TREE GROWTH CHARACTERISTICS, BIOMASS, CARBON STOCK AND CO_2 EMISSION EQUIVALENT POTENTIAL OF GMELINA ARBOREA ROXB. PLANTATION IN J3 ZONE OF OMO FOREST RESERVE, OGUN STATE, NIGERIA

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ABSTRACT

Plantation forests are being increasingly viewed as crucial for climate change mitigation due to their higher productivity and carbon storage compared to natural forests. The study assessed the Tree Growth Characteristics (TGS), Above and Below Ground Biomass (AGB; BGB), Carbon Stock (Cs) and Carbon dioxide (CO_2) emission potential of the J3 zone of the Omo forest reserve, Ogun state, Nigeria with the aim of assessing how the plantation contribute to climate change mitigation in the area. A 1000m baseline was established 20 m from the edge of the forest. Five transect lines were laid out at 200m intervals, with ten 20m x 20m plots systematically set up along these transects, and all trees with Dbh ≥ 10cm were measured for Dbh, height, basal area, and volume. TGS of Diameter at breast height (Dbh) and total height (Ht), were measured. Basal Area (BA), Volume (Vol), AGB, Cs and CO_2 equivalent emission potential were estimated using appropriate formulae. The mean Dbh, Ht, BA and Vol were 72.83 cm±1.64; 18.09 m±0.42; 0.4 m^2±0.02; 9.85 m^3±0.53.There was variability in the TGC with plot 8 and 9 having the highest TGC values and plot 2 having the lowest. The AGB, BGB, AGC, BGC and CO_2 equivalent emission were 3268.81 Kg/ha; 653.76 Kg/ha; 1634.41 Kg/ha; 254.996 Kg/ha and 6933.98. The study concludes that the area stores considerate amount of Carbon that can contribute to cleaning the atmosphere of CO_2. The study recommends enhancing plantation forests in Nigeria through expansion, improved practices, monitoring, and increased support to maximize their climate and economic benefits.

Keywords: Aboveground biomass, Belowground biomass, Carbon stock, Gmelina arborea plantation, Tree growth characteristics

INTRODUCTION

Climate change is a global challenge and its mitigation has received earnest attention from all stakeholders (Abebe et al., 2021). Consequently, biomass, carbon stock and CO_2 by natural forest and managed forest have been recognized as a major strategy to mitigate climate change (Akintunde-Alo et al. 2024). Forests play a pivotal role in global carbon cycling, acting as significant carbon sinks that help mitigate the impacts of climate change. However, forest resources especially the ones in the tropical areas are experiencing increasing pressure due to growing population and its attendant demands resulting in deforestation and degradation of these forests, leading to a loss of biodiversity and a reduction in carbon storage capacity (Abebe et al., 2021).

The increasing rate of forest clearance and degradation has made the search for alternative natural resource crucial. Plantation forests; emerge as significant contributors to global carbon cycling. Studies indicate higher productivity in plantations compared to natural forests. The productivity of plantations is higher (3.2 Mg ha^{-1} yr^{-1}) than natural forests (1. 1 Mg ha^{-1} yr^{-1}), probably because of their enhanced silvicultural practices (Chauhan et al., 2020). The United Nations Framework Convention on Climate Change has recognized the importance of plantation forests as a terrestrial emission mitigation option and subsequent terrestrial Carbon stores (Tamang et al. 2021; Olajiire-Ajayi et al., 2024). As a result, there are now many tree plantations in Nigeria and other countries.

The tree growth characteristics of a forest plantation, encompassing parameters such as tree density, basal area, and diameter distribution, provides essential insights into the health and productivity of a plantation. This structure plays a crucial role in determining the biomass and carbon stock accumulation and carbon dioxide sequestration capacity. Research by Dada et al. (2024) indicates that well-managed plantations with optimal stand structures can significantly boost biomass production and carbon storage, thereby contributing to the reduction of atmospheric CO_2 levels. Additionally, biomass, carbon stock, and carbon dioxide sequestration potential are critical components of forest ecosystems, serving as major carbon pools.

