*Original Research Article*

Assessment of Carbon Stock Potential of Arecanut Plantations in Coimbatore District of Tamil Nadu, India

ABSTRACT

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| Climate change, driven largely by anthropogenic greenhouse gas emissions, demands the identification of sustainable carbon sequestration strategies. Agroforestry systems, particularly plantation crops like arecanut (*Areca catechu* L.), have gained attention for their potential to serve as carbon sinks while offering socio-economic benefits. Despite widespread arecanut cultivation in India, its role in climate mitigation remains underexplored. This study aims to address the existing knowledge gap by quantifying the biomass and carbon stock of arecanut plantations in the Coimbatore district of Tamil Nadu, India. This study quantifies the biomass and carbon stock potential of arecanut plantations at two managed sites, Onappalayam (Site 1) and Vedapatti (Site 2) in the Coimbatore district of Tamil Nadu, India. Each site comprises a 1-hectare plantation with different intercrops (teak at Site 1 and coconut at Site 2) and crop spacing. Using a standardized quadrat method (25 quadrats per hectare), tree girth measurements were collected to estimate above-ground and below-ground biomass through established allometric equations. To estimate biomass, both above-ground biomass (AGB) and below-ground biomass (BGB) were calculated using standard allometric equations. Total carbon stock was calculated as 50% of the total biomass. Results revealed significantly higher tree density, biomass, and carbon stock at Site 1 compared to Site 2. Site 1 recorded a mean total biomass of 3.04 ± 0.95 tonnes/quadrat and total carbon stock of 1.52 ± 0.48 tonnes/quadrat, while Site 2 reported 1.61 ± 0.52 tonnes/quadrat and 0.80 ± 0.26 tonnes/quadrat, respectively. Differences were attributed to higher tree density and better soil potassium levels at Site 1. Above-ground carbon stock accounted 85% of total carbon, underscoring the dominant role of canopy biomass in carbon sequestration. This study demonstrates that arecanut plantations, beyond their economic value, possess substantial carbon storage potential. Given their long lifespan and adaptability, arecanut systems can contribute meaningfully to climate change mitigation efforts. The findings advocate for their inclusion in agroforestry-based carbon accounting and climate policy frameworks, particularly in tropical regions where such systems are already well established. As global concerns about climate change grow, it becomes increasingly important to recognize the role of agricultural and plantation systems in climate mitigation strategies. This study underscores the contribution of arecanut plantations to carbon sequestration and advocates for their integration into broader agroforestry systems. When managed sustainably, these plantations offer multiple benefits: they not only absorb atmospheric carbon but also improve soil quality, and provide steady income to farmers. |

*Keywords: Carbon sequestration; Arecanut plantation, Agroforestry, Biomass estimation, Climate change mitigation*

1. INTRODUCTION

Land and plant resources have been exploited for human needs and greed since civilization, impairing the ecological balance. Burning fossil fuels and destroying forest cover aggravate the problem, leading to the build-up of greenhouse gases (GHGs), predominantly Carbon Dioxide (CO2), one of the major culprits in global warming. Carbon is the major structural element in organic compounds and is an essential non-mineral nutrient element necessary for normal plant growth and development because plants are considered effective sinks that can fix the CO2 during the process of photosynthesis and store the surplus carbon as biomass and add to soil carbon upon senescence and decay (Wungshap et al., 2023). Climate change is among the most pressing global environmental challenges, primarily driven by anthropogenic greenhouse gas emissions (Filonchyk et al., 2024). In response, nations worldwide are prioritizing strategies to reduce atmospheric carbon dioxide (CO₂) concentrations, with particular attention on natural ecosystems that act as carbon sinks (Chen and Lin, 2021; Manjunath et al., 2024). While natural forests have long been recognized for their carbon sequestration potential, agroforestry systems are increasingly gaining recognition for their dual role in climate mitigation and socio-economic development (Ghale et al., 2022).

