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Original Article

Carbon sequestration potentials of selected tree species in University of Maiduguri campus, Maiduguri, Nigeria

OPEN ACCESS

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ABSTRACT

This study evaluated the carbon and carbon dioxide (CO_2) sequestration potential of three species (Eucalyptus camaldulensis, Khaya senegalensis, and Syzygium cumini) at the University of Maiduguri Campus, using systematic random sampling across six transects. Data were collected using non-destructive methods to estimate biomass accumulation and carbon sequestration. Data on diameter, stem height, and age were compared with ANOVA. The annual CO_2 sequestration was correlated with DBH, height, and age. Results revealed significant interspecies variation: Khaya senegalensis sequestered the most carbon (359.69 kg) and CO_2 (1318.70 kg), whereas Syzygium cumini sequestered 94.54kg of carbon and 34.66 kg of CO_2/year as against Eucalyptus camaldulensis, which captured 161.70 kg of carbon and 16.94 kg of CO_2/year. Correlation analysis showed diameter as the strongest predictor of biomass and carbon sequestration, followed by stem height; tree age exhibited no consistent relationship. These findings highlight the critical role of species selection and structural traits in optimizing carbon capture while positioning Khaya senegalensis as a key species for climate mitigation in semi-arid regions. Further investigation into age-related sequestration dynamics is recommended to enhance long-term agroforestry strategies.

KEYWORDS: *Biomass accumulation, Carbon sequestration, Climate change mitigation, Interspecies variations.*

INTRODUCTION

Global warming is an increase in average global temperatures, natural events and human activities are believed to be contributing to the increase in average global temperatures (Singer, 2008). This is caused primarily by increases in greenhouse gases such as Carbon Dioxide (CO_2), leading to climate change which is considered a global threat that needs urgent action from the global community (Nema *et al*., 2012) All countries will be affected by climate change and its impacts, particularly the developing countries (McGuigan *et al*., 2022) Temperature is one of the climate change indicators, According to National Center for Atmospheric Research (NCAR, 2014) which reported that earth's average temperature has risen by 1.4°F (0.72°C) over the past century. They also projected that it will further likely to rise another 2 to 11.5°F over next century.

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Therefore, it is important to understand Carbon cycle, climate change and how climate change can be mitigated.

Ecological society of America (ESA, 2000) reported that Climate change is one of the defining issues of our time, it is now more certain than ever, based on many lines of evidence, that humans are changing Earth's climate. They further documented that the atmosphere and oceans have warmed, which has accompanied by sea level rise, a strong decline in Arctic Sea ice, and other climate-related changes, the impacts such as unprecedented flooding, heat waves, and wildfires have cost billions in damages and are becoming increasingly apparent on people and nature. Habitats are undergoing rapid shifts in response to changing temperatures and precipitation patterns.

Carbon dioxide is the most abundant greenhouse gas which that traps heat in the atmosphere, and consequently rises the atmospheric temperature (El Zein & Chehayeb, 2015). However, as forests grow, the trees store carbon in woody tissues and retain carbon during their lifetime and act as carbon sinks. Growing trees for long-lived products is an effective strategy to help reduce global atmospheric CO_2, because the net sink for carbon in long-lived wood products is still relatively small, (ESA, 2000). According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report of 2007, sequestration and reduction of emissions over the next two to three decades will potentially have a substantial impact on long-term opportunities to stabilize levels of atmospheric CO_2 and mitigate impacts of climate change. Unfortunately, little is been done in this part of the world (Africa) towards reducing the concentration of atmospheric CO_2. Therefore, assessment of carbon sequestration potentiality of some species can be a good move leading to identification of the best carbon storing species so as to be used for the purpose. The study is aim to identify the species with highest carbon and CO_2 sequestration potentials.