For sustainable forest management and climate change mitigation, it is essential to comprehend the dynamics of forest ecosystems, in particular, tree growth characteristics, biomass (both above and below ground), carbon stock, and carbon dioxide sequestration capacity. *Gmelina arborea*, a fast-growing exotic species, has been extensively planted in Nigeria for timber production and reforestation efforts. This deciduous tree, native to South and Southeast Asia, has drawn substantial attention for its significant carbon sequestration potential (Ige, 2018). In Nigeria, *Gmelina arborea* plantations are widely established to address various forestry needs, including timber production, land rehabilitation, and environmental conservation (Akhabue et al., 2020). Understanding the growth characteristics and carbon stock of *Gmelina arborea* is essential for optimizing forest management practices and enhancing carbon sequestration.

The J3 zone of Omo Forest in Ogun State, Nigeria, is a vital area for forestry activities, encompassing both natural forests and plantation estates. Despite the extensive planting of *Gmelina arborea* in this division of the reserve, there is limited empirical data on its growth characteristics and carbon sequestration potential. This knowledge gap may hinders the development of effective forest management strategies that maximize both economic and ecological benefits. Without detailed information on tree growth characteristics and carbon stock, assessing the contribution of this plantation to climate change mitigation and sustainable forest management maybe challenging. Understanding the growth characteristics and carbon stock of *Gmelina arborea* in the J3 zone is crucial for optimizing forest management practices aimed at enhancing both timber production and carbon sequestration. Therefore, this study aims to assess the growth characteristics of *Gmelina arborea* in the J3 Zone of Omo Forest Reserve, Ogun State, Nigeria, estimate its biomass accumulation, and quantify the carbon stock sequestered by the plantation. Additionally, the study aims to calculate the CO_2 emission equivalent potential of the plantation as a measure of its environmental benefits.

The information from this study is crucial for evaluating how *Gmelina arborea* plantations fit into climate mitigation and sustainable forest management plans. Furthermore, understanding the CO_2 emission equivalent potential of the plantation provides important information for creating carbon credit schemes and other environmental services that support international climate initiatives.

THE STUDY AREA

The study was carried out in the J3 area of the Omo Forest Reserve Located in Ogun state, South West, Nigeria. Omo Forest Reserve is located between latitude 6° 42' N to 7 ° 05' N and longitude 4° 12' to 4° 35' E (Figure 1).

