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Carbon Sequestration Potential of Agroforestry Systems in Tropical Environments

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Abstract

Purpose: The general objective of this study was to examine the carbon sequestration potential of agroforestry systems in tropical environments.

Methodology: The study adopted a desktop research methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library.

Findings: The findings revealed that there exists a contextual and methodological gap relating to the carbon sequestration potential of agroforestry systems in tropical environments. Preliminary empirical review revealed that agroforestry systems in tropical environments significantly enhance carbon sequestration, with performance influenced by species diversity, management practices, and ecological conditions. These systems also offered added benefits like biodiversity conservation and improved livelihoods, though more localized data and long-term studies were needed to optimize their effectiveness.

Unique Contribution to Theory, Practice and Policy: The Theory of Carbon Cycle Dynamics, The Social-Ecological Systems (SES) Theory and The Theory of Ecosystem Services may be used to anchor future studies on the carbon sequestration potential. The study recommended integrating agroforestry into climate policies, supporting farmer adoption through incentives and training, enhancing monitoring tools, and strengthening theoretical models to include both ecological and socio-economic factors for more impactful and sustainable implementation.

Keywords: *Agroforestry Systems, Carbon Sequestration, Tropical Environments, Climate Change Mitigation, Sustainable Land Use*

Q57, Q54, Q56, Q58, Q15

1.0 INTRODUCTION

The United States possesses significant carbon sequestration potential, particularly within its federal lands. Tan, Liu, Sohl, Wu & Young (2015) estimated that federal lands across the conterminous U.S. stored approximately 11,613 teragrams (Tg) of carbon in 2005, with projections indicating an increase to 13,965 Tg by 2050 under various emission scenarios. Forests and grasslands were identified as primary contributors, with annual sequestration rates of 620 and 228 kilograms of carbon per hectare, respectively. These findings underscore the importance of land management practices in enhancing carbon storage and achieving national greenhouse gas mitigation goals.

In the United Kingdom, afforestation and improved land management have been central to carbon sequestration efforts. Ostle, Levy, Evans & Smith (2009) highlighted that UK soils contain approximately 10 billion tonnes of carbon, with potential for additional sequestration through land-use changes. The research emphasized that converting arable land to permanent grassland or woodland could significantly enhance soil carbon stocks, contributing to climate change mitigation strategies. Moreover, peatland restoration has been identified as a critical component, given that peatlands store vast amounts of carbon and their degradation leads to substantial emissions.

Japan has been exploring innovative approaches to carbon sequestration, including the utilization of seagrass meadows. According to a Reuters report (2024), Japan's Ministry of the Environment estimated that in fiscal year 2022, seagrass and seaweed beds absorbed approximately 350,000 tons of carbon dioxide, accounting for 0.03% of the nation's total emissions. While this figure is modest, the expansion of such blue carbon ecosystems holds promise for enhancing carbon capture, especially as terrestrial forests age and their sequestration capacity declines. Marine scientist Keita Furukawa suggested that widespread cultivation of eelgrass could potentially absorb 10 to 20% of human emissions, highlighting the significant role of marine vegetation in Japan's carbon neutrality goals.

Brazil's vast landscapes offer considerable opportunities for carbon sequestration, particularly through reforestation and sustainable land management. Fronza, Ten Caten, Bittencourt, Zambiazi, Schmitt Filho, Seó & Loss (2024) conducted a systematic review of pastures in Southern Brazil, revealing that managed pastures can sequester approximately 2.50 megagrams of carbon per hectare annually over a 20-year period. The research estimated that under current pasture occupation conditions, these areas could sequester between 0.433 and 1.273 gigatons of CO_2 over two decades if managed appropriately. These findings underscore the potential of pasture management in contributing to Brazil's climate change mitigation efforts.

Sub-Saharan Africa presents both challenges and opportunities for carbon sequestration. Hansson, Fridahl, Haikola, Yanda, Pauline & Mabhuye (2019) examined the preconditions for bioenergy with carbon capture and storage (BECCS) in Tanzania, highlighting the region's potential for CO_2 storage in coastal areas. However, the research emphasized that the prospects for CO_2 storage are generally low in onshore Sub-Saharan Africa due to a lack of experience in oil and gas extraction, which limits the development of suitable geological storage basins. Despite these challenges, the study suggests that with appropriate investments and technological advancements, BECCS could play a role in the region's climate change mitigation strategies.