With the global demand for forests and forest products worldwide the importance of plantations has increased due to their economic meets. Also, the increases in plantation forests are reducing stress on natural forests for wood and other resources but also poses threat by replacing the natural forests (Dabi et al., 2021; Choden et al., 2021). Among agroforestry systems, plantation crops such as coconut (Kumar and Aggarwal, 2013; Nair, et al. 2018; Dissanayaka, et al. 2023; Pragasan and Kalaiselvi, 2024), oil palm (Paterson and Lima, 2018), and arecanut (Das, et al. 2021) are emerging as viable alternatives for climate change mitigation. These systems offer not only ecological benefits such as biodiversity conservation and soil protection, but also economic opportunities through mechanisms like carbon trading (Newaj et al., 2021).

Arecanut (*Areca catechu* L.), commonly known as betel nut, is a tropical palm cultivated predominantly for its nut, which is widely consumed across South and Southeast Asia (Gunjal et al., 2020). Globally, arecanut is cultivated over approximately 1.42 million hectares, with an annual production of around 2.1 million tonnes. India is the leading producer, accounting for 51.12% of the cultivation area and 57.56% of total production (Singh and Karun, 2022). Major producing states in India include Karnataka, Kerala, Assam, and West Bengal. While the economic significance of arecanut is well established, its ecological functions, particularly its potential role in carbon sequestration, remain underexplored.

Due to their perennial nature and long-standing canopy, arecanut plantations contribute to microclimate regulation, soil conservation, and increasingly, carbon sequestration (Demie et al., 2024). Through photosynthesis, trees fix atmospheric carbon, which is stored as biomass in both above-ground (stem, leaves, branches) and below-ground (roots) components (Pragasan and Karthick, 2013; Pragasan and Kalaiselvi, 2024). It is generally accepted that 50% of dry biomass is composed of carbon (Pragasan et al., 2025). Accurate estimation of biomass is thus crucial for assessing carbon stocks and understanding the role of land-use systems in the global carbon cycle. To address the regional carbon stock and carbon sequestration potential of the forest ecosystem, it is ultimately necessary to assess the forest biomass of the region. Researchers around the globe have used three major approaches, such as field-based measurements, an integrated approach of field inventory and satellite-based data, and the process-based ecosystem model (Galidaki et al., 2017).

In India, rapid development has led to rising CO₂ emissions, necessitating the evaluation of mitigation strategies, particularly in the context of the United Nations Framework Convention on Climate Change (UNFCCC) (Niles et al., 2002). Agroforestry not only sequesters carbon but also opens avenues for carbon credits, offering a sustainable income source for developing nations (Jindal et al., 2008). Despite the extensive area under arecanut cultivation, scientific studies on its carbon sequestration potential are limited (Demie et al., 2024). Most existing research has focused on productivity, pest management, and socio-economic impacts (Jose et al., 2011; Sujatha and Bhat, 2015; Nair and Nair, 2021; Mohanraj et al., 2021).

With increasing concern over global climate change, it is necessary to evaluate the carbon sink potential of agroforestry systems, including lesser-studied plantation crops like arecanut. Biomass estimation is essential for evaluating carbon stocks, and the Intergovernmental Panel on Climate Change (IPCC) provides guidelines for converting biomass into carbon stock using a standard carbon fraction of 0.5 (Brown and Lugo, 1982; Dixon et al., 1994; McRoberts et al., 2018).

This study aims to address the existing knowledge gap by quantifying the biomass and carbon stock of arecanut plantations in the Coimbatore district of Tamil Nadu, India. The novelty of this research lies in its focus on the underexplored carbon sequestration potential of arecanut plantations, with implications for both climate mitigation and economic sustainability through carbon trading mechanisms.

2. materialS and methods

This study was conducted on two managed arecanut (*Areca catechu* L.) plantations located in the Coimbatore district of Tamil Nadu, India. The two sites, designated as Site 1 (Onappalayam) and Site 2 (Vedapatti), are situated at coordinates 11°00'41.9″N & 76°52'19.7″E and 10°59'59.0″N & 76°53'17.6″E, respectively (Figure 1). Both plantations are approximately eight years old.

At Site 1, arecanut palms are planted at a spacing of 2 × 2 meters, with teak (*Tectona grandis*) used as an intercrop. In contrast, Site 2 features a wider spacing of 2.8 × 2.8 meters, with coconut (*Cocos nucifera*) as the intercrop species.