MATERIALS AND METHODS

Study Area

The study was carried out in the University of Maiduguri, which is located in Maiduguri the capital city of Borno State, along Bama Road, situated between latitude 11°52' N and 11°84', and longitude 13°09' and 13°16'E, with an average elevation of 320 meters (1,050 ft) above mean sea level. And shares borders with Mairi towards the North-East direction, and opposite to 202 and 303 Housing estate (Baba *et al*., 2024). The area is characterized by two distinct seasons namely; wet and dry seasons. The wet season occurs between June and October with average annual rainfall of 500 – 600mm (20 -24 inches) August is usually the wettest month, with heavy sporadic rain showers while dry season last from November to May with virtually no rainfall during these months. The temperature is high throughout the year, average high temperatures range from 30^0C – 40^0C whereas average low temperatures range from 14^0C – 25^0C where March – May are the hottest months exceeding 40^0C, December and January are relatively cooler, with nighttime temperatures occasionally dropping to around 14^0C (Ghamba *et al*., 2023) The vegetation of the University is an open savannah, characterized by predominantly fewer and dispersed trees, shrubs and predominantly covered by grasses and thus forest formations (Weether.com).

Sampling Procedure and Data collection

Systematic random sampling techniques was used for the study where the academic area of the university was covered, six (6) paths that runs perpendicular to the main roads within the academic area (three from each side) were considered as transects, in each of the transects the first and every fifth of each of the selected species (*Eucalyptus camaldulensis, Khaya senegalensis, and Syzygium cumini*) was marked and measures until twenty (20) samples from each species were obtained.

Height Measurement

Height of the trees was measured using a 20 m Telemetric staff by stretching the scale to the tip of the tree. Some of the trees were found to be taller than the Telemetric staff (>20m) tall. The Telemetric staff was lifted up to reach the tip of the tree and the height of the Telemetric staff was added to the height taken from the ground to the point where the Telemetric staff has been lifted.

Diameter at Breast Height (DBH)

The girth tape was used to measure the DBH by taken the tape round the tree stem at 1.3 meter. The diameter was taken and recorded in centimeters.

Age Determination

Non-destructive method by using core borer was adopted for estimating the age of each selected tree species. The instrument was driven (in clockwise rotation) at a suitable point 1.3m above ground level, the extracted samples were placed carefully on a surface of plane white board for counting of the annual rings as describe by Helama (2015).

Determination of Biomass and Carbon Sequestration

The non-destructive method recommended by Chavan & Rasal, (2010) was employed which comprises of the following stages where diameter, height and age are used as described below:

Total weight (green)

Aboveground biomass: the aboveground biomass (kg) of tree species in the tropical forest is generally: -

$W = 0.25D^2H$ (1) *for trees with Dbh ≤ 10cm and*

$W = 0.15D^2H$ (2) *for trees with Dbh ≥ 10cm,*

Where W= weight in kg, D= diameter at breast height (cm) and H= height in meters.

Belowground biomass: The weight of root system is generally 20% as much as the above-ground weight of the tree. Therefore, the aboveground biomass was multiplied by 120%.

Dry weight: The dry weight of the tree is calculated by multiplying the green weight of the tree by 72.5%.

Weight of carbon: The carbon content is generally 50% of the tree's total volume (DeWald *et al*., 2005). Therefore, the weight of carbon in the tree is calculated by multiplying the dry weight of the tree by 50%.

Weight of carbon dioxide sequestered: CO_2 is composed of one molecule of Carbon and 2 molecules of Oxygen and the atomic weight of Carbon is 12.001115; the atomic weight of Oxygen is 15.9994. Hence,

weight of CO_2 is C + (2 X O) = 43.999915 (3)

while the ratio of CO_2 to C is 43.999915/12.001115 = 3.6663. Therefore, weight of carbon dioxide sequestered in each tree was determined by multiplying the weight of carbon in the tree by 3.6663 (Birdsey, 1992).

Annual CO_2 sequestration: Weight of CO_2 sequestered in the tree per year is calculated by dividing the weight of carbon dioxide sequestered in the tree by the age of the tree.

