

Original Research Article

Assessment of carbon sequestration and plant diversity in cocoa agrosystems in the Man region, Côte d'Ivoire

ABSTRACT

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Aims: Cocoa-based agroforestry systems in the Man region of Côte d'Ivoire play a crucial role in reconciling agricultural productivity and environmental preservation. This study assessed the capacities of these agrosystems in terms of plant biodiversity conservation and carbon sequestration.

Study design and methodology: The different agrosystems were described, botanical inventory collection plots were set up. Elementary surfaces of 10 meters by 20 meters were used to collect the heights, diameters at breast height and heights of the individuals present.

Place and Duration of Study: The study was held in the agrosystems of the Man region, in western Côte d'Ivoire. It took place between January and July 2024.

Results: The cocoa plantations examined vary in age from 8 to 32 years, with a diversity of companion species according to the stages of maturity. Young plantations are often associated with food crops, while older plantations are associated with woody trees. The reported age of plantations, based on the initial establishment date, does not necessarily reflect the current structure of cocoa populations, due to management practices that regularly introduce new individuals. This intra-plot heterogeneity explains the absence of significant differences in carbon sequestration between the different age groups of plantations. This suggests a dynamic of replacement of young trees that contributes to maintaining a high level of biomass.

Conclusion: This study highlights the importance of taking into account species diversity, continuous plantation management, and individual dynamics to maximize the ecological benefits of cocoa-based agroforestry systems. Optimized agroecological management is essential to strengthen the sustainability of these systems, while contributing to biodiversity conservation and the fight against climate change.

Keywords: *Theobroma cacao*, climate change, carbon credit, agrotechnology

1. INTRODUCTION

Sustainable management of natural resources has become a major global concern, particularly in the context of climate change and loss of biodiversity. Agriculture, the main land use, plays a crucial role in this dynamic. The massive destruction of forests by agricultural practices leads to serious ecological consequences including loss of biodiversity, soil degradation and climate change [1].

At the local level, the cultivation of *Theobroma cacao* (Sterucliaceae), a major economic activity in Côte d'Ivoire, has considerably accelerated the destruction of the country's forests. Since its introduction, the cultivation of *Theobroma cacao* has mainly developed under an extensive model, based on the conversion of large areas of tropical forests into plantations [2]. This process has led to rapid deforestation, particularly in regions with a high concentration of cocoa trees, such as western Côte d'Ivoire [3]. The continued expansion of cocoa cultivation has been to the detriment of primary forests, which have been massively cleared to meet the growing demand for agricultural land. Between 1960 and 2015, the country's forest cover decreased from 12 million hectares to approximately 3 million hectares, an estimated loss of nearly 75% [4]. Classified forests, which were initially protected areas, have not escaped this deforestation, some of which have been illegally occupied by cocoa farmers looking for new fertile land [5]. This production model, although economically profitable, raises the question of its impact on the environment and sustainable resource management. Faced with these challenges, the need to find sustainable alternatives to this cultivation model has become urgent. Approaches such as agroforestry and mixed cocoa systems offer solutions for producing cocoa while preserving forest ecosystems and promoting carbon sequestration.

Cocoa-based agrosystems thus appear as a promising opportunity to reconcile agricultural productivity and environmental preservation, particularly in terms of carbon sequestration and maintenance of plant biodiversity. This study is therefore initiated with a view to assessing the capacities of cocoa-based agrosystems in the sustainable management of plant biodiversity and carbon sequestration. The objective is to analyze the impact of these systems on biodiversity conservation and carbon storage in the Man region, in western Côte d'Ivoire. This will involve determining the carbon sequestration and plant diversity conservation capacities of cocoa-based agrosystems.

2. material and methods

2.1. Data collection

This study was conducted in the Man region, western Côte d'Ivoire. This region is part of the new cocoa loop [6], an area of high cocoa production with varied cropping systems. The villages of Gloyogouin, Dakouipleu and Goziogouiné were identified to conduct the field work (Figure 1). In each locality, inventory plots were laid according to the age and type of crop association of the cocoa plantations. Rectangular plots 20 m long by 10 m wide are laid for botanical inventories in the different cocoa plantations. In each plantation inventoried, between 2 and 5 plots were laid. In total, 60 plots were laid on all the floristic inventories in the different agroforests. Thus, 21 cocoa plantations were studied. For dendrometric measurements, all woody plants present on the plots as well as cocoa trees were identified and counted. For each individual, the name,

diameter and height were recorded.

