

Review Article

A Review of Comparative Assessment of Carbon Sequestration Potential of Selected Indigenous Species (*Parkia Biglobosa*, *Vitellaria Paradoxa* and *Tamarindus Indica*) In The Savannah Ecological Zone of Ghana

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Abstract: Climate change poses a significant threat to ecological stability and rural livelihoods in the savannah ecological zone of Ghana. Indigenous tree species, long integrated into traditional agroforestry systems, offer considerable potential for climate change mitigation through carbon sequestration. This review provides a comparative assessment of the Above-Ground Carbon (AGC) and Below-Ground Carbon (BGC) stocks of three ecologically and socio-economically important indigenous species, *Vitellaria paradoxa* (Shea), *Parkia biglobosa* (Dawadawa), and *Tamarindus indica* (Tamarind), to evaluate their role in climate mitigation through carbon sequestration. Using data synthesized from over 20 peer-reviewed studies across West Africa, the average AGC and BGC values were compiled to estimate the Total Carbon Storage (TCS) of each species. The analysis reveals that shea trees possess a higher carbon sequestration capacity, with an average AGC of approximately 58.60MgC/ha and BGC of 2.0MgC/ha, with TCS of 61.40 MgC/ha. This is attributed to shea's longevity, extensive canopy development, and cultural protection in parkland systems. Tamarind, being second in carbon storage, with a mean AGC of 8.40MgC/ha and BGC of 14.0MgC/ha, with a TCS of 22.4MgC/ha. It shows promise in fast-growing systems, hedgerows, and mixed agroforestry setups. Dawadawa recorded the lowest carbon stocks. AGC of 4.59MgC/ha and BGC of 1.6 MgC/ha, with TCS of 6.55MgC/ha. Though lower in TCS, *P. biglobosa* contributes significantly to soil fertility improvement and nitrogen fixation, enhancing the sustainability of farming systems. The study concludes that while shea dominates in terms of carbon stock, all three species serve complementary ecological roles that support resilient landscapes and long-term carbon storage. A species-diverse, site-specific agroforestry approach is recommended to enhance both mitigation and adaptation outcomes.

Keywords: Carbon Sequestration, Indigenous Species, Carbon Stock, Climate Change Mitigation, Agroforestry

Introduction

Climate change, being a global challenge, has intensified the interest in nature-based solutions, especially those interventions that leverage agroforestry systems for carbon sequestration and ecosystem restoration. In the savannah dry lands of West Africa, indigenous trees such as Shea (*Vitellaria paradoxa*), Dawadawa (*Parkia biglobosa*), and Tamarind (*Tamarindus indica*) are widely integrated into parklands and agroforestry systems. They have substantial potential in the capture and storage of atmospheric carbon in both above-ground and below-ground (Bayala *et al.*, 2014; Soro *et al.*, 2020).

According to the FAO 2010, agroforestry is recognized as a multifunctional land use strategy that not only enhances rural livelihoods but also contributes to climate change mitigation by increasing the terrestrial carbon stock and reducing land degradation. The Intergovernmental Panel for Climate Change (IPCC), 2006, reported that the Total Carbon Stock (TCS), obtained from the summation of the Above Ground Carbon (AGC) and the Below Ground Carbon (BGC), is a key metric for evaluating the climate benefit of agroforestry tree species.

With a TCS ranging from 3.0 to 77.6MgC/ha, depending on stand age, density and soil condition, *Vitellaria paradoxa* (shea tree) remains a dominant agroforestry species in West Africa. It is valued for its economic importance through shea butter production and has demonstrated significant carbon storage in matured parklands (Soro *et al.*, 2020). *Parkia biglobosa* (Dawadawa tree) exhibits moderate but stable carbon sequestration capacity. It has a TCS ranging between 5.1- 8.5MgC/ha in the semi-arid regions (Bayala *et al.*, 2015). Also, *Tamarindus indica* (Tamarind tree) shows a TCS value ranging from 8.5 to 25.6MgC/ha (Akinyele *et al.*, 2014; Bosu *et al.*, 2022).

