Journal of Scientific Research & Reports

18(2): 1-12, 2018; Article no.JSRR.39457
ISSN: 2320-0227

Carbon Stock Assessment in Majiya Fuelwood Reserve, Sokoto State- Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2018/39457
Editor(s):
(1) Suleyman Korkut, Associate Professor, Department of Forest Industry Engineering, Duzce University, Division of Wood Mechanic and Technology, Turkey.
Reviewers:
(1) Daniel Jaleta, Sokoine University of Agriculture, Tanzania.
(2) Fikir Alemayehu, University of Nairobi, Kenya.
Complete Peer review History: http://www.sciencedomain.org/review-history/23502

Original Research Article

Received 10th December 2017
Accepted 12th February 2018
Published 6th March 2018

ABSTRACT

This research was conducted with a view to assess the carbon stock in Majiya Fuel Reserve in Dange Shuni Local Government Area of Sokoto State. A 150 m line transect was laid at both sides of the reserve and the area was divided into 30 x 30 m plots, of which simple random sampling was used to select 15 plots from each side. A total of 474 trees from 30 randomly selected plots using 5 line transects were used for this study. Detailed measurement of the trees were carried out in terms of merchantable height, diameter at base, diameter at breast height (Dbh), diameter at middle and top in all the selected plots. Stem cores were also taken from 5 randomly selected trees in each selected plot for density estimation. Near the center of each plot, soil samples were collected at three different depths (0-10, 10-20 and 20-30 cm) for soil organic carbon (SOC) estimation. The data collected were used to compute volume and density for aboveground biomass (AGB) estimation and 20% of the AGB was adopted for belowground biomass (BGB) estimation. The AGB was estimated to be 44.58t ha^{-1}, BGB of 8.92t ha^{-1} and SOC of 252.04t ha^{-1} which amounts to a total carbon stock of 305.54t ha^{-1} and the atmospheric CO_2 capture of the reserve was 1121.33t CO_2e ha^{-1}. The result of this study revealed that Majiya Fuel Reserve has a great potential for sequestering atmospheric CO_2 if managed sustainably.

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Keywords: Carbon sequestration; carbon estimation; aboveground and belowground biomass.

1. INTRODUCTION

Tropical forests play an important role in the global carbon cycle [1]. They contain about 40% of global terrestrial carbon, account for more than half of global gross primary productivity, and sequester large amounts of carbon dioxide (CO_2) from the atmosphere [2,3,4]. Carbon is stored in forests predominantly in live biomass and in soils, with smaller amounts in coarse woody debris [5,6]. In tropical forests worldwide, about 50% of the total carbon is stored in aboveground biomass and 50% is stored in the top 1 m of the soil [7].

Carbon sequestration is the process of capture and long-term storage of atmospheric carbon dioxide (CO_2) in the biosphere such as the oceans, terrestrial biomass, soils and geologic formation. Carbon sequestration describes long-term storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change. It is also the capturing of anthropogenic (human) CO_2 from large scale stationary sources like power plants before it is released to the atmosphere. Carbon dioxide is naturally captured from the atmosphere through biological, chemical or physical processes [8].

Most terrestrial carbon storage is in tree trunks, branches, foliage, and roots which is often called biomass. It is believed that the goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests [9].Terrestrial vegetation and soil represent important sources and sinks of atmospheric carbon [10] with land use change accounting for 24% of net annual anthropogenic emission of Greenhouse gases (GHG) to the atmosphere [11].

Forest sequester and store more carbon than any other terrestrial ecosystem and are an important natural "brake" on climate change [12]. The world forest sequester and store more than 650 billion tonnes of carbon, 44% in the biomass, 11% in dead wood and litter and 45% in the soil [13]. Tropical savannas are a major component of the world's vegetation covering one-sixth of the land surface and accounting for 30% of the primary production of all terrestrial vegetation. Africa contain by far the largest areas of savanna, with as much as 50% of African territory [14].

In savannas, world-wide as expected, the above-ground carbon stock vary widely according to the extent of tree cover from 1.8tCha^{-1} where trees are absent, to over 30tCha^{-1} where there is substantial tree cover [15]. Tropical savannas can be remarkably productive, with a net primary productivity that ranges from 1 to 12tCha^{-1}year^{-1}. The lower values are found in the arid and semi-arid savanna occurring in extensive regions of Africa [15].