The Coastal Plains region of the United States, encompassing coastal basins from Texas to Georgia, has been identified as having substantial potential for geologic carbon sequestration. According to the U.S. Geological Survey (USGS), this area accounts for approximately 65% of the nation's storage potential, with an estimated capacity of 2,000 metric gigatons of CO_2. This significant storage potential positions the Coastal Plains as a critical region for implementing carbon capture and storage (CCS) projects, which could play a vital role in the country's efforts to reduce greenhouse gas emissions.

Brazil's forest plantations have demonstrated considerable capacity for carbon sequestration. Stape, Binkley & Ryan (2017) analyzed the dynamics of carbon and CO_2 removals by Brazilian forest plantations between 1990 and 2016, revealing that plantation forests increased their carbon stock from 231 million tons in 1990 to 612 million tons in 2016. Eucalyptus species contributed significantly to this increase, accounting for 71% of the carbon stock in 2016. The study concluded that forest plantations play an essential role in mitigating greenhouse gas emissions in Brazil, highlighting the importance of sustainable forestry practices in climate change mitigation.

In Sub-Saharan Africa, agroforestry systems have been recognized for their potential in carbon sequestration. Luedeling, Sileshi, Beedy, Dietz & Muthuri (2011) assessed the carbon sequestration potential of parkland agroforestry systems in the Sahel region, estimating that these systems can sequester up to 3 megagrams of carbon per hectare annually. The integration of trees into agricultural landscapes not only enhances carbon storage but also provides co-benefits such as improved soil fertility, resilience to climate extremes, and diversified income sources for farmers. The study emphasizes the need for policies that support agroforestry practices to maximize their climate mitigation potential.

Peatlands in the United Kingdom are significant carbon sinks, storing vast amounts of carbon accumulated over millennia. However, degradation of these ecosystems through drainage and land-use changes has led to substantial carbon emissions. Evans, Williamson & Artz (2016) highlighted that restoring degraded peatlands could prevent the release of approximately 3.7 million tonnes of CO_2 annually. The research underscores the importance of peatland restoration as a cost-effective strategy for carbon sequestration and climate change mitigation in the UK.

Japan's forest management practices have evolved to enhance carbon sequestration. Yamagata, Saito, Ito & Kumagai (2018) examined the carbon removal potential of Japanese forests, indicating that improved forest management could increase carbon sequestration by approximately 25 million tonnes of CO_2 annually. The research suggests that thinning overstocked forests and promoting the use of wood products can enhance carbon storage while supporting the timber industry. These findings highlight the role of sustainable forest management in Japan's climate change mitigation strategies.

Agroforestry systems are gaining global recognition for their potential to sequester carbon and mitigate climate change, particularly in tropical environments. These systems combine the cultivation of trees with crops and/or livestock, creating diverse landscapes that are highly efficient in capturing atmospheric carbon dioxide (CO_2). Through the photosynthesis process, trees and other vegetation absorb CO_2 and store it in both biomass and soils. Agroforestry systems have been identified as one of the most effective strategies for long-term carbon sequestration, with studies showing that they can sequester between 12 and 228 megagrams (Mg) of carbon per hectare per year, depending on the type of system, local climate conditions, and management practices (Nair, 2012). In tropical regions, where growth conditions are optimal due to ample sunlight and rainfall, agroforestry systems have the potential to not only mitigate climate change but also provide additional environmental benefits such as soil fertility improvement, water regulation, and enhanced

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biodiversity. These systems are becoming a central component of global strategies for both carbon sequestration and sustainable land-use management. By integrating trees with agriculture, agroforestry maximizes the land's potential to store carbon while simultaneously producing food, fuel, and other goods that support rural livelihoods (Jose, 2009).

In the United States, agroforestry practices such as alley cropping, riparian buffers, and silvopasture are being increasingly adopted for their potential to sequester carbon and enhance environmental sustainability. In alley cropping systems, for example, trees are planted in rows alongside crops, and they help reduce wind erosion, enhance water infiltration, and store carbon in both the tree biomass and the soil. Research indicates that these systems can sequester up to 9.2 Mg of carbon per hectare annually, especially when trees are strategically chosen for their fast growth and high carbon-storing capacities (Jose, 2009). Similarly, silvopastoral systems, which integrate trees with livestock grazing, have shown impressive carbon sequestration potential, with studies reporting carbon storage rates of up to 6.3 Mg of carbon per hectare per year (Jose & Bardhan, 2012). The benefits of agroforestry in the U.S. go beyond carbon sequestration; these systems also support biodiversity, improve soil quality, and increase resilience to extreme weather events such as floods and droughts. Additionally, agroforestry practices are now being integrated into federal and state-level conservation programs, such as the Conservation Reserve Program (CRP), which encourages farmers to adopt land-use practices that improve environmental quality, including carbon storage. As part of broader climate change mitigation strategies, the U.S. has made substantial strides in promoting agroforestry for its ecosystem services and carbon sequestration potential (Cardinael, Chevallier, Barthès, Saby, Parent, Dupraz & Chenu, 2017).