Despite their differences in carbon storage capacity, the three species contribute to the enhancement of soil organic carbon, microclimate regulation and climate resilience in dryland agroecosystems. Understanding and comparing their carbon stock potential is essential for better integration of these species in agroforestry practices and advocating for the protection and propagation of these species across the savannah ecological zone of Ghana.

Problem Statement and Justification

The International Center for Research in Agroforestry (ICRAF) defined agroforestry as a land use practice that intentionally combines trees and crops together with or without livestock on the same piece of land. It is the same term used to describe the purposeful introduction or preservation of trees on a farm with the view of increasing, diversifying, and improving production. The practice enhances social, economic and ecological benefits to the indigenous community (Adombire *et al.*, 2024). Findings from IPCC, 2007, have

stated with fact that even when agroforestry was not designed purposely for carbon sequestration, it has a great potential to increase terrestrial carbon stock. This practice has gained global recognition as a climate-smart land use system capable of enhancing carbon sequestration (Bayala et al., 2015). It is estimated to sequester between 12 to 228MgC/ha (Adombire et al., 2024).

In West Africa, particularly in Ghana, Côte d'Ivoire, Burkina Faso, Nigeria, Mali and Togo Shea (*Vertillaria Paradoxa*), Dawadawa (*Parkia biglobosa*) and Tamarind (*Tamarindus indica*) are widely integrated into agroforestry systems. Apart from being valued socio-economically (fruits, seeds, shade and fodder), they also provide ecological services such as carbon sequestration (Bosu et al., 2022).

Climate change poses as a threat to environmental stability, food systems and rural livelihood, especially in the savannah zones. Sequestration of carbon into trees and soils from the environment has proven to be effective in reducing their quantity, thereby reducing the impact of climate change (Bayala et al., 2015). Lal (2020) defined carbon sequestration as the process of capturing and storing carbon dioxide in vegetation, soils and other carbon pools with the view of mitigating climate change. The capturing process can occur naturally, thus through photosynthesis where plants absorb carbon dioxide and convert to plant biomass, or through human -managed systems designed to increase carbon storage. Trees play a major role in sequestering CO₂ in the terrestrial ecosystems by storing in their biomass and in soil through litter falls and root turnovers (Nair et al., 2009). However, species-specific data on carbon sequestration potential remains fragmented and underutilized in policy and land use planning in Ghana (Bosu et al., 2022).

Empirical studies have demonstrated significant variations in the TCS of these species depending on age, management and soil condition. Shea can accumulate up to 77.6MgC/ha in matured parklands (Soro et al., 2020), dawadawa tree can store up to 8.5MgC/ha (Bayala et al., 2014), while Tamarind stores up to 25.6MgC/ha (Akinyele et al., 2014; Bosu et al., 2022).

The lack of composite, yet comparative data synthesis on the carbon sequestration performance of these species limits the ability of stakeholders to make informed decision for climate smart agroforestry interventions, and advocate for enhanced integration of either of these species by farmers within the savannah ecological zone.

Therefore, a thorough review of article that comparatively assesses the TCS (AGC +BGC) potential of the species is essential to support sustainable land management policies that align with climate change mitigation goals in the savannah ecological zone of Ghana.

Aim And Objectives

This paper review seeks to comparatively assess the carbon sequestration potential of Shea (*Vertillaria Paradoxa*), Dawadawa (*Parkia biglobosa*) and Tamarind (*Tamarindus indica*) in the savannah ecological zone of Ghana and their role in mitigating the global climate change through agroforestry activities.

Since the selected species have different TCS potentials, quantifying and comparing these values provides insight into which species can offer the highest carbon sequestration benefit. Also, assessing the contribution of above-ground and below-ground biomass components to total carbon storage for each species and evaluating their respective suitabilities for climate-smart agroforestry and carbon offset strategies.