The carbon stock in the forest vegetation varies according to the geographical location, plant species and age of the stand [16]. Soil C on the other hand, depends upon the above ground input received from leaf litter and on the decomposition of fine roots below ground [17]. In order to assess the impact of deforestation and re-growth rates on the global carbon cycle, it is necessary to know the stocks of carbon as biomass per unit area for different forest types. The above ground biomass (AGB) and below-ground root biomass (BGB) both need to be measured to enable better calculations of total forest carbon [18].

Global climate change is widespread and growing concern that has led to extensive International discussions and negotiations [19] [20]. Responses to this concern have focused on reducing emission of Greenhouse gas (GHG) especially CO_2 on measuring the carbon absorbed by and stored in forest, soils and water [21]. One option for slowing the rise of GHG concentration in the atmosphere and thus possible climate change is to increase the amount of C removed by and stored in the forests [20,22].

A major problem being faced by human society is that the global temperature is believed to be rising due to human activities that releases carbon dioxide (CO_2) to the atmosphere that is, global warming. The major culprit is thought to be fossil fuel burning which is releasing increasing amount of CO_2 in the atmosphere. The problem of increasing CO_2 can be addressed in a number of ways. One of these is forestry and forest management, as forest ecosystem sequester carbon released from fossil fuel burning. Therefore, forest carbon inventories are crucial for combating climate change.

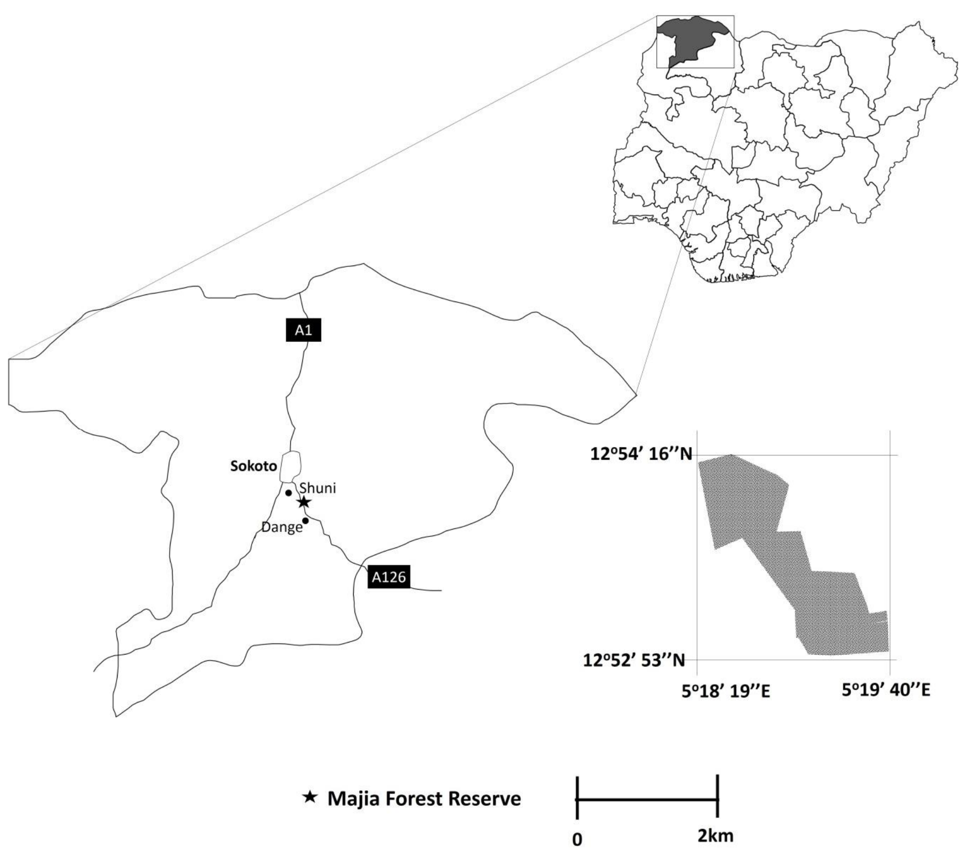
The capacity of forest to serve as a practical means of removing excess carbon from the atmosphere is still relevant today as forest safeguard more carbon in biomass and soils than the entire earth's atmosphere [23]. Therefore, how much is the contribution of Majiya fuel reserve? Reliable and timely information on the state of the forest resources including carbon stock is essential for policy formation and development (carbon trade) as well as for programme planning e.g. REDD (Reducing emissions from deforestation and forest degradation) [24]. The need for suitable data presents a great challenge as information on this particular forest reserve (Majiya) are lacking and even where they exist they are archaic and therefore need to be updated.

