Original Research Article

Assessment of the effect of *Garcinia kola* (Clusiaceae) on the carbon sequestration capacity and productivity of cocoa (*Theobroma cacao*L) in cocoa-based agroforestry systems

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ABSTRACT

Aims: Ivorian cocoa production reaching 2 million ton annually at the expense of the forest reserve, and an annual deforestation rate of around 2.78%. The integration of agroforestry into cocoa plantations appears to be a suitable approach to combating deforestation of the remaining forest reserves and restoring the degraded cocoa landscape. The choice of species is the key to the success of this program. Our objective was to evaluate the interaction between *Garcinia kola* and cocoa in traditional agroforestry systems.
Study design: Around each *G.Kola* tree identified in the orchard, two curves lines with radii of 10 and 20 m respectively were delimited in order to assess the interaction of *G. Kola* on the cocoa tree according to their proximity to *G.Kola*.
Place and duration of study: the study was conducted in cocoa-based agroforestry systems in western Côte d'Ivoire from June 2020 to November 2021.
Methodology: The influence of *Garcinia Kola* on cocoa trees was assessed by measuring the biomass and carbon sequestration rate of *G.kola* and cocoa trees. The productivity of cocoa trees and *G.kola* was also determined.
Results: Our results showed that *G. kola* trees had a negative influence on cocoa density and yield. The 10 m radii showed low density and low pod production compared to the 20 m radii. Yields of cocoa trees located close to *G. kola* were also low compared to those located further away. Our work has shown that stands of cocoa trees and *G. kola* associated have different contributions depending to their proximity.
Conclusion: This complementarity in terms of carbon sequestration capacity and productivity between *G.Kola* and cocoa is an asset that can be exploited for CAFs to improve the sustainable production system and restore the cocoa landscape.

Keywords:*Garcinia kola, Theobroma cacao, Agroforestry system, Yield, carbon stock, sustainability.*

1. INTRODUCTION

Ivorian cocoa annual production reached 2 million tons at the expense of the forest reserve with an annual deforestation rate around 2.78% (Koné *et al*., 2014). The deforestation has exacerbated the ecosystems with the loss of biodiversity, an important seasonal variation, an increase of greenhouse gases (Schroth *et al.*, 2009; Läderach*et al.*, 2013), and reduced ecosystem services such as carbon sequestration (Carpe, 2005). In such a context, the integration of agroforestry into cocoa plantations appears to be a means of combating deforestation of remaining forest remnants and reconstituting degraded forests. Agroforestry is a dynamic natural resource management system based on ecological foundations that integrate trees into farms and the rural landscape (Dupraz&Liagre, 2008). This approach represents one of the solutions for sustainable use of limited natural resources and adaptation to global, demographic, economic and climate change according to Lundgren & Raintree (1982). The management of agroforestry systems is based on the sustainability of diversified production by exploiting the ecological, economic and social interactions between the components of these systems. Ivorian farmers have long been conserving and introducing a lot of trees into their plots (Jagoret*et al.*, 2011; Saj *et al.*, 2013). These trees provide shade for the cocoa trees and also offer households products that contribute to self-sufficiency and balanced family diets. With their forest-like structure, cocoa agroforestry systems (CAFS) help to conserve wood diversity (Sonwa*et al.*, 2007; Saj *et al.*, 2017). Carbon sequestration is also one of the significant ecosystem services provided by these agroforestry systems (Njomnang*et al.*, 2011; Norgrove & Hauser, 2013). This is also the case for *Garcinia kola* commonly named bitter kola, a large tree that can reach 35 to 40 m in height. It is recognized for its economic, food, nutritional, health, social, cultural, cosmetic, pharmaceutical and other uses (Akoègninou*et al.*, 2006; Aké *et al.*, 2013; Adesuyi*et al.*, 2012). The various parts of this tree are used by local populations for their medicinal, nutritive, stimulating and aphrodisiac properties (Codjia*et al.*, 2018). It is also a significant source of income for local populations. The scarcity of these species in the rural forest space compromises the availability of non-timber forest products (NTFPs) and essential goods and services for populations, hence the need to act in favor of these species because of the interest their products generate for rural communities. It is essential to develop a conservation and sustainable management strategy, given the economic, social and environmental benefits that these species represent for local communities. Also, the co-conservation of Garcinia Kola in cocoa orchards with the support of cocoa farmers needs to have a clear scientific basis on their interaction. But to date, no study has specifically targeted agroforestry systems combining *Theobroma cacao* and *Garcinia kola*, which is an IUCN Red List species (Neuenschwander *et al.*, 2011). Two general hypotheses will be tested in this study. The first is that the dendrometric parameters of *G. kola* vary according to locality, and the second is that *G. kola* trees influence agromorphological parameters and cocoa yield. The aim of our study is to improve agricultural productivity and the livelihood of smallholders by associating forest tree species such as *G. kola* with cocoa trees to ensure the sustainability of Ivorian cocoa production and the preservation of remaining forests.