METHODOLOGY

Study Design.

A systematic review approach was adopted during the study. The review focused on critically identifying, selecting and thoroughly analyzing peer reviewed articles, research thesis and reports. This approach allowed for a comprehensive comparative summary and understanding of research findings and case studies related to the topic.

Sources of Data and Literature

In order to avoid selection bias, data was sourced through multiple data pools. Google Scholar, Scopus, ScienceDirect, JSTOR and ResearchGate were the selected databases consulted during the review. Institutional Repositories, including reports from FAO, IPCC, UNDP, ITTO, NASA, UNEP, were considered. Scientific and academic Journals were considered for peer-reviewed papers or articles relating to the following search keywords: indigenous species, agroforestry, carbon sequestration and climate change. Journal of Environment and Biology, Journal of Forest Ecology and Management, Journal of Climate Change, International Journal of Environmental Science, Journal of Forestry, among others, were consulted. Governmental reports from the Ghana Forestry Commission and climate reports from the Environmental Protection Agency of Ghana.

Literature Search Strategy

Keywords used during literature search included "shea tree" OR *Vitellaria paradoxa*, "dawadawa tree" OR *Parkia biglobosa*, "tamarind tree" OR *Tamarindus indica*, "Carbon Sequestration", "Climate Change Mitigation", "Above ground Carbon Stock", "Below ground Carbon Stock", "Forest Carbon Sink", "Tropical Forestry and Carbon". Also, the Boolean operators (AND, OR) were tools and strategies that assisted in the data search

The inclusion criteria constituted peer-reviewed articles, theses, and reports published between 2000 and 2024. Again, studies on shea, dawadawa and tamarind, their above and below ground carbon sequestration potential, thus storage in biomass and soils were considered, especially experimental or field studies including surveys. All articles considered were in the English language. A total of 23 articles spanning across West Africa were considered for the paper review.

Ethical standards were strictly adhered to in the whole process of this paper review. All sources were properly cited and referenced. Data collected were handled with academic integrity to avoid plagiarism and misrepresentation or misinterpretation of the author's findings.

Data Extraction and Analysis

The Preferred Reporting Items for Systematic reviews and Meta Analysis (PRISMA) guidelines were adopted to extract data. By the use of the guidelines, the geographical location of the selected study, the methodology used to measure carbon, and the ecological relevance of the study to this review.

Table 1. Standardized Data Extraction Format

Author/s	Year	Study title	Location	Key Findings	Relevance
Akintunde-Alo <i>et al.</i> ,	2024	Stand Growth, Biomass and Carbon Sequestration Potentials of <i>Parkia biglobosa</i>	Nigeria	Total carbon stock: 6.53MgC/ha AGC: 4.87MgC/ha BGC:1.68MgC/ha	Demonstrates that <i>P. biglobosa</i> can actively sequester carbon,

The literature matrix in the above presents the summary of extracted data. It presents a snapshot of each study in terms of its core contributions as they fit into the broad review objectives.

This systematic data extraction process laid a strong foundation for the thematic analysis in the following results and discussion sections.

RESULTS AND DISCUSSION

This section of the review presents the results in respect of AGC, BGC and TCS for each species, followed by the discussion of the review.

Previous studies from Ghana and other West African countries confirm that indigenous species sequester and store a significant quantity of carbon, thus serving as natural carbon sinks. The Total Carbon Stock (TCS), which includes Above-Ground Carbon (AGC) and Below-Ground Carbon (BGC), is a critical metric for assessing a species' potential for climate change mitigation. The table below shows the carbon sequestration capacities of shea, dawadawa and Tamarind.

