

Full Length Research Paper

Comparative studies of carbon stocks in cashew (*Anacardium occidentale* L.) plantations and primary forest in southeast Ghana

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Trees are essential for carbon sequestration, a critical process for mitigating global climate change. Assessing the carbon stock potential of primary forests and cashew plantations is crucial, especially given the considerable degradation of forest resources in southern Ghana. A series of parallel permanent transects each up to 1 km in length and spaced 200 m apart, were established across different land use types, with their locations determined using GPS. In each community, fifteen cashew plots measuring 20 × 20 m (extending 10 m on either side of the transect) were established at 40-m intervals along the transects. Additionally, fifteen plots of the same size were set up within the forest reserve. A total of sixty plots were delineated in both the cashew plantations and the natural forest. The study revealed a decline in carbon stocks from forest trees within cashew plantations; however, total carbon stocks were higher in 20 to 30-year-old cashew plantations compared to the natural forest reserve. This suggests that carbon storage increases with the age of cashew plantations, emphasizing their potential role in mitigating the effects of climate change.

Key words: Carbon sequestration, biomass, primary forest, cashew, climate change.

INTRODUCTION

Tropical forests are among the richest and most complex terrestrial ecosystems, supporting a diverse array of life forms and demonstrating a tremendous intrinsic ability for self-maintenance (Swamy et al., 2010; Baboo et al., 2017).

However, many of these forests are losing this ability due to excessive biotic interferences, such as anthropogenic perturbations and uncontrolled grazing (Fartyal et al., 2024). As major components of terrestrial

ecosystems, forests represent the largest carbon reservoirs and play a critical role in climate change mitigation by absorbing atmospheric carbon dioxide through photosynthesis. Terrestrial ecosystems absorb about 2.3 Gt of carbon annually (Cherinet and Lemi, 2023), with tropical forests, covering roughly 60% of global forested areas, being particularly significant as carbon sinks (Cherinet and Lemi, 2023). According to Chisanga et al. (2018), effective carbon sequestration

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relies on tree biomass production, which stores carbon in above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter.

Despite the crucial role of forests in climate regulation, deforestation and agricultural intensification have led to significant carbon dioxide emissions. Major causes of forest degradation include population increase, agricultural intensification, and infrastructure development, all of which adversely affect biodiversity and ecosystem functioning (Davidar et al., 2010; Bargali et al., 2019, 2022; Bisht et al., 2024). These factors contribute to an increase in greenhouse gases in the atmosphere and exacerbate climate change (Arora et al., 2011). Disturbances also affect forests and other land use systems in terms of microbial activity (Han et al., 2021; Manral et al., 2020, 2023; Padalia et al., 2022), decomposition patterns and nutrient release (Bargali et al., 2015; Awasthi et al., 2022), microclimates, and nutrient cycling (Bäumler, 2015; Vibhuti et al., 2020; Karki et al., 2022; Pandey et al., 2024), resulting in biodiversity loss (Fartyal et al., 2022).

Deforestation and degradation of tropical forests account for approximately 20 to 25% of global annual carbon dioxide emissions, representing a substantial driver of climate change (Hashmiu, 2012). However, establishing plantations, such as those for cashew, could provide an opportunity to reduce greenhouse gas emissions. Agricultural plantations, including cashew and oil palm, contribute to carbon sequestration by capturing atmospheric CO₂ through photosynthesis and storing it in biomass.

Cashew cultivation has gained prominence in Ghana, particularly for its economic benefits, such as generating income for farmers and supporting rural livelihoods. However, like other agricultural expansions, cashew farming presents both environmental opportunities and challenges in the context of climate change. According to Ashiagbor et al. (2020), cashew plantations in Ghana, especially in the Wenchi Municipality, expanded by 31,103.05 ha between 2000 and 2020, increasing above-ground carbon from 599,956.73 tons to 1,039,402.32 tons—a rise of 696,219.15 tons (883.5%).

These findings indicate that cashew plantations could play a significant role in climate change mitigation, particularly in forest-savannah transitional zones (Victor et al., 2021).