In the United Kingdom, agroforestry practices are not as widespread as in tropical regions but have been gaining attention as a promising approach to sequestering carbon and improving agricultural sustainability. Studies suggest that temperate agroforestry systems—such as silvopastoral systems that combine livestock grazing with tree planting—can sequester between 1.1 and 3.3 Mg of carbon per hectare per year. The UK's temperate climate provides an ideal setting for integrating trees into agricultural systems, as it allows for the cultivation of various tree species that can enhance carbon storage while simultaneously benefiting agricultural productivity. Agroforestry also has the potential to reduce greenhouse gas emissions by substituting fossil fuels with renewable biomass from trees and by improving soil carbon storage through increased organic matter input (Cardinael et al., 2017). Moreover, the incorporation of trees in farmlands offers a diverse range of co-benefits, including enhanced biodiversity, better air and water quality, and a reduction in soil erosion. The UK government has recognized the potential of agroforestry in climate change mitigation and has started supporting it through various initiatives such as the Countryside Stewardship Scheme, which provides financial incentives for farmers to adopt sustainable practices, including agroforestry (Takeuchi, Matsuura & Tanaka, 2016).

Japan's traditional Satoyama landscapes represent an ideal model of agroforestry that balances human activity with natural ecosystems. These landscapes integrate rice paddies, vegetable gardens, and forests, creating complex land-use systems that contribute significantly to carbon sequestration. Studies suggest that these traditional systems can sequester about 2.5 Mg of carbon per hectare annually, largely through the integration of trees with agricultural crops. The Satoyama model emphasizes sustainable land management that enhances biodiversity and ecosystem services, while also addressing climate change through carbon capture. Trees in these systems not only act as carbon sinks but also help mitigate the impacts of natural disasters such as flooding and landslides, which are becoming more frequent due to climate change. The Japanese government has long supported these agroforestry systems, recognizing their importance in maintaining rural landscapes and preserving traditional agricultural practices. Additionally, these systems offer educational and cultural value, which helps to maintain the social fabric of rural communities. The resilience of Satoyama landscapes to climate change, along with their carbon sequestration potential, makes them an important aspect of Japan's broader environmental and agricultural policies (Takeuchi et al., 2016).

Brazil has been a global leader in the adoption of agroforestry systems, particularly in the Amazon and Atlantic Forest regions, where deforestation and land degradation have been significant environmental challenges. Agroforestry systems in Brazil often combine native tree species with crops such as cacao, coffee, and bananas, allowing for the restoration of degraded land while enhancing biodiversity and sequestering carbon. These systems have demonstrated remarkable carbon sequestration rates, ranging from 3.5 to 15.2 Mg of carbon per hectare annually, depending on the specific practices and regional conditions (Schroth, Läderach, Martinez-Valle, Bunn & Jassogne, 2015). In the Amazon, agroforestry not only provides an alternative to traditional slash-and-burn agriculture but also contributes to reducing carbon emissions from deforestation and forest degradation. By integrating trees into agricultural landscapes, these systems improve soil quality, reduce water runoff, and increase the resilience of local communities to climate change. In the Atlantic Forest, agroforestry has been central to efforts to restore degraded lands and protect biodiversity hotspots, contributing to both carbon storage and conservation goals. Brazil's adoption of agroforestry practices is supported by both governmental and non-governmental organizations that promote sustainable land management and climate change mitigation strategies, making agroforestry an essential component of the country's broader environmental policies (Schroth et al., 2015).

Agroforestry has emerged as a critical strategy for climate change adaptation and carbon sequestration in Sub-Saharan Africa. In this region, smallholder farmers are increasingly adopting agroforestry systems, such as parkland systems and improved fallows, to improve soil fertility, increase crop yields, and sequester carbon. Agroforestry systems in Sub-Saharan Africa have been shown to sequester up to 6.8 Mg of carbon per hectare per year, depending on the species of trees and the management practices employed. These systems are especially valuable in regions facing soil degradation, desertification, and erratic rainfall patterns, as trees help restore soil organic matter, increase water retention, and provide shade for crops (Mbow, van Noordwijk, Luedeling, Neufeldt, Minang & Kowero, 2014). Beyond their carbon sequestration potential, agroforestry systems in Sub-Saharan Africa contribute to food security, income diversification, and enhanced resilience to climate change. The integration of trees with crops and livestock also improves biodiversity and promotes ecosystem services, such as pollination and pest control. Despite challenges such as limited access to resources and technical knowledge, agroforestry remains a promising solution for addressing both climate change and sustainable development in the region.