Table 3.1: Above-Ground Carbon Storage

Country	Species	AGC (Mgc/Ha)
Ghana	Shea	58.60
	Dawadawa	4.95
	Tamarind	8.40
Nigeria	Shea	66.87

	Dawadawa	6.21
	Tamarind	7.82
Côte d'Ivoire	Shea	71.31
	Dawadawa	7.68
	Tamarind	7.11
Burkina Faso	Shea	62.34
	Dawadawa	5.11
	Tamarind	6.02
Togo	Shea	52.61
	Dawadawa	4.13
	Tamarind	6.54

The table above shows a significant variation in the carbon sequestration potential of the selected species. In Ghana, the shea tree can accumulate up to 58.60MgC/Ha, Dawadawa stores 4.59MgC/Ha whiles Tamarind stores 8.40MgC/Ha in the above ground. Comparatively, the review revealed that shea can sequester more carbon (seven times more) in the above-ground biomass, followed by Tamarind and then Dawadawa. The sequestration and storage of Tamarind is twice higher than dawadawa. This is confirmed by other studies conducted in Nigeria, Togo, Burkina Faso and Côte d'Ivoire. The AGC of the shea tree in these countries outperforms the Tamarind and Dawadawa trees, respectively.

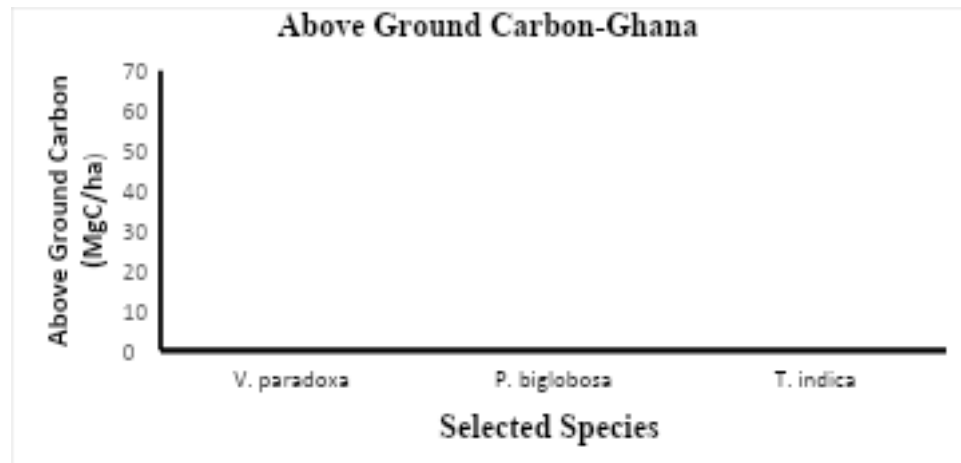


Fig.1. AGC of the selected species

The graph above compares the AGC potential of the selected species. Shea sequesters seven times more carbon than Tamarind and dawadawa.

Table 3.2: Below-Ground Carbon Storage

Country	Species	BGC (MgC/Ha)
Ghana	Shea	2.80
	Dawadawa	1.60
	Tamarind	14.0
Nigeria	Shea	2.03
	Dawadawa	2.13
	Tamarind	9.22
Côte d'Ivoire	Shea	2.90
	Dawadawa	2.18
	Tamarind	16.34
Burkina Faso	Shea	3.02
	Dawadawa	1.91
	Tamarind	11.23
Togo	Shea	4.54
	Dawadawa	2.50
	Tamarind	12.31

The table above shows a significant variation in the carbon sequestration potential of the selected species. In Ghana, the shea tree can accumulate up to 2.8MgC/Ha, Dawadawa stores 1.6MgC/Ha, while Tamarind stores 14.0MgC/Ha below ground. Comparatively, the review revealed that Tamarind can sequester more carbon (five times more) in the below-ground biomass. This is followed by shea and then dawadawa. The sequestration and storage of shea is twice that of dawadawa. This is confirmed by other studies conducted in Nigeria, Togo, Burkina Faso and Côte d'Ivoire.

