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Aboveground carbon storage in *Adansonia digitata* L. (Baobab) in Mkanana agroforestry and Mangalisa forest reserve in Mpwapwa District, Tanzania

Nyatwere Donasian Mganga[1*], Khamis Yusuph[1]

[1]*Department of Biology, University of Dodoma, Dodoma, TANZANIA*
**Corresponding Author: nyatwere2@yahoo.com, Tel+255262310005*
ORCID iDs: https://orcid.org/0000-0001-5628-4063 (Nyatwere); https://orcid.org/0000-0003-0460-9254 (Khamis)

Abstract

Woodlands are important sinks for the ever increasing levels of atmospheric carbon dioxide, which is directly linked to climate change. Baobab (*Adansonia digitata* L.) is among the vascular tree species with a long lifespan of 1250 years thus potential for carbon storage though inadequately studied. This study therefore aimed to account for aboveground biomass and carbon in an agroforestry of Mkanana village (with baobabs and sunflower) and Mangalisa forest reserve in Mpwawa District. The allometric model developed for baobabs in dry areas was used for estimation of biomass which was computed as 50% carbon. The mean aboveground biomass of baobabs of 6.952 ± 0.09546 tonnes/tree in Mangalisa forest reserve was higher than 5.538 ± 0.3064 tonnes/tree recorded in Mkanana agroforestry (Mann-Whitney U-Statistic = 94.000, U’ = 531.00, P < 0.0001). On the other hand, the mean aboveground carbon of 3.476 ± 0.09546 tonnes/tree in Mangalisa forest reserve was significantly higher than 2.769 ± 0.1533 tonnes/tree recorded in Mkanana agroforestry (Mann-Whitney U-Statistic = 93.000, U’ = 532.00, P < 0.0001). The results of this study positively contribute to vegetation carbon storage. Sustainable carbon storage in baobabs can be achieved by planting them in reserve areas rather than in agroforestry.

Keywords: Adansonia digitata, arid, baobab, biomass, carbon, Mpwapwa, semi-arid

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1. Introduction

Adansonia digitata L. (baobab) is an indigenous plant in arid and semi-arid regions of mainland Africa (Patrut *et al*., 2015). Baobab is among the plant species that are commonly called orphan plants because of receiving little attention in international marketing of their products (Assogbadjo *et al*., 2021). It is a deciduous tree, growing up to 20 or 30 m tall, with a diameter ranging between 2 and 10 m at maturity (Rahul *et al*., 2015). The bark of baobab is smooth, reddish brown to grey, soft with longitudinal fibres. The lateral root system of the plant can extend 50 m from the trunk, but the main root particularly in mature plant hardly goes beyond 2 m depth (Rahul *et al*., 2015). The baobabs grow as solitary individuals, though sometimes they form small groups depending on the nature of underlying soil properties (Johansson, 1999). These plants are found in sandy soil with low nutrient levels, which is mostly found in arid and semi-arid areas (Salim *et al*., 2012).

The importance of baobab cannot be overemphasized; for example, the plant is useful in sequestration of carbon, production of medicine, fibres, fruits, vegetable; as well as the main habitat of bats (Lisao *et al*., 2009; Kamatou *et al*., 2011). Baobabs are reportedly tolerant to drought conditions by being able to store high amounts of water (Van Den Bilcke, 2013). This tolerance is aided by the thick fire-resistant bark, shedding of leaves and ability of tree trunk to absorb water during the rainy season and shrinking during the dry season. But nowadays baobabs are reported to be threatened by climate change, wild animals and land clearance for agriculture (Dai, 2013; Birhane *et al*., 2020). Climate change is a long-term shift in weather patterns such as temperature which is caused by atmospheric warming due to locking in of greenhouse gases such as carbon dioxide, chlorofluorocarbons (CFCs), methane and dinitrogen oxide. For example, the expected changes in temperature for the next 30 - 50 years will be in the range of 2 – 3°C (Intergovernmental Panel on Climate Change (IPCC), 2007). Climate change has direct influence on the ecosystems, economy, water resources and sea level rise (IPCC), 2001). In arid and semi-arid regions rainfall has been reported as the main climatic factor influencing the distribution of vegetation particularly baobabs (Msalilwa *et al*., 2020a).

