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A comparative study among different agroforestry systems and natural forests in southern Ghana

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Human disturbance in forest ecosystems poses a significant threat to biodiversity conservation. However, agroforestry systems, offer hope for biodiversity conservation and sustainable agricultural production. Despite this potential, the roles of various agroforestry systems in conserving biodiversity and maintaining ecosystem services are poorly understood. In this study, tree species diversity was investigated, and conservation implications were assessed in the three different agroforestry systems compared to natural forests. Sampling was conducted using parallel transects, establishing fifteen plots each measuring, 20 m × 20 m at 100 m intervals within cocoa, coffee, and cashew agroforestry farmlands. Similarly, fifteen plots each measuring, 20 m × 20 m were marked at 100 m intervals along three parallel transects in the natural forest. The findings revealed a significant reduction in tree species diversity between the agroforestry farmlands compared to natural forests. The findings also indicated a similarity in plant species in the different agroforestry farmlands and compared to the natural forest. Although agroforestry farmlands do not fully substitute for natural forests, they still support a notable amount of tree diversity, contributing to biodiversity conservation within agricultural landscapes. These findings have important implications for the sustainable management of tropical agricultural production landscapes.

Key words: Biodiversity, conservation, deforestation, agroforest, ecosystems.

INTRODUCTION

Tropical rainforests serve as vital reservoirs of biodiversity, harboring one-third of the world's species diversity (Pillay et al., 2022). However, the availability of valuable goods and ecosystem services provided by these forests is rapidly diminishing, especially in developing countries, due to deforestation and degradation (FAO, 2020). This decline poses a significant threat to ecological wealth, jeopardizing both agricultural productivity and biodiversity preservation. As noted by Ma et al. (2023), converting forests to agricultural lands is a widespread practice in the tropics. Unfortunately, prevalent farming practices, such as slash-and-burn,

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shifting cultivation, and monoculture, have proven to be unsustainable and environmentally detrimental. The continued use of these methods, combined with a rapidly growing population, has driven farmers to seek increasingly larger tracts of land to meet their needs for food, fodder, and fuelwood (Tetteh et al., 2018). Consequently, sustaining or boosting agricultural production often necessitates expansion into new areas, leading to significant land degradation, the gradual loss of forest cover, declining soil fertility, and an impending land crisis (Tetteh, 2009).

Despite these challenges, agroforestry systems may offer a promising solution for biodiversity conservation and sustainable agriculture (Scherr and McNeely, 2008). Agroforestry is defined as the intentional integration or retention of trees alongside crops and/or animals within a single management unit to produce multiple products or benefits (Nair et al., 2021). This practice has been recognized as a viable approach to conserving biodiversity while promoting sustainable agricultural production. According to Schroth et al., (2004), agroforestry represents a valuable and promising strategy for natural resource management, merging the goals of sustainable agricultural development with enhanced environmental benefits compared to less diversified agricultural systems. Asase and Tetteh (2016), noted that agroforestry is practiced in all tropical regions, often involving various tree crops such as shade-tolerant species like cocoa (*Theobroma cacao* L) and coffee (*Coffea* species) and canopy species such as rubber (*Hevea brasiliensis*). Previous studies have highlighted the significance of different agroforestry systems in conserving biodiversity and ecosystem services. In Ghana, for example, cocoa agroforestry is widespread, with farmers strategically retaining shade trees to support young cocoa seedlings (Essouma et al., 2020). This approach, which integrates cocoa with high-value tree species and other crops, not only enhances ecological sustainability but also improves farmers' livelihoods. The practice of mixed food crop agroforestry, such as incorporating shade trees with *Musa* species and Xanthosoma sagittifolium, has also been shown to contribute to biodiversity conservation (Asase and Tetteh, 2016).

However, the conservation value of different agroforestry systems, such as cocoa, coffee, and cashew agroforestry, remains poorly understood. Empirical data on coffee and cashew agroforestry systems in the study area are particularly lacking. This study aims to investigate tree species diversity and evaluate the conservation implications across three agroforestry systems in comparison to natural forests. It is hypothesized that while agroforestry systems may exhibit lower tree species diversity than natural forests, they still play a significant role in biodiversity conservation within the agricultural landscape.

