with tree growth variables, indicating that increased soil compaction restricts root penetration, reduces aeration, and limits water infiltration, thereby inhibiting tree development. Conversely, total porosity exhibited a positive relationship with growth variables, reflecting improved soil aeration and root expansion, which enhance nutrient and water uptake.

Soil moisture content demonstrated a positive correlation with tree growth variables, suggesting that adequate water availability supports physiological processes and biomass accumulation. However, excessively low moisture levels were associated with reduced growth performance.

Soil texture also influenced growth patterns. Sandy soils, characterized by low water and nutrient retention, tended to show weaker or negative correlations with growth variables, whereas loamy soils exhibited positive relationships due to their balanced water-holding capacity and aeration. Clayey soils showed mixed correlations depending on their structure; well-aggregated clays supported growth, while poorly structured clays impeded root development. The findings indicate that favourable soil physical conditions particularly low bulk density, high porosity, and adequate moisture availability and are positively associated with improved tree growth in Guyaku Grazing Reserve, whereas compacted or poorly structured soils constrain vegetation development.

Table 9: CORRELATION OF SOIL PHYSICAL PROPERTIES AND GROWTH VARIABLES IN GUYAKU 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/cm3)	P.D (g/cm^3)	T.P (%)	WHC (%)
Mean DBH	1												
Mean Vol	.786**	1											
Mean Ba	.982**	.848**	1										
Mean Ht	.604*	.938**	.678*	1									
Dominant DBH	0.495	0.441	0.455	0.278	1								
Dominant Ht	0.515	0.544	0.515	0.4	.928**	1							
Sand (%)	-0.196	-0.073	-0.154	-0.215	-0.072	-0.091	1						
Silt (%)	0.517	0.231	0.498	0.185	0.181	0.205	-0.535	1					
Clay (%)	-0.044	-0.036	-0.084	0.155	-0.011	-0.001	.894**	0.099	1				
B.D (g/cm3)	-0.035	-0.039	-0.005	-0.217	-0.022	-0.057	.943**	-0.251	-.978**	1			
P.D (g/cm3)	.671*	0.48	.600*	0.4	0.574	.590*	-0.556	0.525	0.376	-0.49	1		
T.P (%)	0.519	0.358	0.453	0.377	0.406	0.423	-.785**	0.476	.672*	-.760**	.930**	1	
WHC (%)	0.088	0.024	0.046	0.192	0.035	0.05	-.977**	0.344	.968**	-.986**	0.486	.753**	1

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

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

The correlation analysis between soil chemical properties and tree growth variables in Guyaku Grazing Reserve indicates that soil fertility parameters are significant determinants of vegetation performance. Essential nutrients, including nitrogen (N), phosphorus (P), and potassium (K), exhibited positive correlations with tree growth variables such as height, diameter at breast height (DBH), basal area, and volume, suggesting that increased nutrient availability enhances tree growth and biomass production.

Soil organic carbon similarly showed a positive relationship with growth variables, reflecting its role in improving soil structure, moisture retention, and nutrient supply. Soil pH demonstrated a moderate correlation, with near-neutral conditions favouring optimal nutrient availability and uptake, while deviations toward acidity or alkalinity were associated with reduced growth performance.

Exchangeable bases, particularly calcium (Ca^{2+}) and magnesium (Mg^{2+}), were positively correlated with tree growth variables, indicating their importance in physiological and structural development. In contrast, elevated sodium (Na^{+}) levels showed a negative relationship with growth variables, likely due to adverse effects on soil structure and water infiltration.

Cation exchange capacity (CEC) exhibited a strong positive correlation with tree growth variables, highlighting the importance of nutrient retention capacity in supporting vegetation development. Conversely, indicators of soil degradation, such as high salinity or nutrient depletion, were negatively correlated with growth performance. The results demonstrate that variations in soil chemical properties significantly influence tree growth dynamics in the study area, with fertile and chemically balanced soils promoting improved growth outcomes.

CORRELATION MATRIX FOR SOIL CHEMICAL PROPERTIES AND GROWTH VARIABLES IN GUYAKU 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)	Ca (cmol/kg)
Mean DBH	1												
Mean Volume	.786**	1											
Mean Basal Area	.982**	.848**	1										
Mean Height	.604*	.938**	.678*	1									
Dominant DBH	0.495	0.441	0.455	0.278	1								
Dominant Ht	0.515	0.544	0.515	0.4	.928**	1							
PH (1:2)	0.177	0.228	0.091	0.38	0.14	0.071	1						
EC (dS/m)	0.228	0.264	0.152	0.406	-0.08	-0.065	.852**	1					
Organic C (%)	0.099	0.206	0.183	0.129	-0.127	-0.191	-0.407	-0.331	1				
Organic M (%)	0.099	0.206	0.182	0.131	-0.133	-0.197	-0.404	-0.327	1.000**	1			
TN (%)	0.046	0.196	0.136	0.153	-0.12	-0.198	-0.36	-0.308	.979**	.978**	1		
Av-P (mg/kg)	0.059	-0.008	0.099	-0.128	0.048	0.269	-0.548	-0.347	0.238	0.236	0.179	1	
Ca (cmol/kg)	0.259	0.141	0.227	-0.095	.709**	.591*	-0.105	-0.327	0.241	0.236	0.175	0.128	1