2. MATERIAL AND METHODS

2.1. Material and methods

2.1.1. Prospection and identification of *Garcinia kola* trees in cocoa orchards

The areas targeted for this study are cocoa-growing zones in South-west Côte d'Ivoire. These are the villages of Kouamékro, Konankro and Wenedougou in Gueyo and Wonsealy in Buyo (Figure 1). The region's climate is characterized by two dry seasons (December-March and July-August) and 2 rainy seasons (April-June and September-November), with average temperatures fluctuating between 26 and 28°C. Average rainfall is between 1,300 and 1,600 mm/year, with 115 days of rain. The soil is ferralitic, with dense, humid, intermediate evergreen forest vegetation that has been reduced over time in favor of huge plantations of perennial crops such as cocoa, of which the Region is the leading producer in Côte d'Ivoire (Nawa, 2016). The farms considered for our study were orchards in full production, where the presence of one or more *G. kola* trees was noted. Twenty-six (26) *G. kola* trees were identified in the cocoa plantations, including 25 in Gueyo and 1 in Buyo. In fact, the unevenly distributed number of trees testifies to the rarity of the species. Cocoa plantations in full production were thus selected in order to assess the influence of *G. kola* on cocoa productivity.

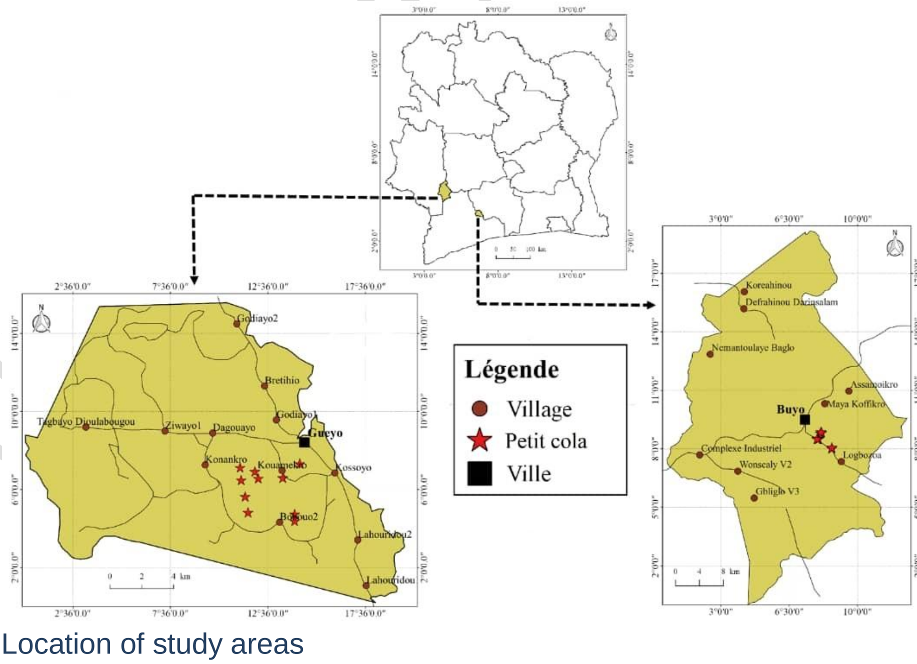

Fig 1: Location of study areas

2.2.2. Assessment of dendrometric characteristics and productivity of *Garcinia kola*

- **Evaluation of *Garcinia kola*dendrometric parameters**

The dendrometric parameters measured on *Garcinia kola* species are Diameter at breast height (dbh) (or 1.30 m above ground level) and total tree height. The circumference values obtained were used to calculate the diameter of these trees, based on the assumption that the cross-sectional shape of the trunk is circular, using the following formula:

$$\mathbf{D} = \frac{\mathbf{C}}{\boldsymbol{\pi}} \text{(equation 1)}$$

Where C = Circumference (cm), D = Diameter (cm) and π = 3.14.