Land use changes and forest management activities have high potential to mitigate carbon emission. Forest management offers one of important options for mitigating carbon emissions [7,25,26,27]. Terrestrial ecosystems especially forest vegetation have the greatest potential for mitigating atmospheric CO_2 emissions through conservation and management [9,28,29]. Also measuring the impact of long and short term storage capacity of forest to sequester CO_2 would allow for development of informed policies aimed at reducing net CO_2 emissions. Also monitoring of changes in soil carbon stock is a topical challenge due to the current requirements to report the carbon balance of forests. The research therefore, signifies the role of forest in mitigating global warming and climate change by storing carbon in tree biomass.

2. MATERIALS AND METHODS

2.1 Study Area

Majiya is a plantation located along the side ways of the west and east of the road from Sokoto to Gusau precisely at Inya area. It lies between the latitudes $12^0 52'53''$ and $12^0 54'16''$N and longitudes $5^0 18'19''$ and $5^0 19'40''$E. The reserve covers an area of 252ha [30].



Map 1. Map showing Majiya Fuelwood Reserve

The area falls within the Sudan savannah zone. It has about 70 - 125 days of rainy season [31]. Temperatures are variable during the dry and rainy seasons with minimum temperature between 10 and 23°C and the maximum between 33 and 45°C. The mean maximum ranges from 35 - 37°C. Relative humidity is between 52 - 56% [31].

It is characterized by alternating rainy and dry seasons. The mean annual rainfall is 700 mm per annum. Rainfall is short and erratic, falling between the months of June and September with an altitude of 350 m above sea level [31]. Sokoto has two main seasons; the dry season which lasts from October to May/June, and the rainy season that lasts from June to September/ October. The harmattan season stretches from November to March, which is dry and dust laden wind [31].

2.2 Sampling and Data Collection

A 150 m line transect was laid at either sides of the plantation. The area was divided into 30 X 30 m plots, of which simple random sampling was used to select 15 plots from each side of the area making a total of 5 line transect.

Measurement of tree variables was carried out in each of the selected plots. Dbh and diameter at base were measured using girth diameter tape at 1.3m and 0.45m above ground level, respectively (in cm). Merchantable height measured using Spiegel relaskop (in meters). The middle and upper diameter were measured using Spiegel relaskop (in cm).

2.3 Stem Core Sampling

Five trees were randomly selected from each plot for the estimation of wood density [i.e. dry weight (DW) and wet volume] this was estimated using dimensional method [32]. Cores were taken at breast height to determine the volume, then oven dried at 70^0C to a constant weight.

2.4 Soil Sampling

Soil samples were collected using the default depth prescribed by [33]. Near the center of all plots, a micro pit of 30 cm depth was dug. For the purpose of determining bulk density, three individual soil samples, one each from the three depths (0-10 cm, 10-20 cm and 20-30 cm) was collected by using a 150.57 cm^3 steel core sampler and were transferred to a pre-weighed sampling bags. Wet weight of the soil was determined in the field with 0.1g precision. Soils were taken to the laboratory and oven dried at 70^0C until a constant weight was achieved to determine the moisture content. In each plot, samples collected from each of the three depths were composited and well mixed by removing stones, plant residues >2 mm, crushed and sieved for carbon stock estimation [34].

2.5 Data Analysis

Data collected were subjected to screening to ensure biological validity and to remove outliers before running analysis. Descriptive statistics was used to summarize and group the data into different diameter and height classes. R statistical package was used for the analysis.

2.6 Biomass Estimation

Aboveground Biomass (AGB) and Belowground Biomass (BGB) were used for biomass estimation.

2.7 Aboveground Biomass Estimation

The AGB was estimated using the following:

$$ABG = Volume\ of\ tree\ * Wood\ Density$$

The volume of tree was estimated using Newton's formula

$$V = H\frac{\pi}{24}(D_b^2 + 4D_m^2 + D_t^2)$$

Where V = Merchantable volume; H = tree height; Db, Dm and Dt are diameters at base, middle and top of the trees respectively. Also, the wood density was estimated using the following expression

$$\text{Density} = \frac{\text{dry weight}}{\text{fresh volume}}$$

The biomass of all sampled trees in all the sample plots were calculated and extrapolated for the total area (t ha^{-1}). The biomass estimated was divided by 2, as it is universally assumed that the carbon is approximately half of biomass (i.e. when all the moisture content is removed).