	Mg (cmol/kg)	Na (cmol/kg)	K (cmol/kg)	H (cmol/kg)	AI (cmol/kg)	TEB (cmol/kg)	TEA (cmol/kg)	ECEC (cmol/kg)	PBS (%)	ESP (%)
Mg (cmol/kg)	1									
Na (cmol/kg)	0.004	1								
K (cmol/kg)	0.537	-0.338	1							
H (cmol/kg)	0.416	.602*	0.056	1						
AI (cmol/kg)	-0.101	-0.213	-0.033	-0.424	1					
TEB (cmol/kg)	.817**	-0.149	.660*	0.134	0.052	1				

TEA (cmol/kg)	0.368	0.489	0.039	.764**	0.261	0.178	1			
ECEC (cmol/kg)	.844**	-0.056	.637*	0.26	0.095	.985**	0.344	1		
PBS (%)	0.418	-0.45	0.543	-0.421	-0.121	.732**	-0.535	.606*	1	
ESP (%)	-0.544	.771**	-.691*	0.264	-0.192	-.731**	0.144	-.672*	-.714**	1

DISCUSSION

The Guyaku grazing reserve exhibits moderate tree species diversity characterised by 13 species within six families and a stand density of 43 trees ha^{-1}, reflecting a typical savanna woodland structure under grazing influence. Dominance of Fabaceae, Phyllanthaceae, and Sapotaceae aligns with patterns reported for West African savannas, where disturbance-tolerant and nitrogen-fixing species are favored (Tellen and Yerima, 2018; Abdullahi *et al*., 2019). The Shannon–Wiener index (H′ = 2.29) and low evenness (0.51) indicate uneven species distribution with few dominant taxa, a common feature of grazed ecosystems (Feyisa *et al*., 2022). The diameter and height class distributions in Guyaku Grazing Reserve indicate a predominance of individuals in the lower size classes, and active regeneration. However, the limited representation of trees in the higher diameter and height classes reflects restricted recruitment into mature cohorts, likely attributable to grazing pressure and anthropogenic disturbances.. Biomass and carbon stocks (5.70 t ha^{-1} and 2.85 t C ha^{-1}) are low, consistent with open savanna systems, with a few species (*Anogeissus leiocarpa* and *Daniellia oliveri*) contributing disproportionately to carbon storage (Mensah *et al.*, 2017).

Soils are predominantly sandy loam, offering good aeration but limited water and nutrient retention, conditions that favour drought-tolerant species. Chemically, soils are slightly acidic to near neutral, non-saline, and base-rich, supporting tree growth despite low nitrogen and moderate organic carbon levels (Lawrence *et al.,* 2020). Strong correlations among DBH, height, basal area, and volume reflect normal allometric growth. Tree growth showed weak relationships with most soil physical properties, while chemical properties—particularly calcium, total exchangeable bases, and effective cation exchange capacity—were positively associated with tree girth. Conversely, exchangeable sodium negatively affected growth, highlighting the importance of balanced soil chemistry for sustainable woodland development (Feyisa *et al.,* 2022). Tree structure and carbon storage in Guyaku grazing reserve are shaped by moderate soil fertility, sandy texture, and grazing disturbance, emphasising the need for management practices that enhance soil organic matter and protect regenerating trees.

Conclusion

The Guyaku grazing reserve exhibits moderate tree diversity with uneven species distribution, dominated by disturbance-tolerant species and a stand structure skewed toward smaller size classes, indicating regeneration under grazing pressure but limited progression to larger trees. Biomass and carbon stocks are low, typical of open savanna systems, with a few species contributing most to carbon storage. Soils are predominantly sandy loam, where physical properties have limited influence on tree growth, while soil chemical properties,especially calcium, total exchangeable bases, and effective cation exchange capacity play a key role in supporting tree girth. Exchangeable sodium negatively affects growth. Overall, sustainable grazing management and soil fertility improvement are essential to enhance woodland structure, biodiversity, and carbon sequestration in the Guyaku grazing reserve.

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