Soil organic carbon (SOC) is another crucial component for maintaining soil health and regulating greenhouse gases, directly affecting climate change outcomes (Hagedorn, 2018). SOC levels are influenced by factors such as rainfall, temperature, vegetation, and soil type (Kirkegaard, 2007). However, there is limited research on the trade-offs between agricultural practices and carbon storage in cashew plantations in Southern Ghana. Understanding these dynamics is vital for informing strategies that contribute to global carbon markets and initiatives like Payment for Environmental

Services within cashew plantations.

This study aims to fill the gap by quantifying above- and below-ground carbon stocks in various cashew plantations in Southern Ghana. The research focuses on the carbon dynamics of cashew agro-ecosystems and explores their potential implications for climate change mitigation and sustainable agricultural practices. The hypothesis driving this study is that cashew plantations can serve as effective carbon sinks, contributing to both environmental sustainability and economic development.

MATERIALS AND METHODS

Location of the study site

The study was conducted in three cashew-growing communities in the Ashanti Mampong municipality, namely Nkwanta, Abuotem, and Bomsumkyekye, located approximately twelve to fifteen kilometers from the municipal center (Figure 1).

Geographically, Ashanti Mampong municipality lies between longitudes 0°05' and 1°30' W and latitudes 6°55' and 7°30' N, encompassing a total land area of 449 km². It shares borders with the Sekyere South District, Sekyere Central District, and Ejura-Sekyedumasi District.

The study area experiences two distinct seasons: a major rainy season and a minor season. The average annual temperature is 27°C, with monthly temperature variations ranging from 22 to 30°C. The area is situated within the wet semi-equatorial forest zone. However, human activities such as charcoal production, logging, and bushfires have degraded the forest vegetation, particularly in the northeastern region, transforming it into savannah.

Common tree species found in the area include *Terminalia ivorensis* A. Chev., *Khaya ivorensis* A. Chev., *Triplochiton scleroxylon* K. Schum, *Cedrela odorata* Blanco, and *Milicia excelsa* (Welw.) C.C. Berg. Other food crops grown in the area include *Musa sapientum* L., *Musa paradisica* L., *Manihot esculenta* Crantz, *Zea mays* L., *Colocasia esculenta* (L.) Schott, and *Elaeis guineensis* Jacq.

The fourth site of interest is the Tano-Offin Forest, located in the Atwima Mponua District of the Ashanti Region, Ghana (Figure 2). It lies between longitudes 6°54' N and 6°35' N, and latitudes 1°57' W and 2°17' W. The forest is home to a variety of plant species, including *Cynometra ananta*, *Heritiera utilis*, and *Tieghemella heckelii*, and serves as a watershed for two major rivers in the Ashanti Region. The Tano-Offin Forest is renowned for its rich biodiversity and the socio-economic services it provides to surrounding communities. It is also designated as a protection area (Globally Significant Biodiversity Area, GSBA) for both plant and animal species.

Sampling procedure

Sampling was carried out using a series of parallel permanent transects, each up to 1 km long and spaced 200 m apart, established across different land use types. Their positions were determined using the Global Positioning System (GPS). In each community, fifteen cashew plots measuring 20 m × 20 m (extending 10 m on either side of the transect) were set up at 40-m intervals along the transects. An additional fifteen plots of the same dimensions were established within the forest reserve. In total, sixty plots were delineated in both the cashew plantations and the natural forest. The cashew plantations were grouped into three age categories: 1 to 10, 10 to 20, and 20 to 30 years.



Figure 1. Map showing cashew growing communities in the Ashanti Mampong municipality.