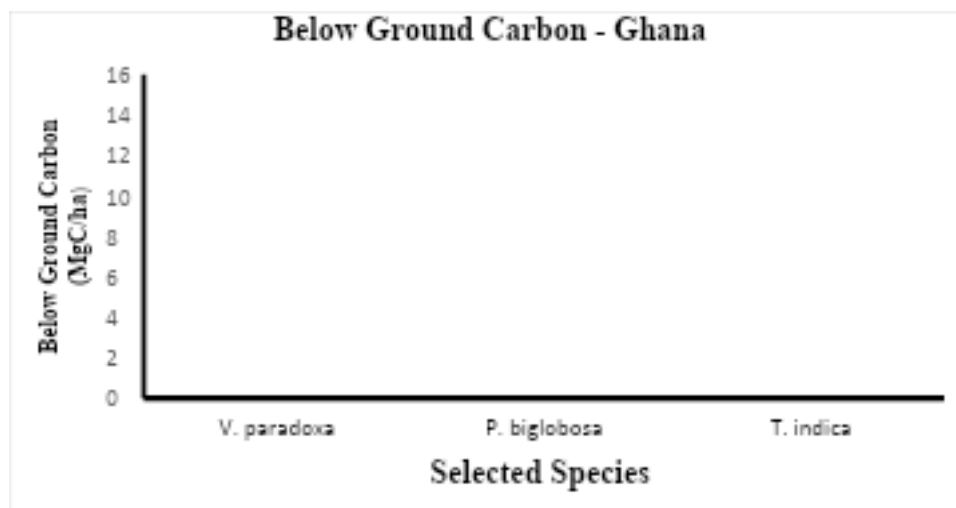


Fig. 2. BGC of the selected species

The graph above compares the BGC of the selected species. Tamarind sequesters five times more carbon than shea and dawadawa.

Table 3.3: Total Carbon Storage

Country	Species	TSC (MgC/Ha)
Ghana	Shea	61.4
	Dawadawa	6.55
	Tamarind	22.4
Nigeria	Shea	68.90
	Dawadawa	8.34
	Tamarind	17.04
Côte d'Ivoire	Shea	74.72
	Dawadawa	9.86
	Tamarind	23.45
Burkina Faso	Shea	65.36
	Dawadawa	7.02
	Tamarind	17.25
Togo	Shea	57.15
	Dawadawa	6.63
	Tamarind	18.85

The review reveals that in Ghana, the Shea tree has a mean TCS of 61.40MgC/Ha. The mean TCS for Tamarind is of 22.4MgC/Ha and Dawadawa is 6.55MgC/ha. Comparatively, the shea tree proves to sequester and store more carbon (three times higher)

in the TCS. This is followed by Tamarind then Dawadawa. Tamarind stores three times more carbon than dawadawa. The review is confirmed by similar studies conducted in Nigeria, Togo, Burkina Faso and Côte d'Ivoire.