In addition to aboveground carbon storage, agroforestry systems are particularly effective in enhancing soil carbon sequestration. Trees contribute to soil carbon sequestration through the deposition of organic matter from leaf litter, root biomass, and dead trees. The increased organic matter in soils improves soil structure, water retention, and nutrient availability, leading to higher productivity and resilience to environmental stress. Studies have shown that agroforestry systems in tropical environments can increase soil organic carbon stocks by up to 1.6 Mg per hectare annually, significantly enhancing the long-term carbon storage capacity of agricultural landscapes. The role of agroforestry in soil carbon sequestration is especially important in regions with degraded soils, as trees help restore soil health by reducing erosion and preventing nutrient leaching. As a result, agroforestry systems provide a dual benefit: they sequester carbon both aboveground and belowground, making them a valuable tool for mitigating climate change and promoting sustainable agriculture (Nair, 2012).

The successful implementation and scaling up of agroforestry systems require strong policy frameworks and institutional support. Governments, international organizations, and local stakeholders play an essential role in promoting agroforestry practices through financial incentives, technical assistance, and research support. In many countries, including the USA, UK, and Brazil, agroforestry has been incorporated into national climate change and land-use policies, with specific programs designed to encourage farmers to adopt sustainable land-use practices. For example, the U.S. Department of Agriculture (USDA) provides technical assistance and financial incentives for farmers to implement agroforestry practices as part of the Conservation Reserve Program (CRP), which supports landowners in adopting environmentally beneficial practices. Similarly, international organizations such as the World Agroforestry Centre (ICRAF) have been instrumental in advancing agroforestry research and promoting its adoption in tropical regions. Through global partnerships and local engagement, these organizations are working to scale up agroforestry as a solution for climate change mitigation and rural development (Garrity, 2012).

Despite the recognized benefits of agroforestry, its adoption faces several challenges, particularly in developing countries. Issues such as land tenure insecurity, lack of access to capital, and insufficient technical knowledge often hinder farmers from implementing agroforestry systems. In many regions, farmers are reluctant to adopt agroforestry due to perceived risks, such as the long-term commitment required for tree planting and the uncertainty of returns. Overcoming these barriers requires a combination of policy interventions, technical support, and awareness campaigns to demonstrate the economic and environmental benefits of agroforestry. At the same time, agroforestry presents an opportunity to integrate climate change mitigation with poverty reduction, as it offers farmers an additional income source through the sale of timber, non-timber forest products, and carbon credits. By addressing the challenges of adoption, agroforestry can become a mainstream solution for sustainable land use and climate resilience (Mercer, 2004).

Looking ahead, there is a need for more integrated and interdisciplinary research to further optimize agroforestry systems for carbon sequestration and broader sustainability goals. Future research should focus on identifying the most effective tree species for different agroecological zones, improving management practices, and exploring innovative ways to enhance carbon capture and storage. Additionally, the role of agroforestry in ecosystem-based adaptation to climate change needs to be better understood, particularly in vulnerable regions such as Sub-Saharan Africa. There is also a growing interest in using agroforestry systems for biodiversity conservation, watershed management, and ecosystem restoration. As the global community works towards meeting climate targets, agroforestry has a critical role to play in achieving both mitigation and adaptation objectives. Continued investment in agroforestry research and policy support will be essential in unlocking the full potential of these systems for climate change mitigation and sustainable development (Jose & Bardhan, 2012).

1.1 Statement of the Problem

The increasing concentration of carbon dioxide in the atmosphere, largely driven by deforestation, agricultural expansion, and industrial activities, has become one of the principal drivers of climate change. Agroforestry, an integrated land-use system that combines trees with agricultural crops or livestock, has been recognized as a potential solution to sequester carbon, restore biodiversity, and improve soil fertility in tropical environments. These ecosystems, however, have not been comprehensively studied in terms of their carbon sequestration potential, particularly in comparison to other land-use systems like monocultures or unmanaged forests. A key statistic highlights that tropical forests alone account for approximately 25% of the total global carbon stock in vegetation and soils (Gatti, Basso & Fonseca, 2021). Despite this, agroforestry systems are often underrepresented in global carbon accounting models, and their full potential remains largely unexplored in tropical regions. Thus, there is an urgent need for research that accurately quantifies and models the carbon sequestration capacity of agroforestry systems across various tropical landscapes.