Of the greenhouse gases, elevated levels of carbon dioxide are responsible to more than half of the atmospheric warming (Mwandosya, 1999; IPCC, 2018). The gas exists in the earth's atmosphere primarily as one of the raw materials for synthesis of food in green plants such as baobabs. The food synthesized through photosynthesis is sequestered and stored in different parts. Before natural and artificial disturbances of the globe there was a fairly balance between the uptake of CO_2 and its release back to the atmosphere (Joos and Spahni, 2008). However, drought condition which is mainly associated with climate change and deforestation have negatively influenced fixation of CO_2 in plants (Wu *et al*., 2022). Elevated levels of CO_2 lower photosynthetic activities, biomass accumulation (Zheng *et al*., 2018) and hence carbon storage. Forest biomass stores over 45% of terrestrial carbon stocks, with about 70% and 30% contained within the above and belowground, respectively (Mokany *et al*., 2006).

In the tropics forests cover 1.73 billion hectares which is nearly half of the total land (Poker *et al*., 2016) and carbon storage in this area is approximately 1.3 Pg (Lewis *et al.*, 2009; Lung and Espira, 2015). Yet, tropical forests are cleared at an approximate rate of 15 – 17 M ha/year (Naveenkumar *et al*., 2017). If mitigation measures are not carried out, the carbon sink of ecosystems will gradually decline while emissions of greenhouse gases increasing; consequently promoting extreme climatic events. It should also be noted that different plant species differ in their capacities to sequester and store carbon. To precisely account for carbon storage in plants, allometric models have been developed which are both general and species specific (Malimbwi *et al*., 2016). Reliable data on estimation of carbon stock in vegetation are normally obtained when using species specific models (Munishi and Shear, 2004; Malimbwi *et al*., 2005).

In Tanzania baobabs are found in Dodoma, Iringa, Lindi, Morogoro, Singida, Tabora, Manyara, Kilimanjaro, Simiyu and Shinyanga regions (Coates-Palgrave, 1983). Mpwapwa District of Dodoma Region has a higher number of baobab trees (Ministry of Transport, 2016). However, anthropogenic disturbance such as harvesting of vegetable, barks and fruits from baobabs is reported in this area (Ernest *et al.,* 2018). Disturbance on baobabs in semiarid areas of the central part of Tanzania (Mpwapwa inclusive) was depicted by a few big sized trees (Msalilwa *et al*., 2020b; BirdLife International, 2022). This situation is likely to affect the accumulation of biomass hence carbon stock in that area. Literature recommends on agroforestry system as a way of restoring baobabs in arid and semiarid areas (Msalilwa *et al*., 2020b). By consideration that the potential of biomass accumulation in agroforests is species specific (Kimaro *et al*., 2009), there is a need to compare the stock of carbon in baobabs in both agroforestry and forest reserve. On top, there are limited studies on biomass accumulation in baobab trees (Masota *et al*., 2018) despite their long life span of 1250 years through radiocarbon dating (Patrut *et al*., 2007).

In Tanzania agroforestry systems date back to mid 1980's under the International Council for Research in Agroforestry (ICRAF). Agroforestry was seen as a means of climate change adaptation and mitigation. There were massive deforestations in many parts of the country, which necessitated rehabilitation of the land for sustainable agriculture production. Currently there are tens of thousands of farms under agroforestry schemes. In Mpwapwa District agroforestry is conducted by the International Small Group and Tree Plant Programme in partnership with One Tree Planted. The activities conducted involve intercropping of trees and crops such as sunflower, maize, millet and groundnuts. It is reported that since the inception of agroforestry agricultural production has increased (Afr100 (The African Forest Landscape Restoration Initiative, 2019). We do not know if carbon is well sequestered in the trees and crops, or one is flourishing under the expense of the other.

With these views in mind, this study aimed to determine the aboveground carbon stock in baobab trees in Mkanana village agroforestry and Mangalisa forest reserve of Mpwapwa District.