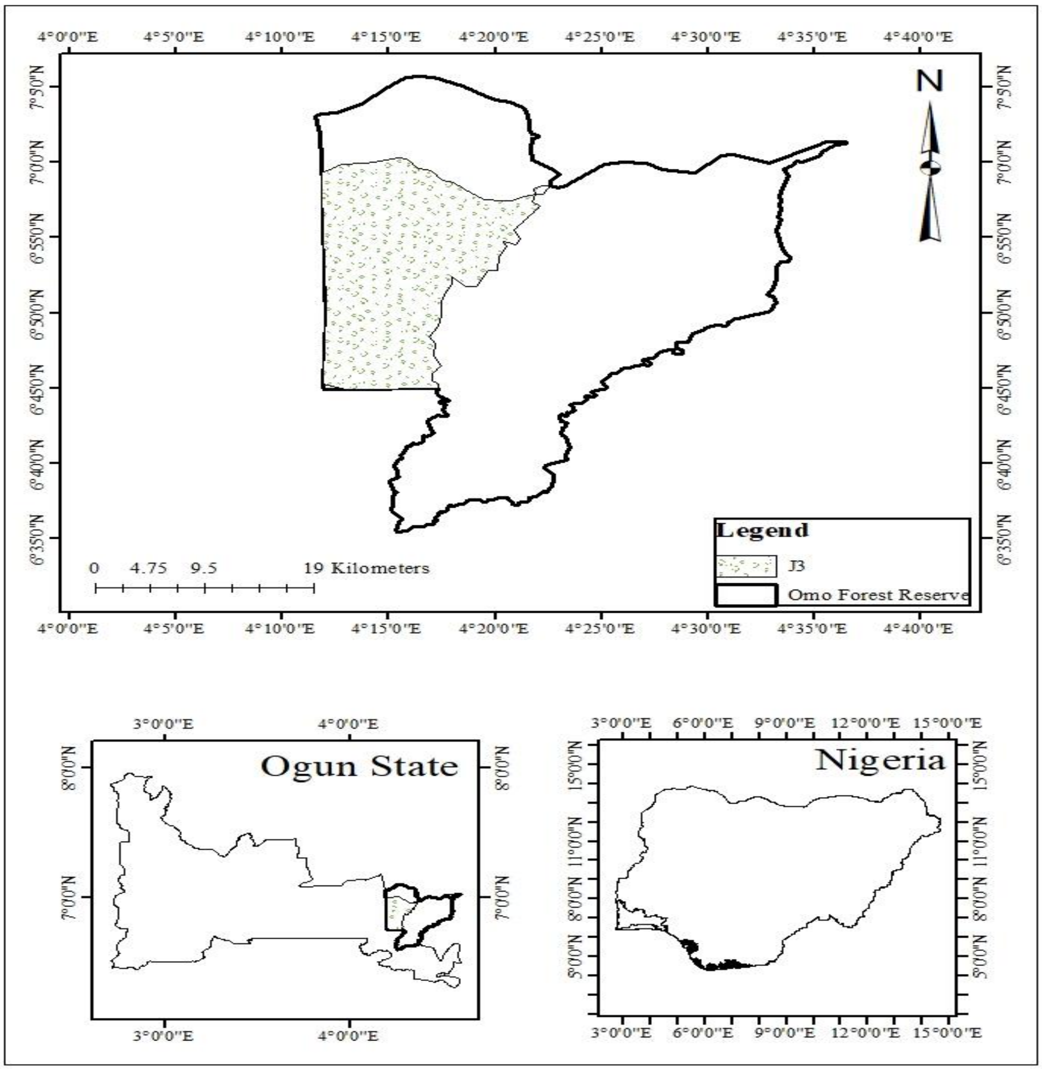

Figure 1: Map of Omo Forest Reserve showing the study area

The reserve is sub divided into different areas. Mainly; J1, J3, J4, J6 and a Strict Nature Area (Mshelia et al., 2021). The climate of the area is humid tropical with distinct dry and wet seasons. The rainy season starts runs March to November while the dry season spans December to January with occasional rains during the period (Ige, 2018). The mean annual rainfall ranges from about 1600 mm to 2000 mm with two peak periods (June and September). The mean annual temperature is approximately 26.5 °C, with a minimum of 21.4 °C and a maximum of 32.15 °C (Ige, 2018; Adeyemi & Adeleke, 2020; Mshelia et al., 2021).

The topography is gently undulating with average elevation of 12 m above sea level (Ige, 2018). The geology is made up of undifferentiated basement complex outcrop with older granites in some places (FRIN, 2011; Ige, 2018). The vegetation is characterized by mixed moist semi evergreen tropical lowland rainforest in most part of the central and southern part while the northern part is made up of dry mixed semi deciduous rainforest (Adedeji et al., 2015; Mshelia et al., 2021).

There are more than 50 villages within and around the reserve and with a population of about 59,100 according to the 2006 population census.

MATERIAL AND METHOD

Sampling Technique and Data Collection

The systematic sampling technique was adopted for the study. A 1,000-meter baseline was established 20 meters from the forest edge. Five line transects were then set up at 200-meter intervals along the baseline, with 10 alternating 20m x 20m plots laid out on each transect. This was done because of the relatively small size and nature of the shape of the forest.

Total enumeration of all the trees with Diameter at breast height (Dbh) ≥ 10cm in the sample plots were carried out. That is; all laid plots were sampled. Data were collected on Dbh (cm), total height (m) and these parameters were used to compute basal area (m^2) and volume (m^3)

Basal Area Estimation:

The basal area of individual trees within each stand was estimated using the formula by Hedl *et al.* (2009) and adopted by Olajiire-Ajayi et al. (2024). The equation for basal area is as follows:

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

Where: BA = Basal Area (m^2); π = 3.142 (constant); D = diameter at breast height (m).

To obtain the total basal area of the stand for each tree species, the basal areas of individual trees were summed up.

Tree Volume Estimation:

This was estimated using the formula adopted by Salami et al (2020) which is given as:

$$V = BA \times H \ldots\ldots\ldots\ldots..(2)$$

Where BA = Basal Area (m^2); H = Height of tree (m)

Biomass Estimation:

The standing biomass of each tree was estimated using allometric equation by Terakumpisut & Amin (2012) developed for tropical rainforest. The functions were expressed as follows:

$$Ws = 0.0509\,(D^2H) \ldots \ldots \ldots .(3)$$
$$Wb = 0.00893\,(D^2H)0.977 \ldots (4)$$
$$Wl = 0.0140(D^2H)669 \ldots \ldots ..(5)$$

Where: Ws = stem biomass (tons/individual tree); Wb = branch biomass (tons/individual tree); W_l = leaf biomass (tons/individual tree); D = diameter at breast height (cm); H = height (m)

The stem, branch and leaf biomass together constitute the standing biomass of individual tree.