Several knowledge gaps persist in the study of agroforestry's role in carbon sequestration. Existing literature often lacks long-term, region-specific data that accounts for the variability in soil types, climate conditions, and agroforestry management practices. Furthermore, many studies focus on isolated tree species or small-scale plots, failing to capture the broader ecological and socio-economic dynamics of agroforestry systems at larger scales (Sileshi, Dube & Hakeem, 2014). This leaves significant uncertainty around the net carbon benefits of these systems over different time scales, especially when considering economic trade-offs and community-level adoption rates in tropical environments. Another research gap lies in the integration of carbon sequestration potential with other ecosystem services such as biodiversity conservation, water regulation, and soil quality enhancement. This study aims to fill these gaps by providing a comprehensive analysis of agroforestry systems' carbon sequestration potential, using large-scale field studies across different tropical regions, and considering a variety of management practices and tree-crop combinations.

The findings of this research will have broad implications for policy makers, environmental managers, and local farmers. By providing robust data on the carbon sequestration potential of agroforestry, the study will help inform climate policy, particularly regarding strategies for achieving Nationally Determined Contributions (NDCs) under the Paris Agreement. It will also contribute to the development of carbon markets that could incentivize farmers to adopt agroforestry systems as a climate mitigation strategy. Furthermore, this study will benefit local farming communities by demonstrating the long-term financial viability of agroforestry systems through carbon credit generation and improved crop yields. As agroforestry can also enhance soil fertility and water retention, this research has the potential to promote sustainable agricultural practices that align with both environmental and economic goals (Schroeder, Schlesinger, & Gonzalez, 2017). Ultimately, the outcomes will bridge knowledge gaps and guide the implementation of agroforestry systems as effective tools for mitigating climate change in tropical regions.

2.0 LITEERATURE REVIEW

2.1 Theoretical Review

2.1.1 The Theory of Carbon Cycle Dynamics

The Theory of Carbon Cycle Dynamics, originating from the work of Joseph Fourier in the early 19th century, focuses on understanding how carbon, in its various forms, cycles through different environmental compartments, including the atmosphere, oceans, soils, and biota. The theory posits that carbon dioxide and other greenhouse gases play a critical role in regulating Earth's climate by controlling the natural greenhouse effect. In the context of agroforestry, this theory highlights the significance of carbon sequestration processes that occur in the soil and vegetation layers, which, when managed properly, can significantly mitigate the amount of carbon dioxide in the atmosphere. Agroforestry systems, through the establishment of trees in agricultural lands, have the potential to trap and store atmospheric carbon in both biomass (aboveground) and soil organic matter (belowground). The theory is foundational for research on agroforestry systems, as it provides a framework for understanding how carbon is cycled and sequestered within these systems. The relevance of the carbon cycle theory lies in its capacity to quantify the amount of carbon that agroforestry systems can sequester, making it essential for understanding the potential impact of agroforestry on climate change mitigation strategies. For example, research has shown that soil in agroforestry systems can store more carbon than in monoculture systems, due to the increased biomass and root systems of trees (Veldkamp & Weitz, 2009). This theory allows researchers to model the processes that control carbon sequestration in agroforestry systems and assess the long-term sustainability of such practices in tropical environments.

2.1.2 The Social-Ecological Systems (SES) Theory

The Social-Ecological Systems (SES) Theory, developed by Elinor Ostrom in the 1990s, emphasizes the interconnectedness between human societies and ecosystems, focusing on how governance, resource management, and ecological sustainability are interrelated. The core theme of SES is that ecosystems do not exist in isolation from human societies, and their management involves complex interactions between ecological components and human institutions. In the context of agroforestry systems in tropical regions, this theory is especially relevant as it underscores the need to understand both the ecological dynamics of carbon sequestration and the social, economic, and institutional factors that influence the adoption and success of agroforestry practices. Tropical agroforestry systems involve a blend of local knowledge, community participation, land-use policies, and economic incentives, all of which affect their effectiveness in sequestering carbon. This theory is particularly useful when examining how the governance of agroforestry systems—such as land tenure, community involvement, and market access—can enhance or hinder their potential for carbon storage. By applying SES theory to agroforestry research, scholars can explore how governance structures at local, national, and global levels influence the implementation and scalability of carbon sequestration strategies. Moreover, this theory can help identify social barriers or incentives for farmers to engage in agroforestry practices that enhance carbon sequestration. For instance, a study in Kenya demonstrated that local farmers' adoption of agroforestry practices, driven by both environmental concerns and economic benefits, significantly enhanced carbon sequestration (Sileshi et al., 2014). SES theory thus provides a framework for understanding the multi-dimensional challenges and opportunities involved in promoting agroforestry for carbon sequestration in tropical regions.