2. Materials and methods

2.1 Study area

This study was carried out in Mpwapwa District which is one of the seven districts of Dodoma Region in the central part of Tanzania. Mpwapwa is 120 km away from Dodoma City. The district is located between latitudes 6º 00'' and 7º 00'' S and longitudes 35º 45'' and 37º 00'' E. The district is reasonably arid with total rainfall of 753.5 mm and temperature range of 17ºC and 29ºC (Myeya, 2021). According to the 2012 National Census, the population of Mpwapwa District was 305,056 people (National Bureau of Statistics, 2013). Most residents in Mpwapwa District live on the central plateau at about 3,500 ft above sea level, though others live at top of the 7,000 ft mountain that benefit from better rainfall. Vegetation of Mpwapwa region was once characterised by open *Acacia spirocarpa* woodland, semi-arid deciduous woodland, *Combretum* belt and descending miombo woodland (Gillman, 1943). Economic activities conducted in Mpwapwa District include farming, livestock keeping and business (Ernest *et al*., 2018). Yet reports on forest disturbance are heard from Mpwapwa District signifying the need to compare carbon storage in Mkanana agroforestry (with baobabs and sunflower) and Mangalisa forest reserve (Figure 1). Mkanana agroforestry is 8 km from Mangalisa forest reserve.