Belowground Biomass Estimation:

The belowground biomass was estimated using the formular developed by Cairns et al., (1997) and adopted by Ubaekwe (2020). The formular is given as:

$$BGB = AGB \times 0.2 \ldots \ldots \ldots \ldots (6)$$

Carbon Stock Estimation:

The Aboveground and Belowground carbon content was estimated using the allometric equations developed by Kauffman & Donato (2012) and adopted by Dada et al., (2024). The equations are as follows:

$$AGCs = AGB \times 0.50 \ldots \ldots .(7)$$
$$BGCs = BGB \times 0.39 \ldots \ldots .(8)$$

Where: *AGCs= Aboveground Carbon stock; BGCs = Belowground Carbon stock*

CO_2 Emission Estimation:

The estimated carbon stock were converted into CO_2 equivalents for calculating CO_2 stock by biomass of trees (Bhatta et al., 2018; Dada et al., 2024). This is given by

$$CO_2Emission = C \times 3.67 \ldots \ldots \ldots (9)$$

Where: C= Carbon stock; 3.67= constant of estimating CO_2 equivalent

RESULTS AND DISCUSSION

The Table 1 presents the Mean Dbh, Height, Basal Area and Volume of the *Gmelina arborea* plantation across ten plots in the study area.

Table 1: Mean Dbh, Height, Basal Area and Volume of the sampled plots in J3 zone of Omo Forest Reserve

Plot	No. of indv.	Av. Dbh(cm)	Av. Height(m)	Av. BA(m^2)	Av. Vol(m^3)
1	25	75.35	14.51	0.54	9.5
2	21	61.77	15.19	0.34	5.91
3	17	64.02	16.2	0.39	7.91
4	24	75.51	18.26	0.52	10.85
5	27	77.61	21.35	0.51	11.56
6	31	77.14	19.6	0.51	10.82
7	35	68.87	19.62	0.4	8.32
8	27	80.71	20.2	0.55	12.03
9	23	77.18	21.59	0.52	12.29
10	38	68.96	14.91	0.46	8.45
Total	**268**	**727.12**	**181.43**	**4.74**	**97.64**
Mean		**72.71**	**18.14**	**0.474**	**9.76**

Table 1 presents the stand characteristics of a *Gmelina arborea* plantation across ten plots. The total number of individuals across all plots is 268, with an average of 27 individuals per plot. The number of individuals however ranges from 17 (Plot 3) to 38 (Plot 10). The average Dbh across all plots is 72.71 cm. Plot 8 has the highest average Dbh (80.71 cm), while Plot 2 has the lowest (61.77 cm). The average height across all plots is 18.14 m. The height varies from 14.51 m (Plot 1) to 21.59 m (Plot 9). The average BA across all plots is 0.474 m^2. Plot 1 has the highest BA (0.54 m^2), while Plot 2 has the lowest (0.34 m^2). The average volume across all plots is 9.76 m^3. Plot 9 has the highest volume (12.29 m^3), while Plot 2 has the lowest (5.91 m^3).

Table 2 presents the statistical summary of the growth variables of the study area.

Table 2: Summary of Tree Growth Characteristics in the J3 zone of Omo Forest Reserve

Parameter	Mean	Min	Max	S.E
Dbh (cm)	72.83	13.6	157.1	1.64
Height (m)	18.09	3.9	28.2	0.42
B. A (m^2)	0.47	0.01	1.94	0.02
Volume ($m^{3)}$	9.85	0.1	49.4	0.53

The mean Dbh of 72.83 cm wide range of Dbh values (13.6 cm to 157.1 cm) while the average height is 18.09 m with a height range (3.9 m to 28.2 m). The Dbh and Height suggests that the plantation is relatively mature. The wide range of Dbh and height values indicates a significant variation in tree sizes and growth rate. The mean BA of 0.47 m^2 and the range from 0.01 m^2 to 1.94 m^2 suggest variability in tree girth across the plantation.