MATERIALS AND METHODS

Study area

The study was conducted at Aketen Appiah-Menka University of Skills Training and Entrepreneurial Development, located in Ashanti Mampong within the Ashanti Region of Ghana. This area is bordered to the south by the Sekyere South District, to the east by the Sekyere Central District, and to the north by the Ejura Sekyedumasi District. Mampong serves as the municipal capital. Geographically, the study area lies between longitudes 0°05' and 1°30'W and latitudes 6°55' and 7°30'N. The research took place on the university's experimental farm, which includes sections of cocoa, coffee, and cashew plantations, along with an adjacent natural forest (Tetteh and Amos, 2024). Due to human activities such as charcoal production, lumbering, and bushfires, the natural forest has been degraded into a secondary forest. The study site falls within the wet semi-equatorial forest zone and has been reforested with a mixture of exotic species including *Acacia angustissima, Artocarpus communis, Cassia siamea, Cedrela odorata,* and *Tectona grandis*. These species, though not native, are well-suited to various climatic conditions in sub-humid and semi-arid regions of West Africa and exhibit fast growth with high biomass production potential. The dominant grasses in the area include *Imperata cylindrica* (Imperata), *Panicum maximum* (Panicum), and sedges such as *Cyperus* species (nutgrass).

Biophysical conditions

The area experiences a bimodal rainfall pattern, with peak rainy seasons occurring from May to June and September to October, and dry periods extending from November to February. The mean annual rainfall ranges from 1200 to 1500 mm, with an optimal rainfall of approximately 1270 mm. The mean annual temperature is 27°C, with monthly averages varying between 22 and 30°C. The potential evapotranspiration is estimated at 1450 mm per year. During the wet season, humidity levels are typically high, averaging 86%, and drop to about 57% during the dry season (Tetteh and Amos, 2024). The soil at the study site is classified as Chromic Luvisol (FAO-UNESCO, 1990) or Udic Rhodustalf (USDA, 1999) and is locally known as the Peduase series (Asiamah, 1998). The area is underlain by Precambrian rocks of the Birimian formation and features elevation ranging from approximately 135 m to a peak of 2,400 masl. This topography has significant implications for development, as the region is known to contain valuable mineral deposits, particularly sand and stone.

Field survey

The study was conducted from December 2022 to March 2023. Sampling was carried out in both agroforestry farmlands and the forest reserve using parallel transects. The transects varied in length from 450 to 1000 m and were spaced 200 m apart for each land use category. Fifteen plots, each measuring 20 m × 20 m, were established in the cocoa, coffee, and cashew agroforestry farmlands, with an additional fifteen plots of the same size set up in the forest reserve, following the methodology outlined by Tetteh and Amos (2024) and Manaye et al. (2019). This resulted in a total of sixty (60) plots. The uniform plot size and spacing were designed to ensure consistent data collection across different land use types, facilitating comparability of results and ensuring that variations in data reflect actual differences in vegetation rather than discrepancies in plot size. The geographical coordinates of each plot were recorded using a handheld Global Positioning System

(GPS) device, with pegs placed at the corners to mark their boundaries.

Data collection

The tree diversity assessment was conducted following the protocol described by Valencia et al. (2014). Within each plot, all trees with a diameter at breast height (DBH) of ≥ 5 cm (measured at 1.3 magl) were individually identified to the species level, and their DBH was recorded. Tree species identification was performed in the field by experienced tree observers and verified through comparison with voucher specimens at the Forest Service Department in Ashanti Mampong Municipality.

Determination of vegetation parameters

Vegetation parameters, including relative density, relative dominance, and relative frequency of the most common tree species, were calculated using the methods described by Abdulrasyid et al. (2019) with the following formulas:

$$\text{Relative density} = \frac{\text{Number of individual species}}{\text{Total number of individuals}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Frequency of species}}{\text{The sum of the frequency of all species}} \times 100$$

$$\text{Relative dominance} = \frac{\text{Dominance of species}}{\text{The dominance of all species}} \times 100$$