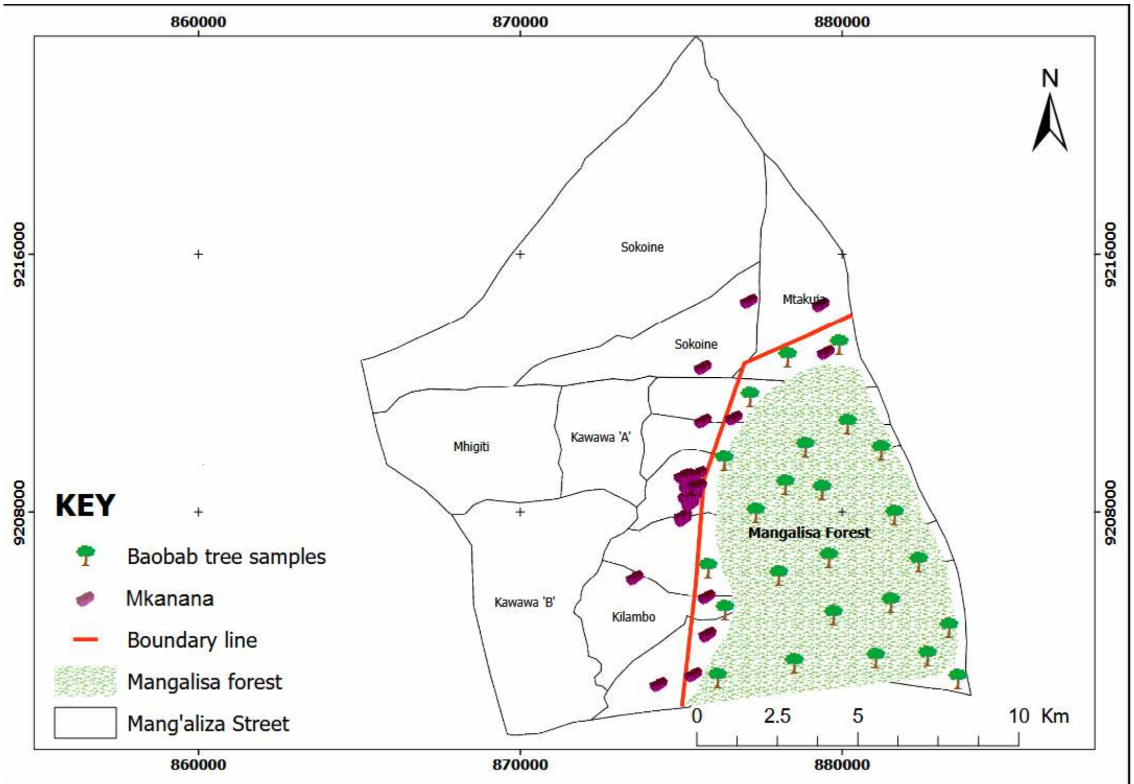

Figure 1: Location of the study areas in Mpwapwa District
Source: Field work

2.2 Research design and data collection

In each of Mkanana agroforestry and Mangalisa forest reserve twenty five baobab trees were sampled. No plots were established in the two areas based on the solitary nature of the plant (Johansson, 1999; Romero *et al*., 2001). In each area sampling was restricted to an area of 25,000 m^2 (2.5 ha). In Mangalisa forest reserve the sampling intensity was 0.05% based on its area coverage of 4988 ha. In Mkanana agroforestry a comparable area was used for sampling. Financial status, time limitation and purpose of the forest stocking may warranty the sampling intensity to be as low as 0.01% (Malimbwi *et al*., 2005). In each site diameter at breast height (DBH) of 25 baobab trees was measured using a diameter tape (Appendix 1).

3. Data analysis

Aboveground carbon stock of baobab trees was estimated using the aboveground allometric model developed for baobabs in arid and semi-arid regions (Masota *et al*., 2018):

$$B = 2.234966 \times DBH^{1.43543} \qquad (1)$$

where:

B is the Aboveground biomass of baobab trees (kg)
DBH is the Diameter at breast height (cm)

This formula is recommended for use in dry areas like Mpwapwa and for trees with DBH ranging from 31 – 318 cm. Also, the use of DBH as the only predictor variable is recommended due to complications of estimating total heights given the rounded crowns of baobab trees (Masota *et al*., 2018). Then, carbon per tree (kg) was estimated as 50% of the biomass (Munishi and Shear, 2004). The total aboveground biomass and carbon (in tonnes) of baobab trees in each site was divided by the area sampled to give biomass and carbon density (Munyebvu, 2015).

The aboveground biomass and carbon stock in agroforestry of Mkanana village (baobabs and sunflower) and Mangalisa forest reserve was analysed using instant software. Mann-Whitney test was used to compare aboveground biomass in the two areas.

Likewise, carbon stock in the agroforestry and reserve forest areas was assessed by Mann-Whitney test due to non-parametric nature of the data.

4. Results

4.1 Diameter at Breast Height (DBH) of Adansonia digitata L. *(baobab) trees in the study area*

In an agroforestry of Mkanana village and Mangalisa forest reserve the mean DBH (cm) of baobab trees was 228.868 ± 10.092, ranging from 51.00 to 284.40, and 271.056 ± 2.60, ranging between 245.90 and 293, respectively (Table 1 and Table 2).

Table 1. Biomass and carbon stock of baobab trees in agroforestry of Mkanana village agroforestry in Mpwapwa District

Tree No.	DBH (cm)	Biomass (kg)	Biomass (tonnes/tree)	Carbon stock (kg/tree)	Carbon stock (tonnes/tree)
01	273.9	7050.67	7.05	3525.33	3.53
02	139.8	2685.57	2.69	1342.78	1.34
03	232.8	5583.62	5.58	2791.81	2.79
04	237.9	5759.88	5.76	2879.94	2.88
05	253.8	6321.26	6.32	3160.63	3.16
06	225.8	5344.00	5.34	2672.00	2.67
07	212.7	4906.05	4.91	2453.03	2.45
08	51.0	630.70	0.63	315.35	0.32
09	210.8	4842.92	4.84	2421.46	2.42
10	259.9	6538.69	6.54	3269.34	3.27
11	156.7	3162.94	3.16	1581.47	1.58
12	222.0	5214.65	5.21	2607.32	2.61
13	212.7	4906.05	4.91	2453.03	2.45
14	218.8	5107.59	5.11	2553.79	2.55
15	265.9	6758.33	6.76	3379.17	3.38
16	276.8	7156.82	7.16	3578.41	3.58
17	282.8	7382.50	7.38	3691.25	3.69
18	236.0	5693.59	5.69	2846.80	2.85
19	248.7	6139.90	6.14	3069.95	3.07
20	251.3	6230.38	6.23	3115.19	3.12
21	252.2	6264.41	6.26	3132.21	3.13
22	284.4	7442.24	7.44	3721.12	3.72
23	227.1	5387.33	5.39	2693.66	2.69
24	243.6	5960.15	5.96	2980.08	2.98
25	244.3	5982.53	5.98	2991.27	2.99