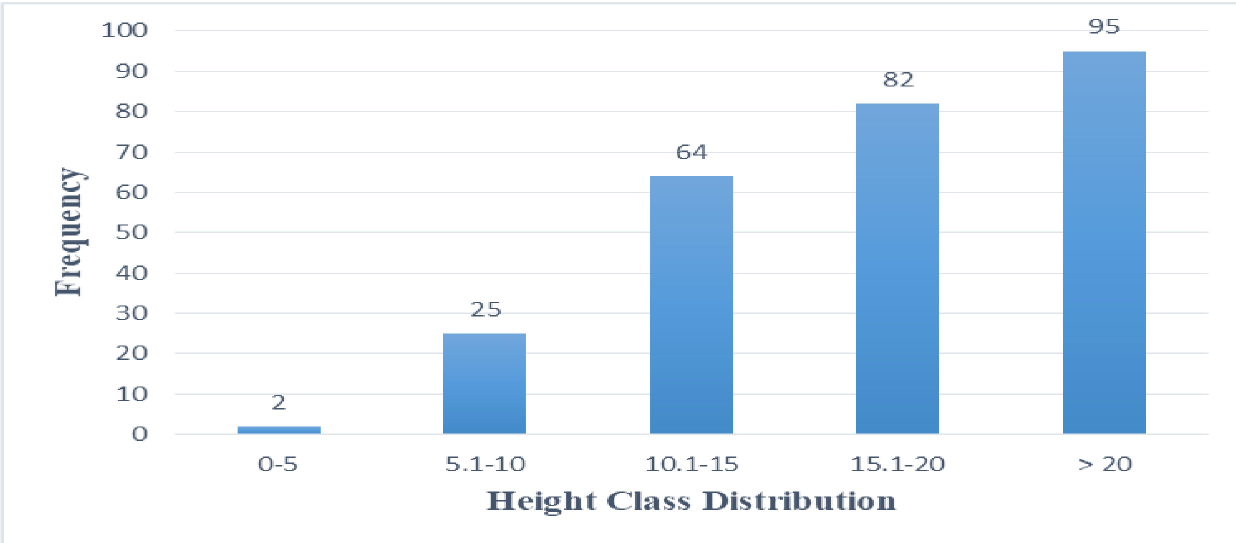

Figure 2: Height Class Distribution of Gmelina arborea in the J3 zone of Omo Forest Reserve

Figure 2 shows the height class distribution of *Gmelina arborea* in the study area. The highest number of trees were in the height class interval of > 20 m. This is closely followed by the class interval of 15.1- 20 m and 10.1- 15 m with frequency of 82 and 64 respectively. The height class interval of 0-5 had the lowest frequency of 2.