2.8 Belowground Biomass Estimation (BGB)

The belowground biomass was estimated using the root: shoot ratio of 0.20 as recommended by [35].

$$\text{Belowground biomass } (\text{t ha}^{-1}) = 0.20 \times \text{aboveground biomass } (\text{t ha}^{-1})$$

2.9 Soil Organic Carbon (SOC)

To accurately obtain the inventory of organic carbon stocks in the soil, three types of variables were measured. The soil depth, soil bulk density and concentration of organic carbon (%C), as recommended by [36,37].

Soil bulk density was computed as the ratio of oven dry weight to soil core volume (150.57cm^3)

$$\text{Bulk density } (\text{gcm}^{-3}) = \frac{\text{oven dry weight of soil}}{\text{volume of the soil corer}}$$

$$\text{SOC } (\text{t ha}^{-1}) = \rho \times d \times \%C$$

Where SOC = soil organic carbon stock per unit area (t ha^{-1})
ρ = soil bulk density (gcm^{-3})
d = total depth at which sample was collected (cm)
%C = carbon concentration (%)

2.10 Total Carbon Stock

The total carbon stock density was calculated by summing all the carbon stock densities of all the individual carbon pools as follows:

$$TCS = C(AGB) + C(BGB) + SOC$$

Where TCS = total carbon stock
C(AGB) = carbon in aboveground biomass (tCha^{-1})
C(BGB) = carbon in belowground biomass (tCha^{-1})
SOC = soil organic carbon (tCha^{-1})

The total carbon stock was converted to tonnes of CO_2 equivalent (tCO_2-e ha^{-1}) values by multiplying it by 44/12 or 3.67 [36]. Which is used as standard for reporting carbon stock estimates in the carbon market.

2.11 Summary Statistics

The data used were carefully obtained from the field and parameters computed were also summarized.

3. RESULTS AND DISCUSSION

The mean, minimum and maximum values, standard deviation and standard error of the variables are also presented in Table 1. The highest contribution of carbon to the total C stock was from the soil (82.49%) and least contribution was from the BGB of 8.92 t ha^{-1} (2.92%). However, the total biomass carbon stock (AGB and BGB) was estimated to be 53.5 t ha^{-1} (Table 2).

3.1 Aboveground, Belowground Biomass and Carbon Stock in the Reserve

The lower AGB recorded in this study was as a result of improper management and silvicultural practices in the reserve. The anthropogenic activities taking place in the reserve, tend to reduce the number of trees thereby decreasing the rate of carbon sequestration and storage. The AGB value in this study is higher than the value (40.5 t ha^{-1}) reported by [38] in the mangrove ecosystem of Rufiji River Delta, Rufiji District in Tanzania. This is also comparable to the result obtained (44.73t ha^{-1}) by [39] in their study on the total sequestered carbon in the AGB and BGB of *Mangifera indica* in Aurangabad city. The AGB estimated in this study falls within the ranges (0.74-203t ha^{-1}) reported by [40]. [41] reported AGB ranging from 18.27-21.92t ha^{-1} (9.13-10.96tC ha^{-1}) in a study that estimated the carbon stock and rate of sequestration in a tropical deciduous forest dominated by *Dipterocapus tuberculatus* in Manipur, north east India which is lower than the value obtained in the current study.

The BGB of Majiya fuel reserve was estimated to be 8.92t ha^{-1} (4.46tC ha^{-1}). The BGB is dependent on the AGB and as BGB is said to be 20% of the AGB [35]. However, the lower value of BGB recorded in this study may be as a result of the lower value obtained from the AGB. In most forest disturbance, it is the AGB that is mostly affected and as a result affecting the BGB. This result falls within the ranges estimated by [40] of 0.10-18.55t ha^{-1} and much lower than the value (21.08t ha^{-1}) estimated by [38]. [39] estimated BGB of 11.63t ha^{-1} which is a bit higher than the result obtained in this study and lower when compared with the result of [42] of 909.69tC.