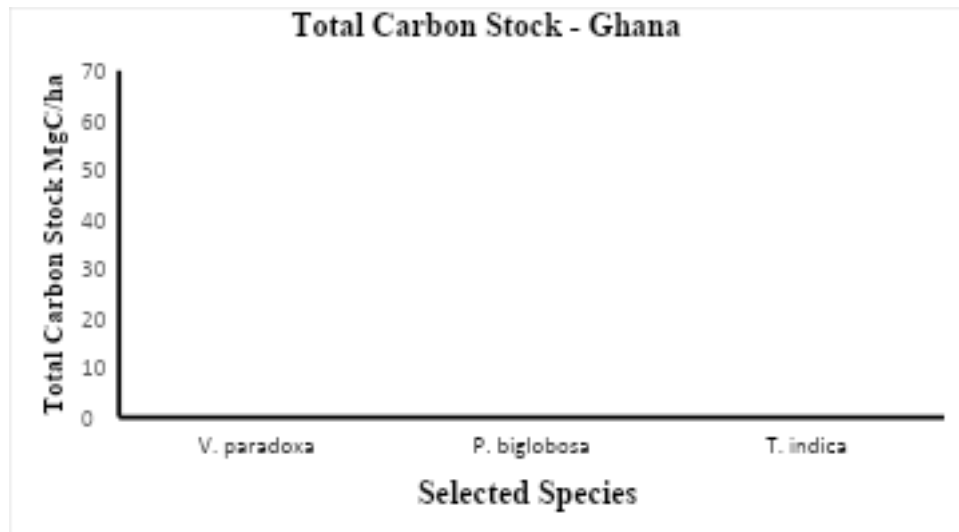


Fig 3. TCS of the selected species

The graph above compares the TCS of the selected species. *Vertilaria paradoxa* stores three times higher compared to *Tamarindus indica* and *Parkia biglobosa*.

The wide range in the AGC for shea (58.60MgC/Ha) suggests that shea has a higher AGC potential, Tamarind (8.40MgC/Ha) follows as second, then Dawadawa (4.59MgC/Ha). The performance of shea is highly dependent on the tree age, soil type and land use intensity. Anthropogenic pressures such as tree felling and land use change can significantly affect shea's effectiveness as a carbon sink, but in protected areas, its role in long-term carbon retention and soil enrichment is notable (Bayala *et al.*, 2015).

The robust root system of Tamarind contributes to its higher BGC (14.0MgC/Ha) compared to Shea (2.8MgC/Ha) and Dawadawa (1.6MgC/Ha). It matures faster with a higher root biomass and produces marketable fruits, making it ideal for short to medium-term climate-smart agriculture and carbon-focused agroforestry.

The TCS of shea is 61.40MgC/Ha, followed by Tamarind, 22.4MgC/Ha and then dawadawa 6.55MgC/ha. The carbon stock of shea is highly site-specific, with higher values recorded in mature and protected areas. Its deep roots contribute to its resilience and soil carbon; however, the long maturation period limits short-term gains in carbon-focused projects (Soro *et al.* 2020). The high biomass potential of shea can be attributed to its longevity (exceeding 100 years), robust trunk girth and dominant role in traditional agroforestry parklands, which makes them culturally protected, leading to a reduced rate of deforestation compared to other selected species (Boffa, 1999). The significant contribution of shea to above-ground carbon stock and soil stability enhances its relevance in regional climate action strategies (Bayala *et al.*, 2015).

As compared to Shea and Tamarind, Dawadawa is relatively lower in carbon stock. This is offset by its resilience to harsh climates, nitrogen-fixing capacity and co-benefits such as edible seeds and fodder. Its consistent performance across agroecological zones makes it well-suited for degraded and low input landscapes, though it is less competitive for high-value carbon sequestration in carbon credit markets. Dawadawa is more uniform and reliable cross sites. The species perform well in dry conditions and contributes to both carbon storage and agroforestry benefits like food, shade and fodder (Kater et al., 2000).

From the carbon sequestration standpoint, shea remains the most carbon-dense indigenous species under ideal conditions but requires long maturation time and stable land tenure systems to realize its full carbon potential. It is best suited for long term climate projects with strong community protection systems. Tamarind follows after Shea, with a higher BGC. Its fast growth, deep rooting and commercial fruits value makes it well-suited for integrated agroforestry and climate mitigation in semi arid zones. While Dawadawa, with a moderate carbon storage, is reliable and ecologically versatile, especially in low input systems making it a stronger candidate for widespread agroforestry in marginal areas. It demonstrates resilience to bushfires and browsing (Gyasi et al., 2014).

Comparative Implications for Climate Mitigation Strategy in Savannah Landscapes

The variations in carbon stocks among the selected species reflect their ecological niches, management history and physiological traits. Shea, dominant in the AGC makes it ideal for long-term carbon storage strategies, particularly in traditional parklands. Dawadawa provides critical supporting ecosystem services that enhance soil-based carbon pools. Tamarind offers a niche for intensive small-scale planting and rapid biomass turnover.