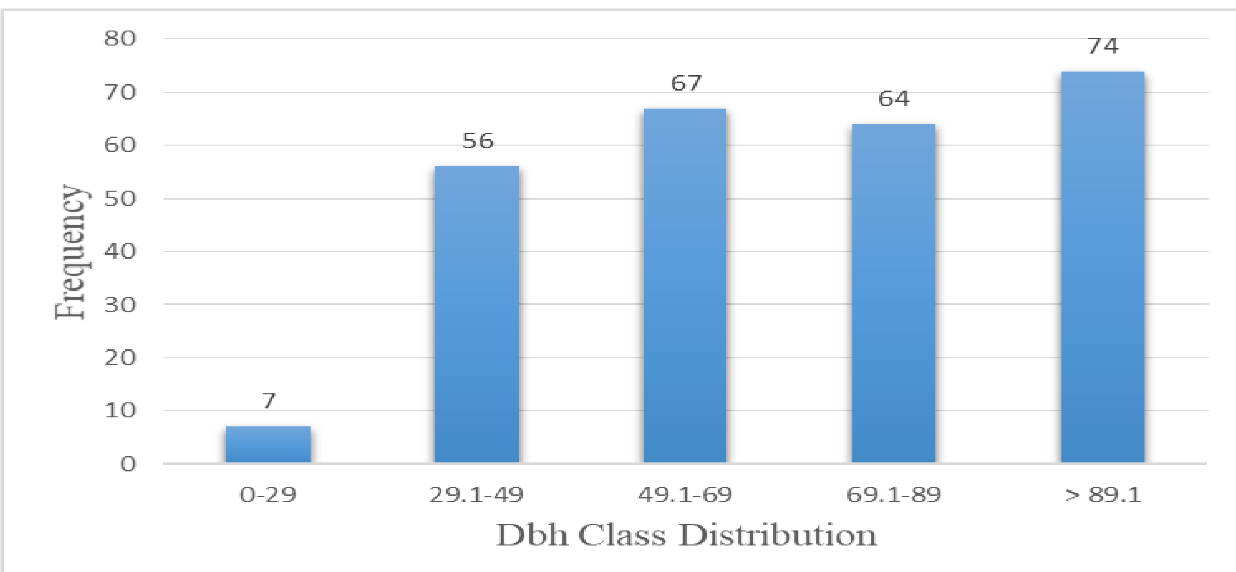

Figure 3: Dbh class Distribution of Gmelina arborea in the J3 zone of Omo Forest Reserve

Figure 3 shows the Dbh class Distribution of Gmelina arborea in the study area. The Dbh class interval of >89.1cm had the highest number of trees (74). This is followed by the Dbh class interval of 49.1- 69 and 69.1-89 cm with frequency of 67 and 64 respectively. The Dbh class interval of 0- 29 cm had the lowest number of trees (7).

Studies on forest structure are important in the management and sustainability of forest because of their importance in conservation of plant species and the overall management of forest ecosystem (Adio et al., 2019). The trees in the J3 zone of Omo forest reserves can be regarded as matured trees based on Adekunle (2006) who reported 48 cm as the minimum merchantable tree size as contained in the logging policy of Southwestern, Nigeria. The Dbh class distribution is considered as important feature in understanding changes occurring in a forest stand and helps in appreciating differences in structural heterogeneity and species size composition (Adio et al., 2019; Sharma et al., 2020; Akintunde-Alo et al., 2024). The majority of the trees in the J3 zone were in Dbh class distribution of 49.1 to >89.1 m. This is an indication of maturity of the forest. The mean height and Dbh in the J3 zone were higher than the height and Dbh observed by Sharma et al. 2020 for Pinus roxburghii. The difference might be due to species or ecological characteristics of their location.

Table 3 shows the biomass, Carbon stock and CO_2 equivalent sequestered by *Gmelina arborea* in the J3 zone of Omo Forest Reserve. The mean ABG, AGC, BGB, BGC were 3268.81; 1634.40; 653.76; 254.96 respectively with plot 2 having the lowest biomass, carbon stock and equivalent CO_2 sequestered. Plot 9 has the highest value for all the biomass assessed.

Table 3: Biomass, Carbon stock and CO_2 equivalent sequestered by *Gmelina arborea* in the J3 zone of Omo Forest Reserve

Plot	AGB (Kg/ha)	BGB (Kg/ha)	AGC (Kg/ha)	BGC (Kg/ha)	CO_2 Equiv
1	3158.28	631.66	1579.14	246.34	6699.53
2	2044.32	408.86	1022.16	159.45	4336.53
3	2642.35	528.47	1321.18	206.10	5605.11
4	3601.68	720.34	1800.84	280.93	7640.09
5	3865.9	773.18	1932.95	301.54	8200.58
6	3632.1	726.42	1816.05	283.30	7704.63
7	2845.65	569.13	1422.83	221.96	6036.36
8	4005.72	801.14	2002.86	312.45	8497.17
9	4061.49	812.29	2030.75	316.79	8615.48
10	2830.57	566.11	1415.29	220.78	6004.37
Total	**32688.1**	**6537.61**	**16344.03**	**2549.67**	**69339.87**
Mean	**3268.81**	**653.762**	**1634.405**	**254.96**	**6933.98**

Tree biomass is the live plant materials, including the roots, stems, branches and leaves. Biomass production is an important consideration in all tropical tree planting programme as the tree biomass plays as essential role in the global carbon cycle (Akintunde-Alo et al., 2024; Dada et al., 2024). The biomass produced by a plant species is a reflection of its primary productivity based on its ability to assimilate solar energy under different environmental conditions. Consequently, different plant species have different rate of biomass production based on their efficiency (Ige, 2018). For this study, the biomass observed indicates the high ability of the species to accumulate biomass. This observation aligns with Tamang et al. (2023) who noted that Gmelina arborea had a high potential to sequester carbon compared to other species in their study Eastern Himalayas.