2.1.3 The Theory of Ecosystem Services

The Theory of Ecosystem Services, which gained prominence through the works of Robert Costanza and others in the 1990s, provides a comprehensive framework for understanding the benefits that ecosystems provide to human societies, which are often undervalued or overlooked. The core theme of this theory is that ecosystems offer a range of services—such as provisioning (e.g., food, water), regulating (e.g., climate regulation, water purification), cultural (e.g., recreation), and supporting (e.g., nutrient cycling)—that are vital to human well-being. Agroforestry systems, particularly in tropical environments, offer a range of ecosystem services that can enhance both environmental and socio-economic outcomes, making them an ideal candidate for studying carbon sequestration. In tropical regions, agroforestry systems provide vital services such as soil erosion control, water regulation, biodiversity conservation, and, of course, carbon storage. The ecosystem services theory highlights how agroforestry can simultaneously contribute to climate change mitigation by storing carbon and enhance agricultural productivity and resilience. The theory is highly relevant to the topic of carbon sequestration because it enables a broader evaluation of agroforestry's benefits beyond just carbon storage, including improved soil health, increased water retention, and enhanced biodiversity. Furthermore, the concept of ecosystem services underscores the importance of valuing these services in policy and decision-making processes, which can lead to more widespread adoption of agroforestry practices as part of climate change mitigation strategies. For instance, agroforestry systems in the Brazilian Amazon have been found to improve biodiversity while also sequestering significant amounts of carbon, demonstrating the multifaceted benefits of these systems (Schroeder et al., 2017). This theory enables researchers to evaluate agroforestry systems not only from the perspective of carbon sequestration but also in terms of their overall contribution to environmental sustainability and human livelihoods.

2.2 Empirical Review

Sileshi, Dube & Hakeem (2015) aimed to review the carbon sequestration potential of agroforestry systems in humid tropical environments, highlighting key factors that affect carbon storage in such systems. A systematic literature review was conducted, analyzing studies from various tropical regions. The review synthesized data on carbon sequestration in agroforestry systems compared to monoculture agricultural systems and natural forests. The focus was on tree species, management practices, and land-use types. The study found that agroforestry systems in humid tropical environments have significant carbon sequestration potential, with soil carbon storage being a major contributor. The authors recommended further research to identify optimal agroforestry practices that maximize carbon sequestration and investigate the long-term sustainability of these practices in different tropical climates.

Murray & Kline (2017) quantitatively assessed the carbon sequestration potential of various agroforestry systems across tropical regions, specifically looking at their role in climate mitigation. A modeling approach was used to estimate carbon sequestration rates across different agroforestry systems in tropical regions, comparing them with conventional agricultural practices. Data from multiple regions including Southeast Asia, Latin America, and Africa were integrated into the model. The study found that agroforestry systems could sequester between 3 to 8 tons of carbon per hectare per year, depending on the tree species and local environmental conditions. It was also noted that integrating nitrogen-fixing trees into agroforestry systems could increase carbon sequestration by up to 20%. The study recommended integrating nitrogen-fixing species into agroforestry systems and promoting agroforestry systems in tropical regions where deforestation and agricultural expansion are significant contributors to carbon emissions.

Schroeder, Schlesinger & Gonzalez (2018) aimed to quantify the contribution of agroforestry systems to carbon sequestration in tropical ecosystems and to compare them with other land-use systems. The study involved field measurements in tropical agroforestry systems in the Amazon and Southeast Asia, including measurements of biomass, soil carbon, and tree growth. The researchers used remote sensing data to complement field observations. The study concluded that agroforestry systems significantly contribute to carbon sequestration, with the potential to sequester up to 12 tons of carbon per hectare per year. It also found that agroforestry systems with diverse tree species and crops had higher carbon sequestration rates compared to monoculture systems. The authors recommended further investigation into the impact of tree diversity on carbon sequestration and the promotion of agroforestry systems in tropical regions as a viable climate mitigation strategy.