The result of the current study obtained an estimate SOC value of 252.04t ha^{-1} at 0-30cm depth. [40] estimated SOC at 0-30cm depth with values that ranged from 120.73-156.78t ha^{-1} which is lower than the value (252.04 t ha^{-1}) obtained in the current study. The result in this study is also higher when compared to the

Table 1. Summary statistics

Variables	Mean	Min	Max	SD	SEM
Db	36.9	11.1	93.3	12.6	0.58
Dbh	26.6	10.2	59.5	7.5	0.34
Dm	23.1	10.0	60.0	6.1	0.28
Dt	18.5	7.5	52.5	5.0	0.23
MH	4.1	1.3	7.5	1.2	0.60
Volume	0.2442	0.0146	1.5297	0.1837	0.01
BA	0.060	0.008	0.278	0.037	0.02
Biomass	0.254	0.015	1.591	0.191	0.09
Carbon	0.127	0.008	0.796	0.096	0.00

results obtained by [43] at 1m depth (168.15t ha^{-1}) and [38] at 60m depth (98.57t ha^{-1}) this might be as a result of the differences in depth used. SOC tends to decrease with increasing depth. The result in this study was also higher than what was obtained by [44] for Oak and Pine forest of 60.82 and 46.12Mg C ha^{-1} respectively. [45] reported carbon sequestration in the soils under different plantations in Haryana State, India at 0-30 cm depth, and the result obtained for the different species used in their study in a mixed plantations are lower than the result obtained in this study.

As stated by [17], the amount of carbon in the soil depends on the AGB input received from leaf litter and the decomposition of fine roots belowground. As it was observed in this study, the forest reserve is under serious deforestation activities that have direct impact on the AGB and consequently on the carbon sequestration potentials of the soil.

Table 2. Carbon stock in Majiya fuel reserve

Variables	Estimated carbon stock
Average AGB (t/ha)	4.01
Average BGB (t/ha)	0.80
Average SOC (t/ha)	22.69
Total AGB (t/ha)	44.58 (14.59%)
Total BGB (t/ha)	8.92 (2.92%)
Total SOC (t/ha)	252.04 (82.49%)
Total carbon stock(t/ha)	305.54

3.2 Volume, Biomass and Carbon at different Dbh and Height Classes

Form the result of volume, biomass and carbon storage capacity at different Dbh and height classes (Tables 3 and 4). It shows that trees that are bigger in size and height produce more volume, biomass as well as in their carbon storage when compared with those with lower diameter and height class. This further confirms the biological validity of the results as trees tapers from bottom to top, as such the larger and taller a tree is the higher the volume content will be.

3.3 Biomass Accumulation and Carbon Storage Distribution at Different Diameter Classes

The result revealed that the biomass and carbon distribution in the reserve at diameter classes tend to be more concentrated and more consistent at lower diameter classes (12.5-33cm) (Figs. 1 and 2). With biomass accumulation of 0.1- 0.9t ha^{-1} and carbon storage of 0.05- 0.45 as carbon is assumed to be half of biomass. The trees were more evenly distributed as they increase in their sizes (diameter). The biomass accumulation and carbon storage at diameter >33cm ranges from 0.7- 1.6t ha^{-1} and 0.35- 0.8 t ha^{-1} respectively. The concentration and the consistency at the lower classes was because they were more in number when compared with the higher classes. However as they grow bigger, there are more competition and they tends to occupy more space. It was stated by [46] that old growth and large trees are important C stock but they play minor role in additional C accumulation. However, most C accumulation occur in young stands and also small trees contributes as much to change in live tree carbon stock within stands as do large trees i.e. young trees rapidly accumulates biomass than older ones [46].

3.4 Biomass Accumulation and Carbon Distribution at Different Height Classes

The biomass accumulation/carbon storage tends to be more consistent at lower height classes (1.5 - 5.5 m) and more scattered as the trees grow taller (> 5.5 m). The tree with the highest biomass/carbon storage falls within the height

Table 3. Volume, biomass and carbon by Dbh class

Dbh Class (cm)	Volume (m^3)	Biomass (t)	Carbon(tC)
10-15	0.0392	0.0408	0.0204
16-20	0.0858	0.0892	0.0446
21-25	0.1628	0.1693	0.0847
26-30	0.2705	0.2813	0.1407
31-35	0.4063	0.4226	0.2113
36-40	0.4884	0.5080	0.2540
41-45	0.5438	0.5656	0.2828
46-50	0.7060	0.7343	0.3672
51-55	0.7456	0.7755	0.3878
56-60	1.2723	1.3234	0.6617