The two sites exhibit notable differences in soil characteristics (Table 1). Site 1 has a lower organic carbon content (0.32%) and a moderate level of available nitrogen (126 kg/ha), indicating relatively lower soil fertility compared to Site 2. However, Site 1 possesses higher levels of available potassium (693 kg/ha) and phosphorus (15.4 kg/ha), reflecting better nutrient availability in these specific components. The soil at both sites is alkaline, with a pH of 8.39 at Site 1 and 8.33 at Site 2, which may restrict the availability of certain micronutrients.

Site 2, on the other hand, shows higher organic carbon (0.70%) and available nitrogen (154 kg/ha), suggesting improved soil fertility and microbial activity. Nevertheless, it has lower levels of available phosphorus (11.6 kg/ha) and potassium (259 kg/ha), which could limit growth, particularly for potassium-demanding crops. Further, Site 2 exhibits a higher electrical conductivity (0.44 dS/m), indicating slightly increased soil salinity that may necessitate careful irrigation and salinity management.

Climatic data from the study area between 1991 and 2021 show an average annual rainfall of 952 mm, with approximately 77% of precipitation occurring between June and November. The region experiences an average monthly temperature of 25°C. The lowest recorded temperature is 18°C in January, while the highest reaches 35°C in April.



**Figure 1.** **Map showing the location of the study sites.**

**Table 1. Soil characteristics of the two study sites.**

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| **Parameter** | **Site 1** | **Site 2** |
| Organic Carbon (%) | 0.32 % | 0.70 % |
| pH | 8.39 | 8.33 |
| EC (dS/m) | 0.16  | 0.44  |
| Available N (kg/ha) | 126  | 154  |
| Available P (Olsen’s) (kg/ha)  | 15.4  | 11.6  |
| Available K (kg/ha) | 693  | 259  |

At each study site, a standardized plot of 100 m × 100 m (1 hectare) was established within the arecanut plantation to facilitate direct comparisons between the two sites. The plots were demarcated using measuring tapes, and their boundaries were marked with ropes.

Data collection was carried out using the quadrat method, a standard non-destructive sampling technique widely used in ecological studies. This method is particularly suitable for plantation and forest ecosystems where destructive sampling (e.g., cutting and weighing trees) is impractical due to ecological and economic considerations.

Within each 1-hectare plot, 25 quadrats of 20 m × 20 m dimensions were systematically laid out. All arecanut trees within each quadrat were identified and measured. For every tree, the girth at breast height (GBH) was measured at 1.3 meters above ground level using a measuring tape.

The tree density was calculated by recording the total number of trees across all 25 quadrats and extrapolating this number to a per-hectare basis.

To estimate biomass, both above-ground biomass (AGB) and below-ground biomass (BGB) were calculated using standard allometric equations. The equations proposed by Brown et al. (1989) were used for AGB estimation, and those by MacDicken (1997) for BGB. The total biomass (TB) was obtained by summing AGB and BGB.

The total carbon stock (TC) of each tree was calculated as 50% of the total biomass, following the conversion factor proposed by Timilsina et al. (2014). The allometric equations used for biomass and carbon stock estimation are provided in Table 2.

To determine whether there were statistically significant differences between the two study sites in terms of tree density, biomass, and carbon stock, an independent samples *t*-test was conducted.

**Table 2. Allometric equations for estimation of biomass and carbon stock.**

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| --- | --- | --- |
| **Parameter** | **Allometric equation** | **Reference** |
| Above-ground biomass | AGB = 34.4703 – 8.0671D + 0.6589 D2 Where, D is diameter at breast height in cm | Brown et al., 1989 |
| Below-ground biomass | BGB = AGB x (15/100)  | MacDicken, 1997 |
| Total biomass | TB = AGB + BGB  | Pragasan and Kalaiselvi, 2024 |
| Above-ground carbon stock | AGC = AGB x (50/100)  | Timilsina *et al.*, 2014 |
| Below-ground carbon stock | BGC = BGB x (50/100) | Timilsina et al., 2014 |
| Total carbon stock | TC = BGB x (50/100) | Timilsina et al., 2014 |

3. results

**3.1 Tree Density**

A total of 2,404 arecanut trees were recorded across 50 quadrats (covering a combined area of 2 hectares) from both study sites. Site 1 recorded a tree density of 1,376 trees per hectare, whereas Site 2 had a density of 1,028 trees per hectare. Similarly, the mean tree density per quadrat was higher in Site 1 than in Site 2, indicating a denser plantation at Site 1 (Figure 2). The *t*-test showed that the tree density varied significantly between the two study sites (*t*(24) = 5.256, p < 0.0001).