The findings suggest that no single species can meet all the climate mitigation needs in the savannah ecosystem, rather a diversified indigenous agroforestry system combining all three species based on site-specific suitability will produce synergistic benefits for carbon capture, biodiversity and livelihood resilience. Tamarind (*Tamarindus indica*) is consistently high in BGC across varied sites, whether degraded or fertile, with a strong root system which ensures carbon is stored both above and below ground. It provides co-benefits such as fruit production, shade, and drought resilience and fast maturity time. These makes Tamarind best suited for carbon-focused agroforestry systems and climate change mitigation, especially in regions with moderate rainfall. This is followed by Shea (*Vitellaria paradoxa*). It has a very high carbon storage potential under ideal conditions (fertile soil and in protected areas and parklands) and strong socio-economic importance (shea butter industry). it is suitable for long-term carbon sequestration projects, especially where protected management is possible. Dawadawa (*Parkia biglobosa*) is stable but lower in TCS. It is valuable for mixed-species systems and soil fertility enhancement, ideal for multi-purpose parklands, though less impactful for carbon sequestration alone.

CONCLUSION

The review has demonstrated that indigenous tree species, shea (*Vitellaria paradoxa*), dawadawa (*Parkia biglobosa*) and tamarind (*Tamarindus indica*), have different but complementary roles in climate change mitigation through carbon sequestration in the savannah agroecological zones of Ghana. By synthesizing findings from peer-reviewed articles, institutional and governmental reports, this assessment provides a clear picture of their respective carbon storage capacity and ecosystem contributions.

The review reveals that shea is the most effective among the three species in terms of the TCS with an average of 61.4MgC/Ha in the savannah agroecological zone of Ghana. However, this is highly dependent on the quality of the site condition, large trunk biomass, extensive canopy and longer life span. This makes it a reliable long-term carbon sink in the savannah agroecosystem. Tamarind follows after shea, with an average TCS of 22.4MgC/ha. It is highly adapted to varied site conditions, it has a faster maturity time and a robust root system with high biomass. This makes it ideal for short -medium term climate mitigation projects. Dawadawa has the lowest TCS, averaging 6.55MgC/ha. It is valuable for mixed-species systems and soil fertility enhancement, ideal for multi-purpose parklands, though less impactful for carbon sequestration alone.

The review also concluded that the AGC of shea outperforms its BGC, with an average of 58.6MgC/ha and 2.80MgC/ha, respectively. This is as a result of the extensive canopy and high trunk biomass. The average BGC of Tamarind was higher than its AGC, 14MgC/ha and 8.40MgC/ha, respectively. This is as a result of the robust root system and higher root biomass. Dawadawa has an average AGC of 4.62MgC/ha and an average BGC of 1.65MgC/ha. This makes its AGC potential higher as compared to its BGC in climate change mitigation. However, this is offset by its resilience to harsh climates, nitrogen-fixing capacity and co-benefits such as edible seeds and fodder.

The study further concludes and suggests that no single species can meet all the climate mitigation needs in the savannah ecosystem, rather a diversified indigenous agroforestry system combining all three species based on site-specific suitability will produce synergistic benefits for carbon capture, biodiversity and livelihood resilience.

Recommendations.

- i. Efforts should be made to promote multi-species indigenous agroforestry systems that incorporate shea, dawadawa, and tamarind to enhance carbon storage and ecosystem services. Species should be selected based on site suitability, farmer preferences, and long-term landscape objectives.
- ii. While there are substantial studies on AGC of the selected species, more empirical research is needed on BGC and soil organic carbon dynamics, particularly for tamarind and dawadawa, to better understand their total carbon sequestration potential under different management regimes.

- iii. Considering its superior carbon storage capacity, shea should be prioritized for protection, regeneration, and domestication, especially in degraded parklands. Policies should support sustainable shea harvesting, fire control, and assisted natural regeneration.

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