Table 4. Volume, biomass and carbon by height class

Height Class (m)	Volume (m^3)	Biomass (t)	Carbon (tC)
1-2	0.0651	0.0677	0.0339
3-4	0.2044	0.2126	0.1063
5-6	0.3946	0.4104	0.2052
7-8	0.7644	0.7950	0.3975

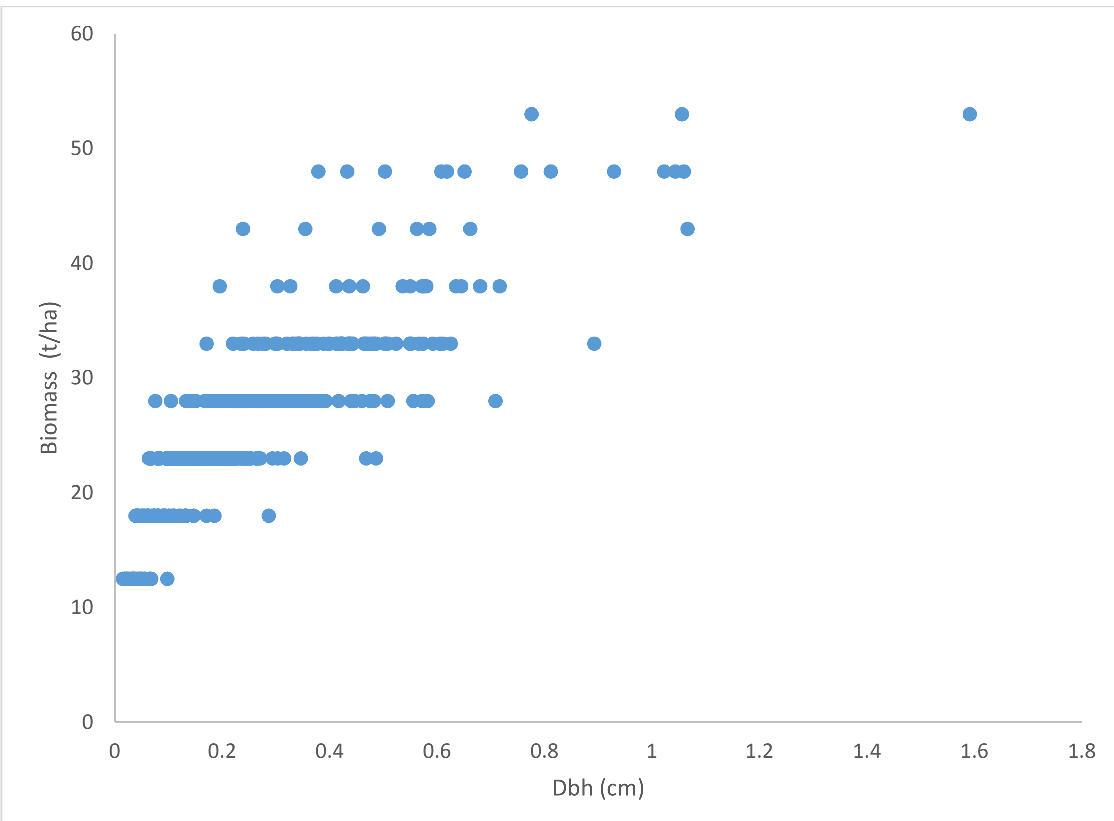


Fig. 1. Biomass accumulation at different diameter classes in Majiya fuel reserve

class of midpoint 5.5 m and the biomass accumulation and carbon storage was 1.6t ha^{-1} and 0.8tC ha^{-1} respectively. The accumulation of biomass and carbon storage with height classes were inconsistent, which might be as a result of the deforestation activities observed in the reserve. The human activities in the reserve tend to affect the height of the trees when trees are cut indiscriminately without giving consideration for proper cutting height (Figs. 3 and 4).