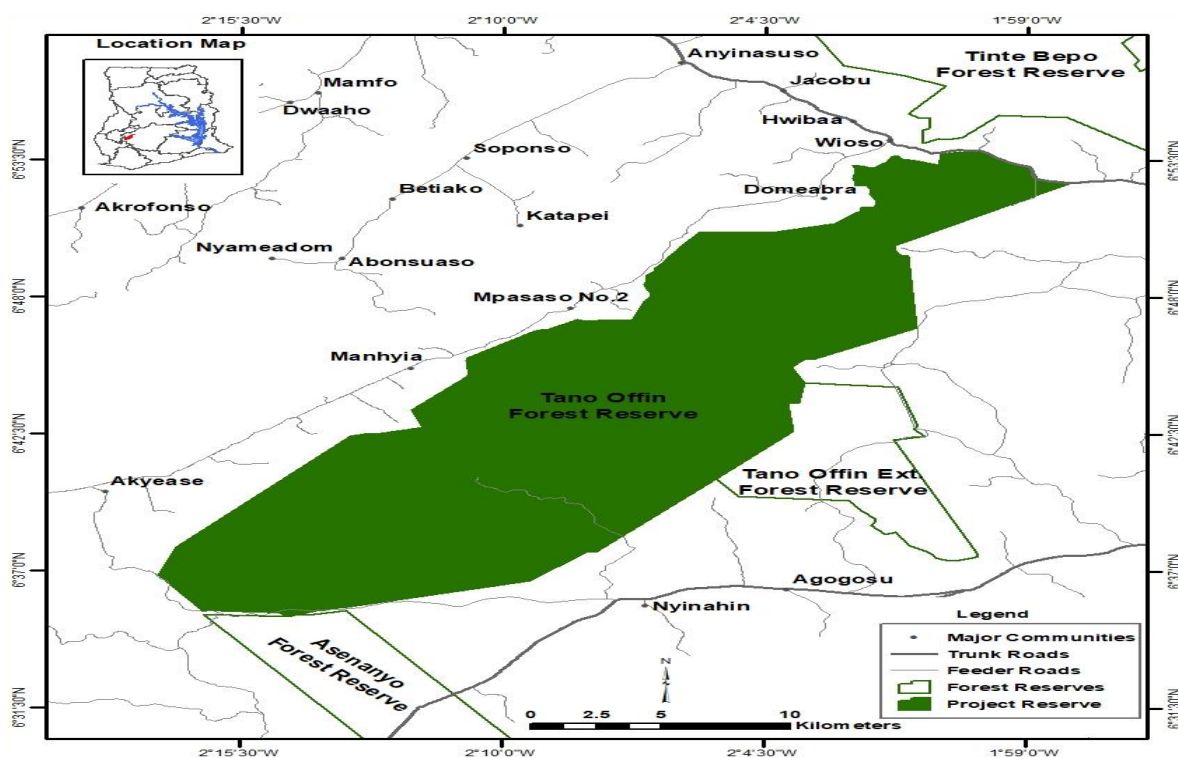


Figure 2. Map showing Tano offin forest reserve in the Ashanti region of Ghana.

Estimation carbon stocks

To estimate the biomass of cashew trees, each tree with a diameter

at breast height (DBH) of ≥ 5 cm, measured at 1.3 m above ground within the 20×20 m plot, was identified and recorded. The total height of the trees was measured using a clinometer. The biomass

was then calculated using an allometric equation ($AB = (-0.463 \times D) + (0.356 \times D^2) + (0.008 \times D^3)$) as cited by Cairns et al. (1997). The amount of carbon (Mg/ha) was obtained by multiplying the biomass by a conversion factor ($CF = 0.5$). The above-ground biomass of forest trees was estimated using the allometric model proposed by Henry et al. (2010), which calculates tree biomass as $Y = 0.30 \times d^{2.31}$, where Y represents tree biomass and d is the diameter at breast height. This model was specifically developed for tropical African forests, distinct from the equations of Chave et al. (2005) and Brown et al. (1989), which were formulated for forests in South America and Asia, respectively. Soil Organic Carbon (SOC) was assessed in the cashew plantations and the forest reserves based on the carbon percentage and soil bulk density. The soil carbon content percentage was determined using the wet combustion method of Walkley and Black (1934) as cited in Tetteh et al. (2018). Bulk density was determined using the core method (Blake, 1965). The sampler was inserted into the soil at each depth and gently hammered until fully buried. Subsequently, the core sampler was extracted, trimmed at both ends, and any extraneous soil was removed from the sides. The soil sample was then placed into a brown envelope, oven-dried at 105°C for 48 h following the procedures outlined by Tetteh et al. (2018). Bulk density was calculated as the ratio of the dry weight of the soil to its volume. Soil organic carbon per hectare was computed using the formula: $(\%C) \times (\text{bulk density}) \times (\text{soil depth})$, with bulk density measured in g/cm^3 and soil depth in cm. SOC stock was converted into Mg C ha^{-1} . To adjust for variations in soil bulk densities across different age groups of cashew plantations, the thickness of the soil layer beneath the cashew farms was modified based on equations provided by Lemenih et al. (2005).