Data Analysis

Data collected was subjected to analysis of variance (ANOVA) with the help of statistical software, Statistix 8.0. The treatment means was compared using least significant difference (LSD) at 5% probability when F value is significant (Gomez & Gomez, 1984). Correlation coefficients (r- values) and coefficient of determination (R^2-values) were computed using the same statistical software for individual species and combined.

RESULTS AND DISCUSSION

Table 1 compares the mean diameter, height and age of the three studied tree species. Results indicated highly significant (P<0.01) differences among the three species in terms of Dbh and stem height within the three species. Thus, mean diameter and height significantly varied from 24.89 cm – 38.33 cm, and 12.71 m – 23.33 m, respectively. From the results mean diameter for *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 38.33, 24.89 and 26.59 cm. Therefore, stem of *K. senegalensis* was significantly thicker than that of the other two species. However, there is no significant difference in stem diameter between *E. camaldulensis* and *S. cumini*.

In respect of height, means for *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 16.39, 23.33 and 12.71 cm. Consequently, *E. camaldulensis* was significantly taller than *K. senegalensis* and *S. cumini*. However, result did not show significant difference in height between *K. senegalensis* and *S. cumini*. The wider diameter of *K. senegalensis* and taller stem height of the specie might be the reason for accumulating the highest biomass and sequester huge carbon as reported by Streeter *et al*. (2023) which stated that larger trees store substantially more carbon than smaller ones, as tree diameter increases, the aboveground carbon storage also increases disproportionately.

Table 1. Diameter size and stem height of the selected species

Species	Diameter (cm)	Height (m)
Khaya senegalensis	38.33[a]	16.39[b]
Eucalyptus camaldulensis	24.89[b]	23.33[a]
Syzygium cumini	26.59[b]	12.71[c]
Mean	29.933	17.473
SE±	2.6528	0.7026
$LSD_{0.05}$	7.5947	2.0114

Table 2 showed the Biomass accumulation and dry weight of the selected species under assessment. The results showed highly significant (P<0.01) variation among the species. Furthermore, mean aboveground, belowground, total biomass and dry weight ranged from 217.34 – 826 kg, 43.47 – 165.38 kg, 260.80 – 992.25 kg and 189.08 – 719.38 kg, respectively.

From the results, mean aboveground biomass for *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 826.88 kg, 372.21 kg and 217.34 kg respectively. Consequently, aboveground biomass of *K. senegalensis* was significantly higher than that of the other two species. However, there is no significant difference in aboveground biomass between *E. camaldulensis* and *S. cumini*.

In the results mean belowground biomass for *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 165.38 kg, 74.44 kg and 43.47 kg respectively. Therefore, belowground biomass of *K. senegalensis* was also significantly higher than that of the other two species. Similarly, result did not show significant difference in belowground biomass between *E. camaldulensis* and *S. cumini*.

With regards to mean total biomass for *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 992.25 kg, 446.06 kg and 260.80 kg respectively. Moreover, total biomass of *K. senegalensis* was significantly higher than that of the other two species. However, result did not show significant difference in total biomass between *E. camaldulensis* and *S. cumini*.

Results also revealed that mean dry weight for *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 719.38 kg, 323.39 kg and 189.08 kg respectively. Consequently, dry weight of *K. senegalensis* was significantly higher than that of the *E. camaldulensis* and *S. cumini*. However, result did not show significant difference in dry weight between *E. camaldulensis* and *S. cumini*. Possession of significantly highest total biomass and dry weight of *K. senegalensis* could be due to the fast growing characteristics and adaptation of the species to the environment which is buttressed in a statement of Behera *et al*. (2022) that said selection of tree species is vital in maximizing carbon sequestration potential, certain species like *Khaya* *sengalensis* have been identified as effective in absorbing and storing carbon dioxide, making them valuable assets in carbon sequestration initiatives.