Table 2. Biomass and carbon stock of baobab trees in Mangalisa forest reserve in Mpwapwa District

Tree No.	DBH (cm)	Biomass (kg/tree)	Biomass (tonnes/tree)	Carbon stock (kg/tree)	Carbon stock (tonnes/tree)
01	268.9	6867.81	6.87	3433.91	3.43
02	290.4	7670.59	7.67	3835.29	3.84
03	261.8	6607.81	6.61	3303.91	3.30
04	276.8	7156.82	7.16	3578.41	3.58
05	281.8	7346.73	7.35	3673.36	3.67
06	248.7	6139.90	6.14	3069.95	3.07
07	251.9	6253.06	6.25	3126.53	3.13
08	262.7	6642.46	6.64	3321.23	3.32
09	281.8	7346.73	7.35	3673.36	3.67
10	293.0	7767.36	7.77	3883.68	3.88
11	273.9	7050.67	7.05	3525.33	3.53
12	261.8	6607.81	6.61	3303.91	3.30
13	258.3	6481.25	6.48	3240.63	3.24
14	245.9	6038.59	6.04	3019.30	3.02
15	286.0	7502.13	7.50	3751.07	3.75

Table 2 (cont'd). Biomass and carbon stock of baobab trees in Mangalisa forest reserve in Mpwapwa District

Tree No.	DBH (cm)	Biomass (kg/tree)	Biomass (tonnes/tree)	Carbon stock (kg/tree)	Carbon stock (tonnes/tree)
16	277.7	7192.32	7.19	3596.16	3.60
17	258.9	6504.21	6.50	3252.10	3.25
18	270.4	6921.58	6.92	3460.79	3.46
19	271.0	6945.00	6.95	3472.50	3.47
20	274.5	7074.22	7.07	3537.11	3.54
21	257.3	6446.87	6.45	3223.43	3.22
22	278.3	7216.01	7.22	3608.00	3.61
23	284.1	7430.28	7.43	3715.14	3.72
24	277.7	7192.32	7.19	3596.16	3.60
25	282.8	7382.50	7.38	3691.25	3.69

4.2 Aboveground biomass and carbon of Adansonia digitata L. *(baobab) in the study area*

The mean aboveground biomass (tonnes/tree) of the separately studied 25 baobab trees in agroforestry of Mkanana village and Mangalisa reserve forest was 5.538 ± 0.3064 and 6.952 ± 0.09546, ranging between 0.63 and 7.44 and, 6.04 and 7.77, respectively (Table 1 and Table 2). Mann-Whitney test showed that the aboveground biomass of baobab trees in Mangalisa forest reserve was significantly higher than that obtained in agroforestry of Mkanana village (Mann-Whitney U-Statistic = 94.000, U' = 531.00, $P < 0.0001$).

Furthermore, in agroforestry of Mkanana village and Mangalisa reserve forest the mean aboveground carbon (tonnes/tree) was 2.769 ± 0.1533 and 3.476 ± 0.09546, ranging between 0.320 – 3.720 and 3.020 – 3.880, respectively (Tables 1 and 2). Mann-Whitney test showed that the aboveground carbon of baobab trees in Mangalisa reserve forest was significantly higher than that in agroforestry of Mkanana village (Mann-Whitney U-Statistic = 93.000, U' = 532.00, $P < 0.0001$).

By considering 25 trees that were sampled in each site and area coverage the density of carbon in Mkanana village agroforestry was 27.69 tonnes ha^- and 34.78 tonnes ha^- in Mangalisa forest reserve.

5. Discussion

The DBH values of baobabs were higher in Mangalisa forest reserve than Mkanana village agroforestry. This suggests limited lateral growth of baobabs in the agroforestry due to competition with common sunflower. Secondary growth of stem is directly related to diameter growth (Sumida *et al*., 2013). On the other hand, the values of DBH of baobabs recorded in the agroforestry and forest reserve are in agreement with the values reported in isolated baobabs of Ghana (Imoro and Barnes, 2013). But the values in this study are higher than those reported in an agroforestry of Burkina Faso (Sanou *et al*., 2012). Furthermore, the DBH values of baobabs recorded in this study were lower than that reported in Malawi (Jenya, 2018). The discrepancy could be due to forest disturbance reported in the study area (BirdLife International, 2022).