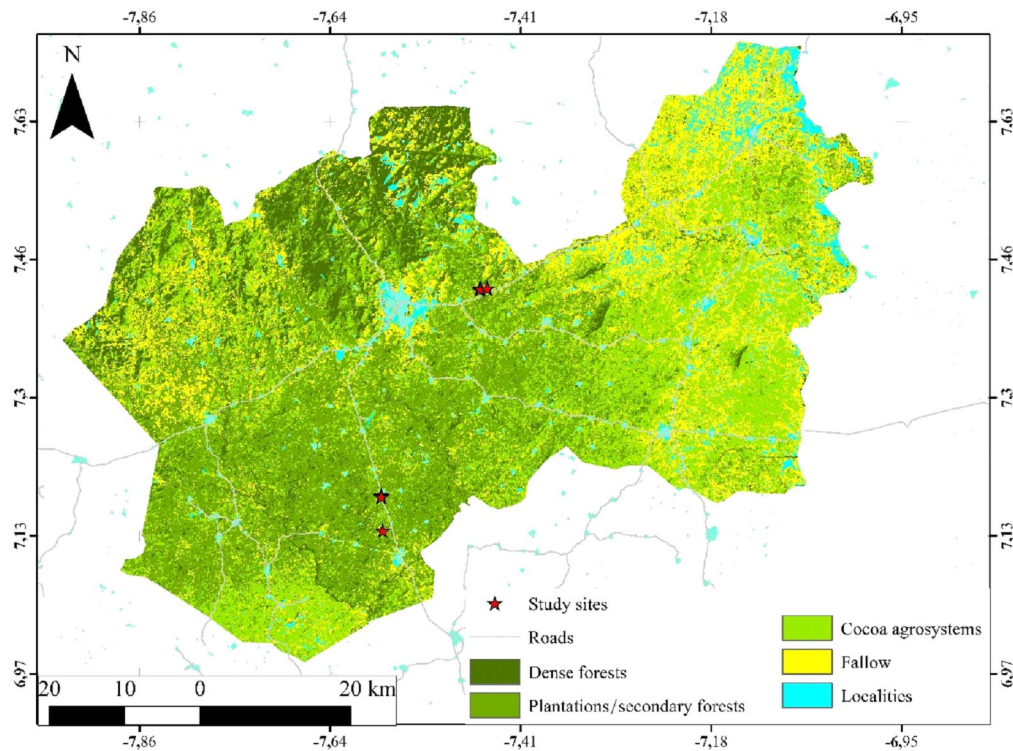


Figure 1: Presentation of the study site

2.2. Data analysis

The estimation of Above Ground Biomass (AGB) of associated trees and cocoa trees

was done using the allometric equation of Chave, Réjou-Méchain [7]. This is an

equation specific to dense humid semi-deciduous forests whose basic mathematical model is $AGB = 0.0673 \times (\rho D^2 H)^{0.976}$. In this equation, AGB is the aboveground biomass of the tree (in kg); D is the diameter of the tree (in cm); H the total height of the tree (in m); ρ the specific density of the tree in ($g \cdot cm^{-3}$). The standard density value of $0.58g/cm^3$ [8] was used.

The estimation of Below Ground Biomass (BGB) of woody plants was done in accordance with the guidelines established by IPCC [9]. The root biomass equivalence of standing woody plants is obtained by the equation $BGB = AGB \times 0.24$.

The total biomass is obtained by adding the aboveground biomass and the root biomass [9] according to the equation $BT = AGB + BGB$. The sequestered carbon stock is obtained from the total biomass [9] according to the equation $C = BT \times 0.5$.