Table 2. Biomass accumulation and dry weight of the selected species

Species	Aboveground Biomass (kg)	Belowground biomass (kg)	Total biomass (kg)	Dry weight (kg)
Khaya senegalensis	826.88[a]	165.38[a]	992.25[a]	719.38[a]
Eucalyptus camaldulensis	372.21[b]	74.44[b]	446.06[b]	323.39[b]
Syzygium cumini	217.34[b]	43.47[b]	260.80[b]	189.08[b]
Mean	472.14	94.429	566.37	410.62
SE±	137.27	27.454	164.80	119.48
$LSD_{0.05}$	392.99	78.598	471.81	342.06

Table 3. Compared the Carbon stocking and carbon dioxide sequestration of the selected species. Results showed highly significant (P<0.01) differences among the three species. Thus, mean carbon stocked, carbon dioxide sequestered and carbon dioxide sequestered on annual basis significantly differ from 94.54 – 359.69 kg, 346.62 – 1318.70 kg and 16.94 – 64.92 kg, respectively. In the results the mean carbon stocked for *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 359.69, 161.70 and 94.54 kg respectively. Therefore, *K. senegalensis* was significantly (P<0.01) higher in term of carbon stocking than the other two species. However, result did not show significant difference between *E. camaldulensis* and *S. cumini* in carbon stocking.

Similarly, the total carbon dioxide sequestered by *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 1318.69 kg, 592.83 kg and 346.62 kg respectively. Consequently, the amount of carbon dioxide sequestered by *K. senegalensis* was significantly (P<0.01) higher than that of *E. camaldulensis* and *S. cumini* that are statistically the same.

Likewise, on annual basis carbon dioxide sequestered for *K. senegalensis*, *E. camaldulensis* and *S. cumini* were 64.92 kg, 16.94 kg and 34.66 kg respectively. Therefore, amount of carbon dioxide sequestered by *K. senegalensis* was significantly higher than that of *S. cumini* which also significantly sequester higher than *E. camaldulensis*. Thus, the results showed that the highest sequestering species among the three species is *K. senegalensis* this agree with the findings of Rasika & Thavananthan, (2016), which stated that *K. senegalensis* ranks top in the carbon sequestration capacity due to being a semi-deciduous tree with a dense and expanding canopy with many branches.

Table 3. Carbon stocking and carbon dioxide sequestration of the selected species

Species	Carbon stocked (kg)	CO_2 Sequestered (kg)	CO_2 Sequestered (kg/year)
Khaya senegalensis	359.69[a]	1318.70[a]	64.92[a]
Eucalyptus camaldulensis	161.70[b]	592.83[b]	16.94[c]
Syzygium cumini	94.54[b]	346.62[b]	34.66[b]
Mean	205.31	752.730	38.838
SE±	59.740	219.030	5.792
$LSD_{0.05}$	171.03	627.05	16.583

Table 4 shows the combined correlation coefficient which indicated that only diameter and height has highly significant (P<0.01) and positively correlated with carbon dioxide sequestration per year, whereas Age of the trees has weak negative correlation with the amount of carbon sequestration and annual carbon dioxide sequestration, this agrees with the findings of Donev *et al*. (2021), which indicated that tree diameter might be a better predictor of aboveground biomass compared to height. Whereas, age negatively correlated with the annual carbon dioxide sequestered considering all the species combined, this is also encapsulated in the report of Forster *et al*., (2021), which stated that the rate of carbon accumulation may vary with age, with younger stands showing higher accumulation rates. Consequently, coefficient of determination expressed that diameter, height and age impacted 88.56, 1.35 and 0.00 % respectively to annual carbon sequestration of the three tree species all together.