Likewise, the low aboveground biomass and carbon of baobabs in the agroforestry of Mkanana village suggests over harvesting of baobab products by farmers due regular accessibility in the area. People in Mkanana village use baobab stem barks to make ropes, while the pulp and extracts of leaves and roots are used as medicine (Personal Communication, 2020). Venter (2012) cautioned on the use of leaves and barks of baobabs by being more destructive because of being directly involved in accumulation of biomass when compared to fruits. Also, Malley *et al*. (2016) observed a common practice in agroforestry associated with a decrease of the forested area with time under the expense of an increase in land used for crop cultivation. The results of this study on low aboveground biomass and carbon in agroforestry are in agreement with Fearnside (2005), who reported low biomass and soil carbon sequestration due to forest clearance in Brazil. On the other hand, these results contradict to Ollinaho and Markus Kröger (2021) who demonstrated that mixed crops under agroforestry perform better when compared with monoculture by being able to improve soil conditions, productivity and contribution to proper functioning of growing trees.

The aboveground carbon density of 34.76 t ha^- and 27.69 t ha^- in Mangalisa forest reserve and Mkanana village agroforestry, respectively suggests the suitability of reserve land in locking carbon. This finding is in agreement with the density of carbon reported in other African dry forests that ranged between 30 – 46 t ha^- (Brown and Gaston, 1995), that baobabs cannot be ignored in carbon storage initiatives. On the other hand, these values are lower than 64 t ha^- of carbon which were reported by Baccini *et al.* (2008) in coastal forests of Tanzania. The difference in carbon density between baobabs in the semiarid and the coastal areas might be due to allometry which mainly contributes to species specific DBH, varying degree of exposure to human degradation and underlying edaphic factors among others. Furthermore, the carbon density estimates from Afromontane Rain Forests of the Eastern Arc Mountains was found to be between 252 and 581 t ha^- (Munishi and Shear, 2004; Munishi and Shirima, 2010). The eastern miombo woodlands of Tanzania have shown to have carbon storage ranging between 25 and 80 t ha^- (Shirima, 2009). Baobab trees have huge structure and longer life span when compared with most tropical trees; they were thus expected to have higher carbon density when compared to other forested areas. However, Chapotin *et al*. (2006) reported on high water content of approximately 79% in baobab trees and a low wood density ranging between 0.09 and 0.17g cm^{-3} as factors for limited carbon density.

6. Conclusion and recommendations

Climate change is no longer just an environmental issue, but it is regarded as a catastrophe threatening carbon balance which is the main contributor of global warming. Consequently, collective efforts are needed in order to mitigate emissions of carbon dioxide through fixation, sequestration and storage in vegetation. This study shows that aboveground biomass and carbon in baobab trees is lower in an area subjected to human activities through agroforestry. It follows therefore, that success in mitigation of climate change through converting forests and woodlands to sinks of carbon requires multifaceted systems targeting at a single point. This means that different areas must be conserved for normal synthesis of food through photosynthesis with ultimate accumulation of biomass in baobabs. Further studies are recommended on regeneration potential of baobabs in arid and semi-arid areas by considering their long time carbon storage. Also, campaigns on nursery establishment and subsequent planting of baobab trees in geographically feasible areas for conservation and promotion of sustainable use are recommended.

Furthermore, below ground biomass and carbon of baobab trees was not covered in this study though known to have reasonable amounts. Height as one of the biomass/carbon predictor variables was not involved in the present study due to the ambiguities in its measurement. Also, only very few allometric models are available for accounting biomass/carbon in baobab trees, so the choice is still narrow.

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Biographical notes

Nyatwere D. Mganga and **Khamis Yusuph** are of the Department of Biology, University of Dodoma, Dodoma, Tanzania.

Appendix 1: Measuring the circumference of a baobab tree in Mkanana village agroforestry

Source: Field work