- **Biomass and carbon sequestration rate of *Garcinia kola***

The above-ground biomass of woody plants corresponds to the mass of dry woody plant matter present in a given environment. The above-ground biomass of *Garcinia kola* was obtained from the sum of the biomasses of all individuals. It was estimated using the following allometric equation of Chave *et al.* (2005):

$$\mathbf{AGB} = \mathbf{exp}\,[-\mathbf{2,977} + \mathbf{0,94}\,\mathbf{ln}\,(\mathbf{Wi}\ \times (\mathbf{DBHi^2}) \times \mathbf{Hi})] \text{(equation 2)}$$

Where:

AGB = above-ground biomass of individualized trees (kg); Hi = tree height (m); Wi = wood density (g.cm-3). The wood density of *Garcinia kola* is 0.80 g.cm-3 (Zanne *et al.*, 2009).

Carbon stock is related to biomass by the relationship: $\mathbf{C}\,(\mathbf{tC/ha}) = \mathbf{CF}\ \times \mathbf{AGB}\,(\mathbf{Kg})$ (equation 3)

Where, CF is the biomass-to-carbon conversion factor. It has been reported that the carbon content of a tree's dry biomass is 50% (Brown & Lugo, 1992; Malhi *et al.*, 2004; Mcghee*et al.*, 2016). CF is therefore 0.5.

- **Estimation of *Garcinia kola* productivity**

Garcinia kola productivity was assessed on trees in production. A total of 26 individuals were identified, including six (06) in production. A daily collection and counting of fallen fruit from these trees were carried out. This activity was carried out during the tree production period, from September to January. The frequency of collection was three (03) passes per week for each tree. These fruits were weighed using a precision balance to determine the annual fruiting mass per tree.

2.2. *Garcinia kola - Theobroma cacao* interaction study

- **Experimental design**

The experimental set-up for the study of the interaction between *Garcinia kola* and *Theobroma cacao* consisted of two circular plots of 10 m and 20 m radius, using *G. kola* trees as a reference. Within each plot, morphological parameters and cocoa yield were assessed (Figure 2). This was much the same set-up used by Kouakou *et al.* (2011) in their study of the impact of the swollen shoot disease on cocoa production in Bazré (Côte d'Ivoire).

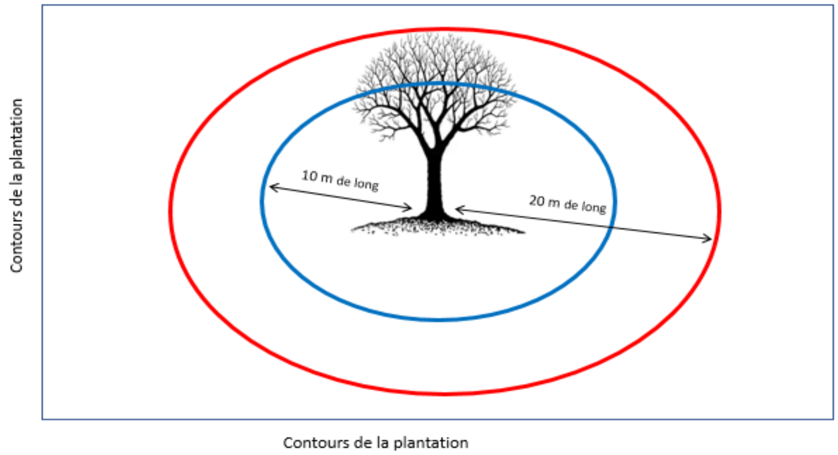

Fig 2: Schematic diagram of the study of the influence of *Garcinia kola* on cocoa trees

- **Study of the agromorphological parameters of cocoa trees**

Cocoa density was determined by counting the number of cocoa trees around the companion tree (*Garcinia kola*), in the two plots of the system. This is done in a first circular plot with a radius of 10 m from the tree. The same operation is then carried out in the plot with a radius of 20 m.