The biomass and carbon stock observed in the study area was higher compared to the 0.05 ton/ha obtained by Dongs et al. (2024) in the Wildlife Park in Jos, Nigeria. However, it is lower than the value obtained for *G. arborea* plantations by Akhabue et al (2021) in University of Port Harcourt

Arboretum and Guuroh et al. (2021) in Ghana with values of 151.52 Mg/ha and 1350.10 Mg/ha respectively. In addition, it is lower the AGB and BGB value obtained for the J4 area of the study location (Adeyemi & Adeleke, 2021).

Biomass production in *G. arborea* is usually affected by physiological aspect of the plant, forestry management and age (Verma et al., 2017). At 6 years, Tamang et al. (2021) observed that *G. arborea* sequestered 31.37 Mg/ha of Carbon with standing biomass ranging from 3.94-53.67 Mg/ha. Subsequently, the differences observed in the values might be due to the age of the *G. arborea* plantation.

The relative high value of carbon stock in the study aligns with findings of Semere et al. (2022) who opined that the intensity of management can affect the carbon stock accumulation potential of a plantation. They further argued that carbon stock is a function of the tree growth characteristics of Dbh and height such plantation. Dida and Tiburan (2020) found that tree with large Dbh had a high AGB estimates in the University of Philippines Les Barmos (UPLB) campus. Kanowski and Catterall (2010) also found the contribution of large tree with Dbh > 10cm to AGB compared to smaller trees. This statement also holds true for this study as plots 8 and 9 with the highest Dbh and height values had the highest biomass, carbon stock and equivalent CO_2 sequestered.

CONCLUSION

The study revealed the potential of the *Gmelina arborea* plantation of the J3 zone of the Omo Forest Reserve to sequester Carbon. The high amount of the total biomass translate to increasing amount of CO_2 that can be sequestered from the Forest area. Consequently, the study recommends proper management of the *Gmelina arborea* plantation for the continued provision of the climate regulatory ecosystem service. It also recommends improving silvicultural practices to maximize carbon storage and the need for ongoing monitoring and research to ensure plantation resilience. Furthermore, the study recommends incorporating findings into national climate policies and involving local communities in forest management, increasing support from the government and private sector through financial incentives. Consequently, enhancing the environmental and economic benefits of plantation forests.

REFERENCES

Abebe, S., Minale, A.S., Teketay, D., Jayaraman, D. & Long, T.T. (2021). Biomass, Carbon stock and sequestration potential of *Oxytenanthera abyssinica* forests in lower Beles River Basin, Northwestern, Ethiopia. *Carbon Balance and Management, 29*(16).

Adedeji, O.H., Tope-Ajayi, O.O. & Abegunde, O.L. (2015). Assessing and predicting changes in the status of Gambari Forest Reserve, Nigeria using Remote sensing and GIS techniques. *Journal of Geographic Information System, 7*: 302-318.

Adekunle, V.A.J. (2006). Conservation of tree species diversity and structure of a Nigerian Strict Nature Reserve. *Journal of Tropical Forest Science, 18*: 91-101.

Adeyemi, A.A & Adeleke, S.O. (2021). Assessment of land cover changes and carbon sequestration potentials of tree species in J4 section of Omo forest Reserve, Ogun state, Nigeria. *Ife Journal of Science, 22*(1), 137-152.

Adio, A.F., Onilude, Q.Q., Kareem, A.A & Suleiman, O.N. (2019). Floristic dynamics and Structure of a degraded community forest in Kwara State, Nigeria. *Australian journal of Science Technology, 3*: 195-200.

Akintunde-Alo, D.A., Onilude, Q.A., Ige, P.O & Adeoti, O.O. (2024). Stand growth, biomass and carbon sequestration potentials of *Parkia biglobosa* (Jacq.) Bench Plantation in South-Western, Nigeria. *Journal of Applied Science and Environmental Management, 28*(4), 1297-1304

Akhabue, E.F., Chima, U.D &Eguakun, F.S. (2021). Assessment of the aboveground carbon stock and the soil physic-chemical properties of an Arboretum within the University of Port Harcourt, Nigeria. *Journal of Forest and Environmental Science, 37*(3), 193-205

Bhatta, S.P., Sharma, K.P & Balami, S. (2018). Variation in carbon storage among tree species in the planted forest of Kathmandu, Central Nepal. *Current Science, 115*: 274-282