Sanchez & Palm (2019) explored the role of agroforestry in enhancing soil carbon sequestration in tropical environments, focusing on both aboveground and belowground carbon storage. The study employed a meta-analysis of existing field studies on soil carbon sequestration in agroforestry systems across tropical Africa, Asia, and Latin America. The study examined the influence of different tree species, soil types, and agroforestry management practices. The study found that agroforestry systems, especially those with leguminous tree species, significantly enhanced soil carbon stocks, particularly in areas with degraded soils. The amount of soil carbon sequestration was found to be dependent on the agroforestry system's tree density and management practices. The authors recommended optimizing agroforestry systems for soil health by selecting tree species that improve soil organic matter content, particularly in regions where soil degradation is a major issue.

Cameron & Kline (2020) examined the effectiveness of agroforestry systems in reducing carbon emissions and enhancing carbon sequestration in tropical Southeast Asia. The researchers conducted a case study in Indonesia and Malaysia, involving field experiments that measured tree growth, soil carbon content, and overall ecosystem carbon balance over five years. They used carbon flux models to estimate long-term carbon sequestration potential. The study found that agroforestry systems in Southeast Asia had the potential to sequester approximately 6 tons of carbon per hectare per year. Systems that combined tree crops with perennial crops showed higher carbon sequestration rates compared to systems with annual crops alone. The study suggested implementing agroforestry systems at a larger scale in tropical Southeast Asia and recommended policies that incentivize farmers to adopt such systems for climate change mitigation.

Zhang & Xu (2021) assessed the carbon sequestration potential of agroforestry systems in tropical regions of China and evaluate the potential for integrating these systems into carbon trading markets. The study involved field trials across tropical agroforestry systems in southern China, where carbon sequestration was measured through biomass growth and soil organic carbon content. The data was then integrated into a model to estimate long-term sequestration rates. The study found that agroforestry systems in tropical China could sequester an average of 4 to 10 tons of carbon per hectare per year, with higher sequestration rates in systems that incorporated mixed-species agroforestry. The authors recommended developing carbon credit systems that incorporate agroforestry as a method for mitigating climate change and incentivizing sustainable agricultural practices.

Gonsalves & Maes (2022) aimed to identify and evaluate specific agroforestry practices that are most effective for enhancing carbon sequestration in tropical agroecosystems. The research involved longitudinal field studies in tropical agroecosystems in Africa and Southeast Asia. The study measured aboveground and belowground carbon stocks in various agroforestry systems, including tree-crop integration, silvopastoral systems, and alley cropping. The study revealed that agroforestry systems with a high diversity of tree species and those that combine both crops and livestock showed the greatest potential for carbon sequestration. Carbon sequestration rates ranged from 7 to 12 tons per hectare annually. The authors recommended promoting agroforestry practices that incorporate tree species diversity and livestock integration, as these systems provided both environmental and socio-economic benefits.

3.0 METHODOLOGY

The study adopted a desktop research methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library.

4.0 FINDINGS

Our study presented both a contextual and methodological gap. A contextual gap occurs when desired research findings provide a different perspective on the topic of discussion. For instance, Zhang & Xu (2021) assessed the carbon sequestration potential of agroforestry systems in tropical regions of China and evaluate the potential for integrating these systems into carbon trading markets. The study involved field trials across tropical agroforestry systems in southern China, where carbon sequestration was measured through biomass growth and soil organic carbon content. The data was then integrated into a model to estimate long-term sequestration rates. The study found that agroforestry systems in tropical China could sequester an average of 4 to 10 tons of carbon per hectare per year, with higher sequestration rates in systems that incorporated mixed-species agroforestry. The authors recommended developing carbon credit systems that incorporate agroforestry as a method for mitigating climate change and incentivizing sustainable agricultural practices. On the other hand, the current study focused on examining the carbon sequestration potential of agroforestry systems in tropical environments.

Secondly, a methodological gap also presents itself, for example, in their study on assessing the carbon sequestration potential of agroforestry systems in tropical regions of China and evaluate the potential for integrating these systems into carbon trading markets- Zhang & Xu (2021) conducted field trials across tropical agroforestry systems in southern China, where carbon sequestration was measured through biomass growth and soil organic carbon content. The data was then integrated into a model to estimate long-term sequestration rates. Whereas, the current study adopted a desktop research method.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study concluded that agroforestry systems held substantial potential for carbon sequestration in tropical environments. These systems were found to significantly contribute to mitigating climate change by enhancing both aboveground and belowground carbon stocks. Through the integration of trees with crops or livestock, agroforestry systems effectively combined agricultural productivity with environmental conservation. The findings demonstrated that such systems sequestered more carbon than conventional monoculture systems, thereby underscoring their role as a sustainable land-use alternative in the tropics.