An analysis of variance followed by a Tukey HSD test with a 95% confidence interval

[10] were carried out to compare the averages of the carbon stocks of the agrosystems according to the age of the plots.

3. results and discussion

The age of cocoa plantations ranges from 8 to 32 years. There are plantations with companion species as well as strict monospecific plantations without companion species. The youngest plots, aged 8 and 10 years, are observed in the village of Glayogouin. This is an association of food crops with cocoa plantations. The associated food plants are *Manihot esculenta*, *Colocasia esculenta* and *Xanthosoma mafafa*. *Spondias mombin* is the only woody species tolerated in this agrosystem. 14- and 15-year-old plantations were visited in the village of Dakouipleu. A total of 12 companion species were observed in the cocoa-based agroforests (Figure 2). *Persea americana* and *Coffea canephora* are the most observed. Cocoa plantations of 16 and 20 years have been inventoried in Glayogouin and Gôziogouiné. *Musa paradisiaca* and *Colocasia esculenta* are present in these plantations. Individuals of *Colocasia esculenta* are essentially regrowths tolerated during sharecropping. Eleven companion species were recorded in cocoa plantations aged 16 and 20 years (Figure 3). The most commonly encountered are *Cola nitida*, *Sterculia tragacantha* and *Albizia adianthifolia*. Agrosystems aged 30 years are observed in the villages of Glayogouin and Gôziogouiné. *Cola nitida* is essentially the companion species encountered in these cocoa plantations (Figure 4). A 32-year-old plantation in Glayogouin has only *Citrus sinensis* and *Terminalia ivorensis* as companion species.

Figure 2: Companion species observed in 14- and 15-year-old cocoa plantations

Figure 3: Companion species observed in 16- and 20-year-old cocoa plantations

Figure 4: Companion species observed in 30-year-old cocoa plantations

Theobroma cacao individuals are observed to have maximum heights of less than 7 meters. In the cocoa agrosystems studied, the vertical structures of the plantations present strata consisting mainly of companion species. The average values per inventory plot are shown in Table 1.

Table 1: Average distribution of individuals according to stratum levels

Strata (meters)	Average individuals (individuals/hectare)
]0 – 5]	26.09±58.50
]5 – 10]	89.13±163.44
]10 – 15]	21.74±26.48
]15 – 20]	10.87±22.53
]25 – [34.78±124.70

In young plantations aged 5 to 10 years, the estimated average aboveground biomasses are of the order of 31.88±3.75 tonnes per hectare. The average belowground biomass obtained is 7.65±0.90 tonnes per hectare. The resulting average total biomass is 39.53±4.65 tonnes per hectare. The carbon sequestered in plantations aged 5 to 10 years is 19.77±2.32 tonnes per hectare.

In plantations aged 10 to 15 years, the average values collected for aboveground biomass allow an estimate of 215.64±408.87 tonnes per hectare. The resulting belowground biomass is 51.75±98.13 tonnes per hectare. The average value of total biomass is of the order of 267.40±507.00 tonnes per hectare. Plantations aged 10 to 15 years have an average carbon sequestration estimated at 133.70±253.50 tonnes per hectare.

As for medium-aged plantations, i.e. plots between 15 and 20 years old, the average value of above-ground biomass is 643.17±1389.52 tons per hectare. The estimated below-ground biomass has an average value of 154.36±333.49 tons per hectare. This allows for an estimate of the total biomass of 797.53±1723.01 tons per hectare. The carbon sequestered in plantations between 15 and 20 years old has an average value of 398.76±861.51 tons per hectare.

For the oldest plantations, those between 30 and 35 years old, the average values obtained for aboveground biomass are of the order of 222.49±452.12 tonnes per hectare. The belowground biomass resulting from this estimate is 53.40±108.51 tonnes per hectare. The total biomass of the oldest plots is estimated at 275.89±560.63 tonnes per hectare. Finally, the carbon stored by plantations aged 30 to 35 years is estimated at 137.94±280.31 tonnes per hectare.

Analysis of variance ($F = 0.73$; $\rho = 0.54$) performed on carbon stocks showed no significant difference. The age of plantations of *Theobroma cacao*-based agroforestry systems has no influence on the amount of carbon stored in inventory plots in the Man region.