Statistical analysis

The data obtained were subjected to a one-way analysis of variance. The Shapiro-Wilk test (Crawley, 2007) was used to assess normality and homogeneity of variance. When the test indicated a significant difference, means were compared using the post hoc Tukey HSD test. The analysis was conducted using R software version 4.1.1.

RESULTS

Above-ground carbon stocks

The total carbon storage per unit area varied significantly across different ages of cashew farms and the natural forest ($p \leq 0.001$). The study revealed that farms aged 20 to 30 years had the highest total carbon stock per unit area, with a mean of $85.27 \pm 4.74 \text{ Mg ha}^{-1}$ (Table 1). This was followed by the natural forest reserve, with a mean of $83.88 \pm 23.92 \text{ Mg ha}^{-1}$, while the lowest carbon storage, $65.15 \pm 4.41 \text{ Mg ha}^{-1}$, was recorded in farms aged 1 to 10 years. The majority of carbon stock across all land use types was stored in forest trees. Among the different cashew-growing communities, Nkwanta had the highest total carbon stock, while the lowest was recorded in Abuotem. The study also found that the total carbon stock in the forest reserve was approximately thirteen times higher than that in 1 to 10-year-old farms and ten times higher than that in 20 to 30-year-old farms (Table 1). Forest trees contributed 4.24% of the total carbon stock

in 1 to 10-year-old farms, 18.4% in 10 to 20-year-old farms, and 77.2% in the natural forest. The difference in total carbon stock between the forest reserve and 1 to 10-year-old cashew farms was statistically significant (post hoc Tukey HSD, $p \leq 0.001$). The above-ground carbon stored in forest trees is presented in Table 1. The mean carbon stock per farm was significantly influenced by land use type ($p \leq 0.001$). The natural forest had the highest average carbon stock per unit area, with a mean value of $80.46 \pm 23.45 \text{ Mg ha}^{-1}$, followed by 20 to 30-year-old cashew farms, which stored 30.13 Mg ha^{-1} . Carbon stocks from forest trees varied significantly among land use types ($p \leq 0.01$), with the natural forest having the highest stock, while the lowest was found in 1 to 10-year-old cashew farms. However, the difference in forest tree carbon stocks between 20 to 30 and 10 to 20-year-old cashew farms was not statistically significant (post hoc Tukey HSD, $p = 0.129$). Cashew trees also stored substantial amounts of carbon across different age groups of cashew farms. The results showed that 20-30-year-old farms stored more carbon $48.29 \pm 2.63 \text{ Mg ha}^{-1}$ compared to 1 to 10-year-old farms, which stored $34.44 \pm 2.44 \text{ Mg ha}^{-1}$. Carbon stocks contributed by cashew trees varied significantly among different age groups of cashew farms ($p \leq 0.01$). Of the total carbon stored in cashew farms, 27.31, 34.37, and 38.34% were stored in the 1 to 10, 10 to 20, and 20 to 30-year-old cashew farms, respectively. Therefore, a significant portion of above-ground carbon was stored in cashew trees.