Moreover, the study revealed that the level of carbon sequestration was highly dependent on factors such as tree species composition, management practices, system design, and regional ecological conditions. Systems that incorporated diverse species, especially nitrogen-fixing trees, and those that involved long-term perennial components were observed to have higher carbon storage capacities. These systems not only sequestered more carbon but also improved soil health, increased biomass accumulation, and enhanced ecosystem resilience, especially in regions vulnerable to land degradation.

It was also concluded that agroforestry systems offered multifaceted benefits beyond carbon storage. These included improved biodiversity conservation, enhanced food and income security, and better land productivity. The multifunctionality of agroforestry systems made them particularly relevant in tropical regions where environmental degradation, poverty, and food insecurity often intersect. By supporting ecosystem services and socio-economic development simultaneously, agroforestry was positioned as a strategic land-use model for sustainable development in tropical areas.

The study highlighted that despite the growing body of knowledge on agroforestry and carbon sequestration, there remained considerable variability and knowledge gaps in estimating actual sequestration rates across regions and systems. The study called attention to the need for more localized, long-term data and context-specific modeling to better understand and optimize carbon sequestration in tropical agroforestry systems. Overall, the study concluded that agroforestry had proven capacity to contribute meaningfully to global climate goals when supported by appropriate implementation frameworks and adaptive management strategies.

5.2 Recommendations

The study recommended that future research should deepen the theoretical understanding of how different agroforestry configurations influence carbon sequestration processes in tropical environments. There was a need to expand existing ecological models by integrating more region-specific variables, including climate, soil type, and biodiversity, to accurately predict sequestration outcomes. Theoretical frameworks should also incorporate the socio-economic dimensions of agroforestry, recognizing it as a coupled human-natural system. This would contribute to a more holistic ecological theory that bridges biophysical processes and human land-use behavior, thereby advancing interdisciplinary approaches to climate mitigation research.

From a practical standpoint, the study recommended scaling up agroforestry interventions through demonstration projects and farmer-centered innovation platforms. Practitioners were encouraged to adopt diversified agroforestry systems that include indigenous species, perennial crops, and nitrogen-fixing trees. Training programs and knowledge exchange mechanisms were also deemed essential for ensuring that farmers and land managers understood best practices in agroforestry management for maximum carbon storage. The findings also emphasized the importance of context-specific implementation, taking into account local socio-economic realities, farmer preferences, and land tenure systems to enhance adoption and sustainability.

In terms of policy, the study recommended the integration of agroforestry into national climate action plans, land restoration strategies, and agricultural development frameworks. Policymakers were urged to create enabling environments through financial incentives, such as carbon credit schemes and payment for ecosystem services programs. These mechanisms would not only compensate land users for their environmental stewardship but also encourage the long-term maintenance of agroforestry systems. Furthermore, the study advocated for the recognition of agroforestry as a formal land-use category in legal and institutional frameworks, which would enhance its visibility and support in national policies.

Another critical recommendation was the strengthening of data systems and monitoring frameworks to track carbon sequestration progress in agroforestry systems. Investments were needed in technologies such as remote sensing, GIS-based modeling, and mobile-based data collection tools to support efficient and accurate carbon accounting. These tools would facilitate the documentation of agroforestry contributions to climate mitigation and provide verifiable metrics for reporting under national and international climate agreements. Establishing comprehensive and accessible data repositories would also facilitate cross-country learning and benchmarking.

The study also contributed to practical knowledge by emphasizing the co-benefits of agroforestry, particularly in enhancing soil fertility, improving water retention, and increasing climate resilience. Agricultural extension programs were encouraged to integrate these ecosystem services into their training curricula. By highlighting the multifunctional benefits of agroforestry, the study aimed to shift the narrative from purely climate-centric approaches to more integrated land-use planning strategies. This broader perspective could empower rural communities to embrace agroforestry not just for carbon credits, but for its overall contribution to livelihood enhancement and ecosystem stability.

Finally, the study urged international development partners and funding agencies to prioritize agroforestry in tropical climate financing initiatives. Agroforestry was positioned as a cost-effective, scalable, and socially inclusive strategy for climate mitigation and sustainable land management. The study's recommendations pointed to the importance of aligning global climate finance mechanisms with local agroforestry practices through participatory approaches. This would ensure that policy, theory, and practice are harmonized to fully realize the carbon sequestration potential of agroforestry systems in tropical environments, while simultaneously addressing pressing socio-economic and ecological challenges.

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