4. discussion

There is a significant diversity of age and associated species in cocoa-based agroforestry systems. Young plantations are often associated with food crops such as *Manihot esculenta*, *Colocasia esculenta*, and *Xanthosoma mafaffa*. Mature agroforests reveal a strong association with *Persea americana* and *Coffea canephora*, while older plantations are characterized by the presence of species such as *Cola nitida* and *Citrus sinensis*.

These results are consistent with previous studies that demonstrate that the integration of food crops and forest trees in cocoa plantations promotes the resilience of agroforestry systems and improves biodiversity [11]. The association of companion species helps to maintain soil fertility and provide protection against climatic hazards, while optimizing agricultural production in a sustainable framework [12]. The distribution of individuals according to their height highlights a multi-storey structure typical of diversified agroforests [13]. Older cocoa plantations, although less diversified, continue to play a crucial role in carbon storage. For Mbow, Smith [14] the presence of companion trees contributes to the accumulation of biomass and carbon sequestration.

The absence of significant difference observed in carbon stocks according to the age of the plantations can be explained by the variability of plot management systems. The establishment and maintenance of companion species can modulate the accumulation of biomass and influence the carbon sequestration capacity [15]. Indeed, agroforestry systems are not homogeneous, and their capacity to store carbon depends on factors such as species diversity, management of companion species and agricultural practices [16]. However, it is essential to note that the declared age of the plantations is generally based on the date of establishment of the cocoa trees. This factor can be confounding, as plantations undergo frequent replacement of individuals due to tree mortality, diseases or cultural practices. Thus, although some plantations are considered "old", they often contain relatively young individuals that represent a significant proportion of the plant cover in some cases [17].

These observations are corroborated by other studies that show that in cocoa agroforestry systems, cocoa mortality leads to a constant turnover of individuals. Wade, Asase [11] point out that trees are often replaced by young plants to maintain production, which implies that plantations can display heterogeneity of age among individuals. In addition, the management of plantations over time, with the integration or elimination of companion species and the introduction of new cocoa plants, contributes to maintaining ecological dynamism despite the overall age of the plot [18].

The heterogeneity of the age of individuals in plantations, even those considered old, can also influence the capacity of these systems to sequester carbon. Young trees tend to grow faster and can therefore accumulate more biomass in a shorter time, while older trees can contribute to the stability of the system in terms of long-term carbon sequestration [19]. These intra-plot dynamics are crucial to understand the variations observed in biomass and sequestered carbon across different plantation age classes, as shown in the results of this study.

Consequently, although plantation age is a useful indicator, it does not necessarily reflect the real population structure of cocoa trees within plots. This could partly explain the large variations observed in carbon stocks and biomass values across different age classes. These dynamics of individual replacement highlight the importance of considering not only the overall age of plantations, but also their internal composition

and the management practices that affect their structure [20].

5. Conclusion

This study highlights the diversity of agroforestry practices and the complexity of cocoa plantations in the Man region. The plantations studied, although ranging in age from 8 to 32 years, reveal a varied internal composition, with a significant presence of young individuals, reflecting a constant renewal process over time. This structural heterogeneity, due to cocoa tree replacement practices and the integration of companion species, plays a crucial role in maintaining the productivity and sustainability of the systems.

The study also highlights that, despite the advanced age of some plantations, carbon sequestration does not vary significantly according to the reported age of the plantations. This observation can be attributed to the mixed composition of the plots, where young trees, even in older plantations, contribute significantly to biomass accumulation. The diversity of companion species observed in these agroforests shows the importance of agroecological management to maximize ecosystem services, particularly in terms of carbon storage and resilience of systems to environmental challenges.

To maximize the long-term benefits of cocoa plantations, it is crucial to consider not only the overall age of the plots, but also their internal dynamics, including species diversity and management practices. This holistic approach will strengthen the sustainability of agroforestry systems while contributing to combating climate change and improving farmers' livelihoods.

Consent (where ever applicable)

Not applicable

Ethical approval (where ever applicable)

Not applicable

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