**3.2. Biomass Estimation**

The mean AGB per quadrat was significantly higher in Site 1 (2.64 ± 0.83 tonnes/quadrat) compared to Site 2 (1.40 ± 0.45 tonnes/quadrat). AGB values ranged from 0.94 to 4.95 tonnes/quadrat in Site 1, and from 0.57 to 2.44 tonnes/quadrat in Site 2.

Similarly, the mean BGB per quadrat was 0.40 ± 0.12 tonnes for Site 1 and 0.21 ± 0.07 tonnes for Site 2. BGB values ranged from 0.14 to 0.74 tonnes/quadrat at Site 1 and 0.09 to 0.37 tonnes/quadrat at Site 2.

The TB was calculated as the sum of AGB and BGB, averaged 3.04 ± 0.95 tonnes/quadrat for Site 1 and 1.61 ± 0.52 tonnes/quadrat for Site 2. The TB values ranged from 1.08 to 5.69 tonnes/quadrat at Site 1 and 0.65 to 2.81 tonnes/quadrat at Site 2. Further, the *t*-test revealed that the TB varied significantly between the two study sites (*t*(24) = 7.331, p < 0.0001).

**Figure 2. The density of arecanut trees in the two study sites.**

**3.3. Carbon Stock**

Carbon stock values were derived from the corresponding biomass measurements. At Site 1, the mean AGC, BGC, and TC were 1.32 ± 0.41 tonnes/quadrat, 0.20 ± 0.06 tonnes/quadrat, and 1.52 ± 0.48 tonnes/quadrat, respectively (Figure 3). The AGC values ranged from 0.47 to 2.47 tonnes/quadrat, BGC from 0.07 to 0.37 tonnes/quadrat, and TC from 0.54 to 2.84 tonnes/quadrat.

At Site 2, the mean AGC, BGC, and TC were 0.70 ± 0.22 tonnes/quadrat, 0.10 ± 0.03 tonnes/quadrat, and 0.80 ± 0.26 tonnes/quadrat, respectively (Figure 4). AGC values ranged from 0.28 to 1.22 tonnes/quadrat, BGC from 0.04 to 0.18 tonnes/quadrat, and TC from 0.33 to 1.40 tonnes/quadrat.

A significant difference in TC of arecanut trees was obtained between the two sites (*t*-test: *t*(24) = 7.331, p < 0.0001), similar to that of TB. Across both sites, AGC was the dominant component, accounting for approximately 85% of the TC. While the contribution of BGC was comparatively smaller, it still plays a critical role in long-term carbon storage and highlights the ecological significance of root systems in overall carbon sequestration.

**Figure 3. Distribution of carbon stock for arecanut trees at Site 1.**

**Figure 4. Distribution of carbon stock for arecanut trees at Site 2.**

4. discussion

In this study, Site 1 consistently outperformed Site 2 in both biomass and carbon stock (measured in tonnes per quadrat). This difference is likely influenced by the higher tree density at Site 1 (1,376 trees/ha), which is approximately 14% greater than that of Site 2 (1,028 trees/ha). Greater tree density generally results in higher cumulative biomass and, consequently, enhanced carbon storage. Figures 5 and 6, reveal that the density of trees had a positive relation with total carbon stock in both the study sites.

**Figure 5. Relationship between tree density and total carbon stock at Site 1.**

**Figure 6. Relationship between tree density and total carbon stock at Site 2.**

Soil characteristics also appear to play a role. Site 1 exhibited significantly higher potassium content (693 kg/ha), which may have enhanced plant metabolic processes, microbial activity, and organic matter decomposition factors that contribute to increased biomass and carbon sequestration. In addition, better management practices such as regular irrigation, fertilization, and timely maintenance could further explain Site 1's superior performance.

The mean TC per quadrat at Site 1 (1.52 ± 0.48 tonnes) was nearly double that of Site 2 (0.80 ± 0.26 tonnes), demonstrating how local agronomic conditions and plantation management can significantly influence carbon sink potential. These findings reinforce the idea that arecanut plantations, when well-managed, can function as effective carbon sinks.