Cairns, M.A., Brown, S., Helmer, E.H., Baumgardener, G.A. (1997). Root biomass allocation in the World's Upland forests. *Oecologia, 111*: 1-11

Dada, A., Olaniran, J.M & Odiwe, A.I. (2021). Nexus between Carbon stock, biomass, and CO_2 emission of woody species composition: evidence from Ise-Ekiti Forest Reserve, Southwestern Nigeria. *Carbon Research, 3*(40), 1-16

Dida, J.J.V & Tiburan Jr C.L. (2020). Aboveground biomass estimation of trees in the University of the Philippines Los Banos Campus, Philippines. *The Technical Journal of Philippines Ecosystems and Natural Resources*.

Dongs, Y.D., Saka, M.G & Adedotun, A. (2024). Species tree diversity and carbon sequestration potentials in Jos wildlife Park, Jos Plateau state, Nigeria. *South Asian Journal of Agricultural Science, 4* (1), 28-36

Forestry Research Institute of Nigeria (FRIN) (2011). High Forest Investigations in Nigeria –A Report on the state of Work by Akinyemi, D.O. Technical Note No.89 Pg. 64

Guuroh, R.T., Foli, E.G., Addo-Danso, S.D., Stanturf, J.A Kleine, M & Burns, J. (2021). Restoration of degraded forest reserves in Ghana. *Reforesta, 12*: 35-55

Hedl. R., Svatek. M., Dancak. M., Rodzay, A.W., Salleh, M., & Kamariah, A.S. (2009). A new technique for inventory of permanent plots in tropical forests: a case study from lowland dipterocarp forest in Kuala Belalong, Brunei Darussalam. *Blumea, 54*: 124-130.

Ige, P.O. (2018). Above Ground Biomass and Carbon Stock Estimation of Gmelina arborea (Roxb). Stands in Omo Forest Reserve, Nigeria. *Journal of Research in Forestry, Wildlife & Environment, 10*(4), 71-80

Kauffman, J. B & Donato, D.C. (2012). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in Mangrove forests. Bogor, Indonesia: Cifor, Pg. 25

Kanowski, J & Catterall, C.P. (2010). Carbon stocks in aboveground biomass of monoculture plantations, mixed species plantations and environmental restoration plantings in northeast Australia. *Ecological Management & Restoration*, *11*(2), 119-126

Mshelia, Z.H., Adamu, I.S & Afolabi, O.S. (2021). Assessment of forest loss and degradation in Omo Forest Reserve, Ogun state, Nigeria. *Journal of forestry Research and Management, 18*(4), 26-40

Olajiire-Ajayi, B.L., Ogundana, O.A & Adenuga, D.A. (2024). Assessment of stand growth and slenderness coefficient of Nauclea diderrichii A. Chev and Terminalia ivorensis De Wild and Thur. in Forestry Research Institute of Nigeria (FRIN) arboretum, Oyo state, Nigeria. *FUDMA Journal of Sciences, 8*(4), 56-61

Salami, K.D., Agbo-Adediran, O.A & Odewale, M.A. (2020). Growth assessment of Nauclea diderrichii De Wild and Thur Merrill Plantation in Forestry Research Institute of Nigeria. *TUW Trends in Science and Technology Journal, 5*(1), 43-47

Semere, M., Cherinet, A. & Gebreyesus, M. (2022). Climate resilient traditional agroforestry systems in Silite district, Southern Ethiopia. *Journal of Forestry Science, 68*: 134-144

Sharma, K.P., Bhatta, S.P., Khatri, G.B., Pajiyar, A., & Joshi, D.K. (2020). Estimation of Carbon stock in the Chir Pine (*Pinus roxburghii Sarg*.) Plantation Forest of Kathmandu Valley, Central Nepal. *Journal of Forestry and Environmental Science, 36*: 37-46

Tamang, M., Chettri, R., Vinneta, J., Shukla, G., Bhat, J.A., Kumar, A., Kumar, M., Suryawanshi, A., Cabral-Pinto, M. & Chakravarty, S. (2021): Stand structure, biomass and carbon storage in Gmelina arborea plantation at agricultural landscape in Foothills of Eastern Himalayas. *Land, 10*(4), 387

Terakumpisut, D. & Amin, M. (2012). Above and below ground carbon stock estimation in tropical rainforest, using allometric functions. *Journal of Forest Science, 58*: 372-379.