Table 5 presented the percentage relative contribution of diameter, height and age which is derived from the coefficient of determination of the correlation coefficient. For *K. senegalensis* the relative contribution of diameter, height and age are 36.3%, 33.8% and 29.9% to carbon dioxide sequestration per year. Similarly, *E. camaldulensis* the contribution from diameter and height is 64.8 %, and 35.2 % respectively, however, age did not contribute. In regards to *S. cumini* diameter, height and age gives 77.9%, 22.0% and 0.1 % respectively. For the combined three tree species the percentage contribution was 98.1%, 1.5% and 0.4% for Diameter, height and age respectively.

The relative contribution of diameter at breast height, stem height and Age of the species to the amount of carbon sequestration is in conformity with the work of Hyong *et al*. (2024), which stated that diameter at breast height of trees significantly influences carbon sequestration. Moreover, Kanniah *et al.* (2022), observed that the diameter at breast height of a tree has a leading role in carbon sequestration compared to tree height. In similar view, Mahari *et al.* (2024), reported that diameter at breast height of trees is a critical factor determining their carbon sequestration potential, with larger-diameter trees storing disproportionately more carbon.

The dwindling contribution of age to the amount of carbon each of the species sequestered is agreed with the report of Borovics *et al*. (2023), which opined that carbon stock tend to increase with stand age, followed by a leveling off or slight decline, a pattern commonly observed in various regions.

Table 4. Correlation coefficient and coefficient of determination for carbon dioxide sequestered per year and other parameters for the combine species

	CO_2/year	CO_2	Carbon	Diameter	Height	Age
CO_2/year	-	**0.7276****	**0.7276****	**0.8856****	**0.0135**	**0.0036**
CO_2	0.8530**	-	**1.0000****	**0.9137****	**0.2185****	**0.1477****
Carbon	0.8530**	1.0000**	-	**0.9137****	**0.2158****	**0.1477****
Diameter	0.9410**	0.9559**	0.9559**	-	**0.1044***	**0.0423****
Height	0.1160**	0.4674**	0.4674**	0.3231*	-	**0.7714****
Age	-0.0601	0.3843**	0.3843**	0.2056	0.8783**	-

*Key: Light = correlation coefficient (r - values), and bold = coefficient of determination (R^2- values). ** = highly significant at 1% probability level and *= significant at 5% probability level.*

Table 5. Relative contribution of diameter, height and age to carbon dioxide sequestration per year

Parameters	Coefficient of determination (R^2)	Relative contribution (%)
	Khaya senegalensis	
Diameter	0.9268	36.3
Height	0.8629	33.8
Age	0.7630	29.9
	Eucalyptus camaldulensis	
Diameter	0.9716	64.8
Height	0.5274	35.2
Age	0.0000	0.0
	Syzygium cumini	
Diameter	0.9465	77.9
Height	0.2672	22.0
Age	0.0008	0.1
	Combined	
Diameter	0.8856	98.1
Height	0.0135	1.5
Age	0.0036	0.4

CONCLUSION AND RECOMMENDATION

In the light of increasing fears about climate change, emission of greenhouse gasses is one of today's major concerns. Carbon capture and storage are the options in the reduction of CO_2 emission intensity. Trees are among the most important and common sinks for atmospheric CO_2.

The present study evaluated the carbon sequestration potentials of three popular tree species in Sudan savanna ecological zone. The study revealed that *Khaya senegalensis* capture and sequester more CO_2 than *Syzygium cumini* whereas, *Eucalyptus camaldulensis* is the least among the species. It was also evident from the research that diameter of the trees is the most contributing factors of carbon stocking of trees followed by height, thus, age of trees reduces the potentials of carbon storage and recommend planting of *Khaya senegalensis* and *Syzygium cumini* for fast reduction of atmospheric CO_2.

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Author's Contributions

This study was carried out in collaboration among all authors. Author MI designed the study, performed the statistical analysis and wrote the first draft of the manuscript. AU managed the analyses of the study. MAG was part of reconnaissance survey, data collection and screening and managed the literature searches. All authors read and approved the final manuscript.

Ethical Statement

Not applicable

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