Data analysis

Diversity estimation and species diversity

The diversity of plant species across the different land use types was analyzed using the Shannon-Wiener diversity index (H), which accounts for the relative abundance of species (Asase and Tetteh, 2016). The Jaccard similarity index was applied for pairwise comparisons of tree species composition across the land use types. This index, which uses species presence and absence data for two samples (in this case, land use types), is calculated as $J = S/(M + N - S)$, where S is the number of species shared between any two land use types, M is the number of species in land use type M, and N is the number of species in land use type N (Chao et al., 2005). These calculations were performed using EstimateS software (version 9.1.0, Colwell, 2019). Additionally, the basal area of trees was determined using the formula $\pi d^2/4$, where 'd' represents the diameter of the trees. Analysis variance (ANOVA) was performed to identify statistically significant differences in the mean density and basal area of trees among the three land-use types. The normality test for homogeneity of variance was determined using the Shapiro-Wilk test (Crawley, 2007). Where the test indicated a significant difference, means were contrasted with the post hoc Tukey HSD test. The R software version 4.1.1 was used.

RESULTS

Floristic composition and diversity

A total of 461 individual forest trees belonging to 62 species in 26 families were identified in this study (Table 1). Families with the greatest number of species were Fabaceae (19), Meliaceae (5), Apocynaceae (3), Violaceae (6), Moraceae (3) and Euphorbiaceae (4). The total number of shade tree species was 263 in the forest reserve, 85 in the cocoa agroforest, 74 in the coffee agroforest, and 39 in the cashew agroforest (Table 2). Out of the species of trees identified, ten of them namely, *Alstonia boonei*, *Albizia ferruginea, Azadirachta indica*, *Ficus exasperata*, *Funtumia africana, Khaya ivorensis, Lannea welwitschii*, *Leucaena leucocephala, Parkia biglobosa*, and *Terminalia superba* were found in all the land-use types. Except for *Elaeis guineensis*, *Carica papaya, Musa sapientum,* and *Musa paradisiaca,* all the trees encountered were native forest tree species. The similarity in non-crop tree species composition was highest between cocoa and coffee agroforests and between cocoa and cashew agroforests. β-diversity analysis indicated that non-crop tree species communities in cocoa and coffee agroforests were most similar (Jaccard index = 0.33), followed by cocoa and cashew agroforests (Jaccard index = 0.12). The last similarity in non-crop tree species composition was between the natural forest and cashew agroforest (Jaccard index = 0.04).

The density of trees varied significantly among the land use types ($p < 0.001$). The mean density of trees found in the natural forest reserve was about nine times that found in the cashew agroforest (Table 2). There was a significant difference in the dominance of trees between the cocoa agroforest and natural forest reserve (post hoc Tukey HSD, $p < 0.001$) and between the coffee agroforest and natural forest reserve (post hoc Tukey HSD, $p < 0.001$). The mean basal area of trees was 24.9 m^2/ha in the cocoa agroforest and 15.5 m^2/ha in the cashew agroforest farmland respectively. The dominance of tree species was significant in the different land use types.

DISCUSSION

Impact of cocoa, coffee, and cashew production on plant diversity

In this study, the rich floristic diversity of shade trees, reminiscent of natural forests were found to have decreased in agroforest farmlands. This outcome was anticipated, as previous studies have documented a reduction in tree species diversity due to habitat modification and land use changes (Ansah et al., 2023; Tetteh et al., 2018; Negawo and Beyene, 2017). This trend aligns with earlier reports (Adahé et al., 2023; Oliveira et al., 2023), which highlight the critical role trees play in providing shade for shade-dependent crops and supporting biodiversity. The shift from natural forests to agroforest ecosystems emphasizes the urgent need for

Table 1. List of Tree Species of DBH ≥ 5 cm with their Families, and Presence or Absence in Natural Forest, Cocoa Agroforest, Coffee agroforest, and Cashew agroforest