Soil organic carbon

Soil organic carbon varied significantly across different age groups of cashew farms and the forest reserve ($p \leq 0.001$). The study found that the mean soil organic carbon was highest in the forest reserve ($3.28 \pm 0.19 \text{ Mg ha}^{-1}$) and lowest in the 20-30-year-old farms ($1.67 \pm 0.10 \text{ Mg ha}^{-1}$) (Figure 3). Soil carbon stocks exhibited a decreasing trend from 1 to 10 to 10 to 20 to 20 to 30-year-old cashew farms. However, the difference in soil organic carbon between the 10-20 and 20-30-year-old farms was not statistically significant (post hoc Tukey HSD, $p = 0.99$).

DISCUSSION

The study shows that carbon stock is significantly higher in above-ground biomass than in below-ground biomass, consistent with the findings of Asase and Tetteh (2016), Tetteh et al. (2018), and Victor (2021). Across plantations, above-ground carbon stocks ranged from 58.12 to 83.9 Mg/ha , differing from the values reported by Victor (2021). This underscores the crucial role forest trees play in contributing to the carbon stock in natural forests. For instance, Chave et al. (2005) estimated that

Table 1. Carbon stocks (Mg ha⁻¹) in the different age group of cashew farms and natural forest reserve.

Parameter	Locality	1-10 years	10-20 years	20-30 years	Natural forest reserve	Statistical significance difference
Forest tree	Nkwanta	9.23 (0.42)	7.21 (0.45)	13.89 (0.45)		P < 0.001
Cashew tree		12.75 (0.87)	15.26 (0.58)	16.27 (0.49)	-	P > 0.05
SOC		2.10 (0.31)	1.76 (0.29)	1.53 (0.29)	-	P < 0.001
Total carbon		23.98 (1.60)	24.23 (1.32)	31.69 (1.23)	-	P < 0.001
Forest tree	Abuotem	8.34 (0.42)	6.32 (0.49)	7.79 (0.43)		
Cashew tree		10.05 (0.98)	14.38 (0.98)	17.56 (1.34)	-	P > 0.05
SOC		2.78 (0.41)	1.84 (0.31)	1.42 (0.02)	-	P < 0.001
Total carbon		21.17 (1.81)	22.54 (1.78)	26.77 (1.79)	-	P < 0.01
Forest tree	Bosumkyekye	6.21 (0.43)	9.42 (0.65)	8.45 (0.87)		
Cashew tree		11.64 (0.59)	13.61 (0.58)	16.84 (0.80)	-	P < 0.001
SOC		2.15 (0.04)	1.63 (0.04)	1.52 (0.05)	-	P < 0.001
Total carbon		20.00 (1.06)	24.66 (1.27)	26.81 (1.72)	-	P < 0.001
Forest tree	Tano Offin forest				80.46 (23.45)	
Cashew tree		-	-	-	-	
SOC		-	-	-	3.42 (0.47)	
Total carbon					83.88 (23.92)	
Overall total (Mg/ha ⁻¹)		65.15 (4.47)	71.43 (4.37)	85.27 c(4.74)	83.8 (23.92)	

late secondary and primary forests in the Panama Canal Watershed store 251.7 Mg C ha⁻¹ in above-ground carbon, providing a valuable point of comparison.

When examining non-tree species across different land-use types, it is evident that carbon fractions are consistently higher in natural forests than in cashew plantations. This suggests that forest trees in natural reserves are vital for maintaining total carbon stocks, largely due to factors such as diameter at breast height, basal area, and species density. The observed decline in forest tree density within cashew plantations further supports this conclusion. Variations in carbon stocks among forest trees can be

attributed to differences in vegetation type and management practices, with the Nkwanta community showing slightly higher above-ground carbon stocks than other cashew-growing areas.

Additionally, the study finds that older cashew tree farms (over 20 years old) in Nkwanta sequester more carbon in their above-ground biomass, likely due to increased diameter at breast height, basal area, age, and tree density. This finding contradicts the results of Awe et al. (2020) in Cameroon and suggests that carbon stocks tend to increase with the age of cashew farms, emphasizing the importance of tree maturity in carbon sequestration.