Previous studies in agroforestry systems have shown that plantation crops can exhibit moderate to high carbon sequestration potential, depending on species, spacing, and cultural practices (Kumar and Kunhamu, 2021). The factors influencing this potential include tree maturity, climate, soil fertility, and stem density (Brahma et al. 2018). While there is limited literature specifically focusing on arecanut (*Areca catechu* L.), early research suggests it holds considerable promise, especially in dense monoculture or mixed plantation systems (Sujatha and Bhat, 2015).

According to Singh and Karun (2022), arecanut plantations are capable of sequestering approximately 7 tonnes of CO₂ per hectare per year, positioning them as viable long-term carbon sinks given their average lifespan of 60 to 70 years (Hebbar et al., 2024). This longevity enhances their value as a sustainable land-use option for both ecological and economic benefits.

The study employed non-destructive quadrat sampling, a widely accepted method in ecological and forestry research (Pragasan and Karthick, 2013; Brown et al., 1989). While destructive sampling remains the most accurate technique, it is impractical in commercial plantations. Thus, using allometric equations to estimate above-ground and below-ground biomass offers a reliable alternative, especially in tropical regions where such equations are well-established (e.g., Chave et al., 2005; MacDicken, 1997). For BGB, which is challenging to measure directly, a default ratio of 15% of AGB was applied as per standard practice (Pragasan et al., 2025).

International frameworks such as the UNFCCC and IPCC have emphasized land-based mitigation strategies, including agroforestry and perennial plantations, as effective means for sequestering carbon (UNFCCC, 1997; IPCC, 2007). Under programs like REDD+, such systems are recognized not only for their carbon storage potential but also for co-benefits like biodiversity enhancement, erosion control, microclimate regulation, and rural livelihood support (Gosnell et al., 2022). However, crops like arecanut remain underrepresented in national and global carbon accounting models.

We advocate for the broader inclusion of arecanut-based agroforestry systems in carbon sequestration strategies, particularly in degraded or marginal lands. These systems offer a cost-effective and scalable solution for enhancing ecological stability while supporting local economies (Newaj et al., 2021).

5. CONCLUSION

This study evaluated the biomass and carbon stock potential of arecanut (*Areca catechu* L.) plantations at two sites, Onappalayam (Site 1) and Vedapatti (Site 2), in the Coimbatore district of Tamil Nadu, India. The findings revealed that Site 1 exhibited significantly higher above-ground biomass (2.64 tonnes per quadrat) and below-ground biomass (0.40 tonnes per quadrat) compared to Site 2, which recorded 1.40 and 0.21 tonnes per quadrat, respectively. Consequently, the total biomass at Site 1 (3.04 ± 0.95 tonnes per quadrat) was almost double that of Site 2 (1.61 ± 0.52 tonnes per quadrat). A similar trend was observed in carbon stock values. The above-ground carbon stock and below-ground carbon stock at Site 1 were 1.32 and 0.20 tonnes per quadrat, while Site 2 recorded 0.70 and 0.10 tonnes per quadrat, respectively. Total carbon stock was estimated at 1.52 ± 0.48 tonnes per quadrat at Site 1 and 0.80 ± 0.26 tonnes per quadrat at Site 2.

These results demonstrate that arecanut plantations, though primarily cultivated for commercial nut production, also serve as important carbon sinks. The observed differences in biomass and carbon stock between the two sites highlight the influence of tree density, soil fertility, and management practices on carbon sequestration potential. Site 1, with its higher tree density and greater nutrient availability, particularly potassium demonstrated significantly higher carbon storage capacity.

As global concerns about climate change grow, it becomes increasingly important to recognize the role of agricultural and plantation systems in climate mitigation strategies. This study underscores the contribution of arecanut plantations to carbon sequestration and advocates for their integration into broader agroforestry systems. When managed sustainably, these plantations offer multiple benefits: they not only absorb atmospheric carbon but also improve soil quality and provide steady income to farmers.

Although the scope of this study was limited to two plantation sites, it offers a valuable foundation for future research into the ecological functions of tropical plantation crops. It also highlights the need to include such crops in national and global carbon accounting frameworks. As the world moves toward ambitious climate targets, tapping into the potential of underrepresented land-use systems like arecanut cultivation could play a significant role in achieving long-term sustainability and environmental resilience.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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