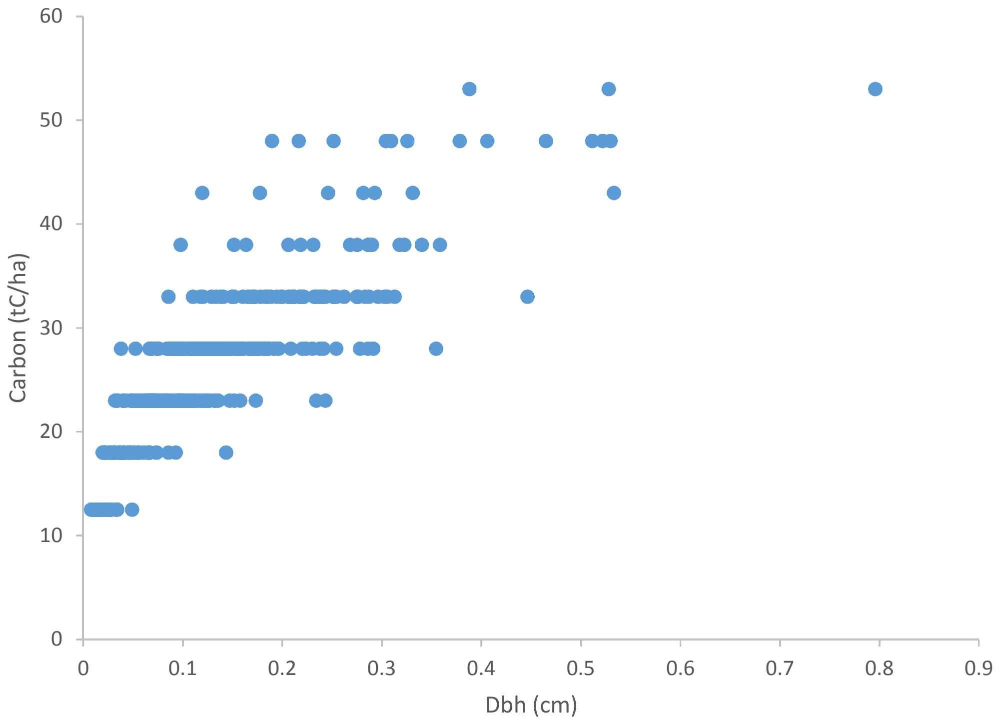


Fig. 2. Carbon storage at different diameter classes in Majiya fuel reserve

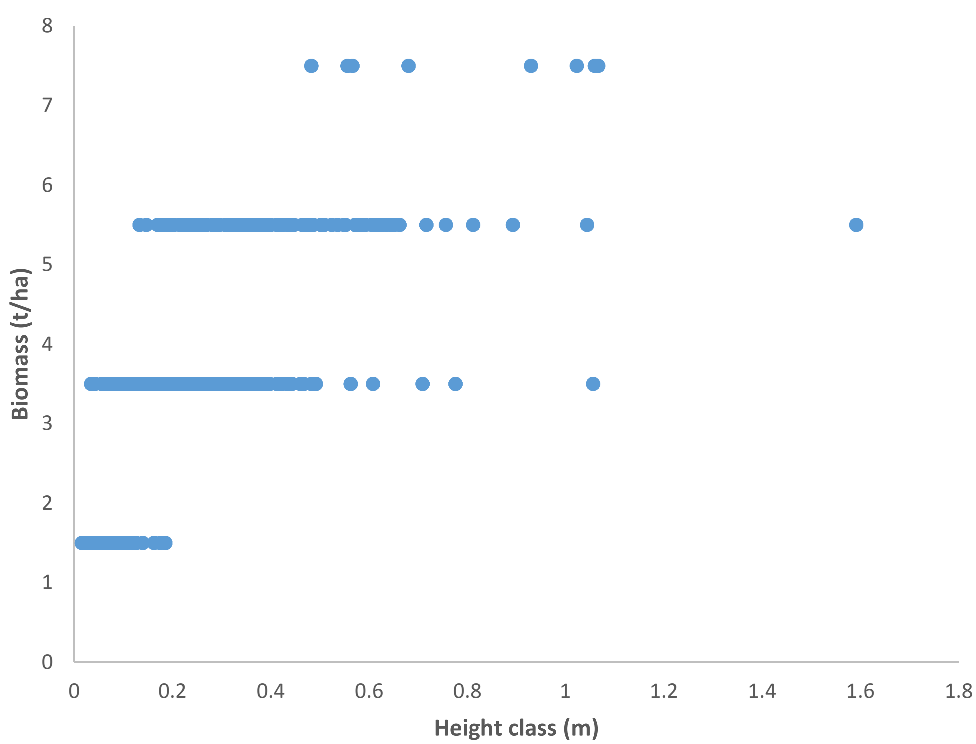


Fig. 3. Biomass accumulation at different height classes in Majiya fuel reserve

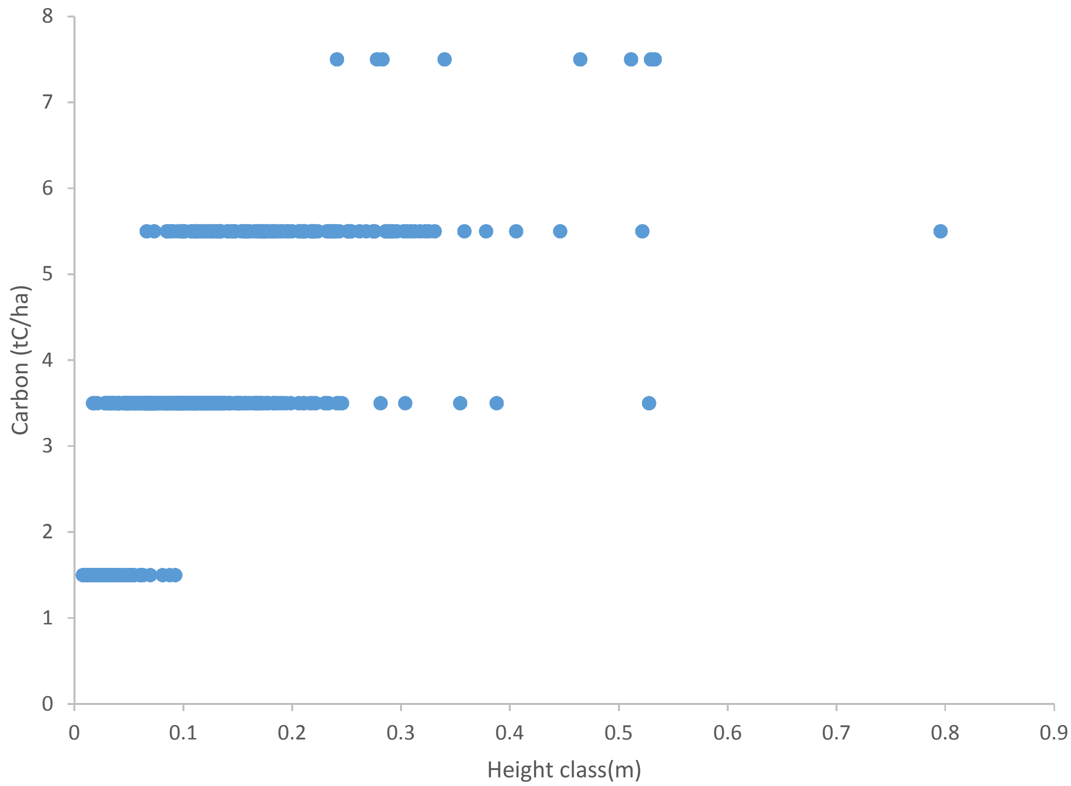


Fig. 4. Carbon storage at different height classes in Majiya fuel reserve

4. CONCLUSION

The result of this study revealed that Majiya Fuel Reserve has a great potential for carbon sequestration. The reserve has a total carbon stock of 305.54t ha^{-1} with soil carbon pool having the highest carbon sequester of 252.04t ha^{-1} and BGB having the lowest carbon sequester of 8.92t ha^{-1}. Sustainable management of the reserve is of high importance as this can significantly enhance carbon storage and also help in the mitigation of climate change through the avoidance of deforestation which will go long way to increasing the aboveground biomass of the reserve as well as the increase in the rate of carbon storage. Other carbon pools such as the dead wood and forest floor (leaf litter) should be included in the assessment of C stock in Majiya Fuelwood Reserve in further researches in other to assess the full potential of this reserve. Government intervention is also of great importance in reducing anthropogenic activities such as deforestation in this plantation. More plantations should be established and retained for a longer period of time as that will be helpful in reducing atmospheric CO_2 concentration as exemplified by the Majiya Fuelwood Reserve.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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DOI: 10.1002/ecs2.1224

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/23502