Regarding soil organic carbon, the study reveals

a decreasing trend in cashew plantations compared to natural forest reserves. Generally, physico-chemical properties vary in space and time due to variations in topography, climate, weathering processes, vegetation cover, and microbial activities (Paudel and Sah, 2003; Bargali et al., 2018) and several other biotic and abiotic factors (Bargali et al., 2019; Pandey et al., 2024). In highly dissected landscapes, bioclimatic conditions can change rapidly, resulting in pronounced heterogeneity in the physicochemical properties of soil (Baumler, 2015; Bargali et al., 2019).

This difference is likely attributed to the ecosystem characteristics of natural forests, such

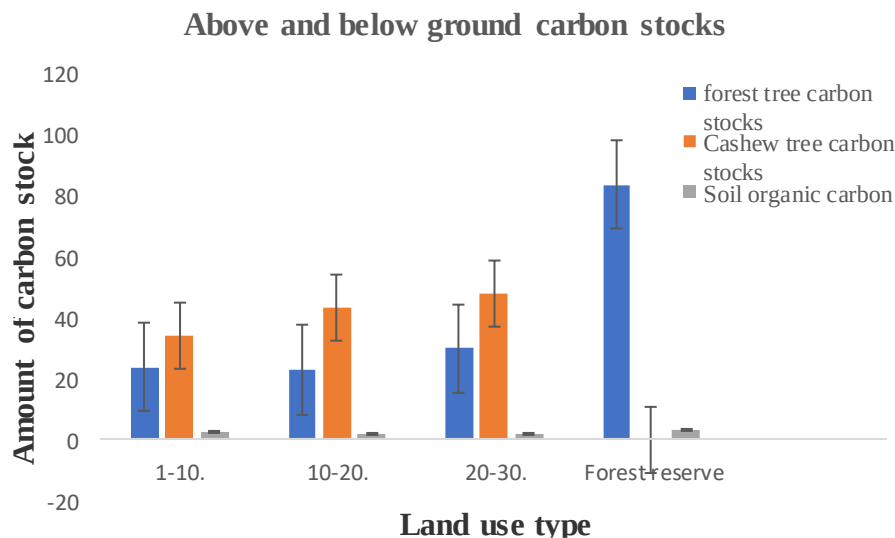


Figure 3. Proportions of above and below group carbon stocks (Mg ha^{-1}) in the different age of cashew farms and natural forest reserve.

as higher litter input, microbial activity, and decomposition rates, which lead to greater humus accumulation than in cashew farmlands. The type of vegetation significantly impacts soil organic carbon levels, with natural forests showing approximately three times higher soil organic carbon stocks than cashew plantations. These findings align with earlier studies by Bessah et al. (2016) in the Guinea savanna and transition agroecology in Ghana but contrast with the results of Awe et al. (2020).

This study contributes to the existing body of knowledge by highlighting the significant roles of tree age, species density, and land management practices in carbon sequestration within cashew plantations. The finding that older cashew plantations sequester more carbon is particularly novel, as it challenges previous assumptions and studies, such as those by Awe et al. (2020). Future research should focus on examining the long-term carbon sequestration potential of various age groups. Additionally, further studies could investigate the impact of specific management practices on carbon stocks in both above-ground biomass and soil. Given the observed differences in soil organic carbon between natural forests and cashew plantations, future research should explore the mechanisms driving these disparities and consider strategies to enhance soil carbon storage in agricultural landscapes.

Conclusions

This study demonstrated that cashew plantations, as agroforestry systems, store varying amounts of carbon depending on the cultivation area and the age of the plantations. Carbon storage increases with the age of the

cashew plantations.

Reforestation efforts aimed to expand forested areas can create new carbon pools, with their effectiveness dependent on the quality and growth rate of the reforested species. Conserving tree diversity in cashew plantations enhances long-term carbon sequestration, significantly contributing to sustainable development. Therefore, cashew plantations have the potential to mitigate the impacts of climate change.

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CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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