Species	Family	Cocoa agroforest	Coffee agroforest	Cashew agroforest	Forest reserve
Acacia sieberiana DC	Fabaceae	-	-	-	+
Albizia ferruginea Benth	Fabaceae	+	-	-	+
Albizia zygia J.F.Macbr	Fabaceae	+	+	-	+
Alstonia boonei De Wild	Fabaceae	+	+	+	+
Artocarpus communis (*Parkinson) Fosberg*	Fabaceae	-	-	-	+
Azadirachta indica A.Juss.	Fabaceae	+	+	+	+
Bombax brevicuspe Sprague	Fabaceae	-	-	-	+
Bombax buonopozense Burkil. H. M.	Fabaceae	-	-	-	+
Bridelia grandis Pierre ex Hutch	Fabaceae	-	-	-	+
Bridelia atroviridis Mull.Arg.	Fabaceae	-	-	-	+
Blighia welwitschii Hiern (Radlk*)*	Fabaceae	-	-	-	+
Ceiba pentandra Gaertn	Fabaceae	+	+	+	+
Carica papaya L	Caricaceae	+	+	-	-
Celtis mildbraedii Engl	Ulmaceae	+	-	-	+
Celtis zenkeri Engl	Ulmaceae	-	-	-	+
Cedrela odorata Blanco	Meliaceae	-	-	-	+
Daniella oliveri Benn	Fabaceae	-	-	-	+
Dialium aubrevillei Pellegr	Caesalpinaceae	-	-	-	+
*Dacryodes klaineana (*Pierre) H.J.Lam	Burseraceae	-	-	-	+
Diospyros gabunensis Gürke	Fabaceae	-	-	-	+
Elaeis guineensis Jacq	Palmae	+	-	-	+
Erythrina senegalensis A.DC.	Fabaceae	-	-	-	+
Ficus exasperata Vahl	Moraceae	+	+	+	+
Ficus sur Forssk	Moraceae	-	-	-	+
Funtumia africana (Benth.) Stapf	Apocynaceae	+	+	+	+
Funtumia elastica (Preuss)Stapf	Apocynaceae	-	-	-	+
*Gliricidia sepium (*Jacq.)	Fabaceae	-	-	-	+
Gilbertiodenron preussii Harms	Fabaceae	-	-	-	+
*Holarrhena floribunda (*G.Don) T.Durand and Schinz	Apocynaceae	-	-	-	+
Khaya ivorensis A.Chev	Meliaceae	+	+	+	+
Lannea barteri (Oliv.) Engl.	Anacardiaceae	+	+	+	+
Lannea welwitschii (Hiern) Engl.	Anacardiaceae	+	+	+	+
Leucaena leucocephala Hendrik D.C. de Wit	Fabaceae	+	+	+	+
Macaranga barterii Müll.Arg	Euphorbiaceae	+	+	-	+
Mareya micrantha (Benth.) Müll.Arg	Euphorbiaceae	+	+	-	+
Morinda lucida Benth	Rubiaceae	+	-	-	+
Parkia biglobosa (Jacq.) R. Br. ex G. Don	Fabaceae	+	+	+	+
Pappea capensis Eckl. and Zeyh	Sapindaceae	+	-	+	-
Pycnanthus angolensi (Welw.) Warb.	Myristicaceae	+	+	-	+
Rhodagnaphalon brevicuspe (Sprague) Roberty	Bombacaceae	-	-	-	+
Ricinodendron heudelotii Perre ex Pax	Euphorbiaceae	-	-	-	+
Rinorea oblongifolia C. Marquand	Violaceae	-	-	-	+
Rinorea prasina (Stapf) Chipp	Violaceae	-	-	-	+
Rinorea sp Aubl	Violaceae	-	-	-	+
Rothmania hispida (K.Schum.) Fagerl.	Violaceae	+	-	-	+
Rothmania longiflora Salisb	Violaceae	+	-	-	+
Rothmania whitfieldii (Lindl.) Dandy	Violaceae	-	-	-	+
Sapium aubrevillei Leandri	Euphorbiaceae	+	+	+	-
Tectona grandis L	Verbenaceae	+	-	-	+

Table 1 Contd.

Terminalia ivorensis A.Chev.	Combretaceae	+	+	+	+
Terminalia superba Engl. and Diels	Combretaceae	+	+	+	+
Trema orientalis Blume	Ulmaceae	-	-	-	+
Tricalysia discolor A. Juss	Rubiaceae	-	-	-	+
Tricalysia sp A. Rich.ex. DC	Rubiaceae	-	-	-	+
Trichilia monadelpha L.	Meliaceae	-	-	-	+
Trichilia prieureana P. Browne	Meliaceae	-	-	-	+
Trichilia tessmannii Harms	Meliaceae	-	-	-	+
Trilepesium madagascariensis DC	Moraceae	-	-	-	+
Xylopia zilosa	Annonaceae	-	-	-	+
Zanthoxylum gilletii L	Rubiaceae	-	-	-	+

Table 2. Floristic and structural characteristics of tree species in the different land use types.

Parameter	Forest reserve	Cocoa agroforest	Coffee agroforest	Cashew agroforest
Number of individual trees	263	85	74	39
Number of tree species	58	25	17	13
Shannon-Weinner index	0.82	0.65	0.61	0.42
Mean stem density (m^2/ha)	17.40	6.45	2.46	2.07
Mean basal area (m^2/ ha)	43.72	24.97	20.14	15.56

effective management strategies to prevent further deforestation. Consequently, the reduction in shade tree diversity within agroforest farmlands leads to significant biodiversity loss, which disrupts essential ecosystem functions such as nutrient cycling, soil fertility, and habitat provision for various fauna (Ansah et al., 2023). Additionally, reduced biodiversity can negatively impact vital services like pest control and pollination, both crucial for sustainable agricultural productivity (Oliveria et al., 2023). Although natural forests exhibit higher shade tree diversity, the findings indicate that shade tree density is particularly higher in cocoa agroforests, suggesting that farmers are actively managing shade levels to optimize crop yields. This underscores the complex trade-offs in agroforestry practices, where balancing adequate shade for crops like coffee and cocoa with maintaining biodiversity is essential.

The observed variations in tree species among different farms suggest that management practices and farm histories significantly influence agroforestry systems. This highlights the potential benefits of tailored extension services and training programs that encourage farmers to adopt sustainable practices balancing productivity with biodiversity conservation. Moreover, farmers introduce fruit tree species into cocoa, coffee, and cashew agroforests to supplement their income and for personal consumption. Additionally, certain species, such as *Terminalia ivorensis* and *Ceiba pentandra*, are preserved by farmers to provide income from the timber industry. The Shannon diversity index values recorded in this study were lower than those documented by Ansah et al. (2023) and Njini (2021), indicating minimal species dominance in agroforest farmlands. The loss of tree species within cocoa farmlands may impact the conservation of other biodiversity, such as insects and rodents, potentially leading to the migration of key fauna species to other ecosystems, thus decreasing overall biodiversity within cocoa, coffee, and cashew farmlands.

Notably, the mean density of shade tree species in agroforest farmlands in this study was lower than values reported by Asase and Tetteh (2016), Ansah et al. (2023), and Njini et al., (2021) in similar studies. The basal area of species also shows a clear reduction in shade tree species in cocoa, coffee, and cashew agroforests. This finding is consistent with Tetteh et al. (2018), who observed a lower basal area of shade tree species in intensive agroforestry systems in Ghana. This demonstrates how management intensity in different agroforest farmlands has contributed to significant species loss due to land use changes. To ensure a sound ecosystem and biodiversity conservation, future research should focus on determining the optimal density and composition of shade trees in various agroforestry systems. Additionally, studies should aim to understand the specific shade requirements of different crops and the ecological impacts of diverse shade tree species. Developing comprehensive agroforestry models that integrate ecological and agricultural data will be crucial for designing sustainable systems that maximize both productivity and biodiversity. These models should consider factors such as climate, soil type, and local biodiversity to generate site-specific recommendations for farmers. Policymakers should also consider implementing incentives to encourage farmers to conserve native tree species and adopt agroforestry practices that enhance biodiversity. Ultimately, this study underscores the critical need for sustainable management practices in agroforestry farmlands to balance agricultural productivity with biodiversity conservation. By addressing the identified gaps and pursuing the proposed future research directions, the sustainability and resilience of agroforest landscapes can be enhanced.

Conclusion

This study has highlighted a drastic decline of shade trees in the cocoa, coffee, and cashew agroforestry farms compared to the natural forest. This decline in diversity notably impacted the floristic composition, leading to a reduction in both the density and basal area of shade trees within these agroforestry ecosystems. Mean Shannon diversity index, density, and basal of shade tree species showed a drastic reduction from the cocoa, coffee, and cashew agroforests farmlands. Agroforests still have the potential of conserving biodiversity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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