Cocoa vigour was determined using agro-morphological parameters such as height and crown diameter (at 20 cm from the ground). The formula used is that of Alexandre (1977): $\textbf{Cocoa tree vigor} = \frac{\text{Cocoa height (m)}}{\text{Cocoa tree collar diameter (m)}}$ (equation 4)

The calculations used to determine the biomass and carbon stock of *Garcinia kola* trees were the same as those used for cocoa trees. However, in this study, the diameter of the cocoa trees was taken at the collar. In addition, the wood density considered for cocoa trees is 0.42 $g.cm^{-3}$ (Saj *et al.*, 2013).

- **Cocoa yield**

Yield was estimated by counting the number of cocoa pods present on each tree in each radius. The rates of gnawed and rotted pods were also calculated using the following formulas: $\textbf{Rate of pods gnawed} = \frac{\text{Number of pods eaten}}{\text{Total number of pods}} \times 100$ (equation 5) and

$\textbf{Rate of rotten pods} = \frac{\text{Number of rotten pods}}{\text{Total number of pods}} \times 100$ (equation 6)

2.3. Statistical data analysis

The collected data were formatted in Excel files. Excel files validated with SAS Insight and outliers were corrected. The General Linear Model (GLM) for analysis of variance in SAS software (9.4) was used to determine the interaction between *Garcinia Kola* and *Theobroma cacao* using the Student-Newman-Keuls test with a threshold of 5 percent.

3. RESULTS

3.1. Structural parameters of *Garcinia kola* and cocoa trees

An overall average of 12.29 m for height and 45.15 cm for dbh were registered for *Garcinia kola*, the highest values were recorded at Konankro (Guéyo) with 15.50 m for height and 57.32 cm for dbh. The lowest values were observed at Wonsealy (Buyo) with 6 m for height and 27.39 cm for dbh (Table 1). The analysis of variance of the structural parameters of bitter kola revealed that there were no significant differences between localities for all the parameters studied ($p > 0.05$). For cocoa trees, the overall average was 58.4 for density and 0.11 for vigour. The highest value was observed in the 20 m radius (82.40) and the lowest in the 10 m radius (34.40) (Table 2). The value obtained in the 10 m radius (0.119) is statistically identical to that of the 20 m radius (0.119) in terms of vigour. Analysis of variance revealed that there were significant differences between the radii for cocoa density ($P < 0.05$). However, no significant differences were observed for cocoa vigour ($P > 0.05$).

Table 1: Structural parameters of *Garcinia kola*

Variables	Means	Guéyo			Buyo	*P* = .05
		Konankro	**Kouamékro**	**Wenedougou**	**Wonsealy**	
Height (m)	12.29	15.5a*	12.16a	12.20a	6.00a	0.1179
Dbh (cm)	45.15	57.32a	43.56a	51.17a	27.39a	0.1150

*On the same line, averages followed by the same letter are statistically identical at the 5% threshold (Student-Newman-Keuls). dbh: Diameter at breast height.

Table 2: Cocoa tree structural parameters

Radius	Density	Vigour
0-10 m	34. 40a*	0.11a
10-20 m	82.40b	0.11a
Means	58.4	0.11
P = .05	0.0001	0.9666

*In the same column, means followed by the same letter are statistically identical at the 5% threshold (Student-Newman-Keuls). P: probability (0.05).

3.2. Biomass and carbon stock of *Garcinia kola* and cocoa trees

The overall averages were 195.82 kg for biomass and 97.91 t C/ha for carbon stock, respectively. The highest values were observed in Konankro with 880.16 kg for biomass and 440.08 t C/ha for carbon stock. The lowest values were recorded in Kouamékro with 64.16 kg for biomass and 32.08 t C/ha for carbon stock. Analysis of variance revealed significant differences in biomass and carbon stock ($p < 0.05$) (Table 3). For cocoa, the overall average was 135.69 kg for biomass and 67.84 t C/ha for carbon stock. The biomass and carbon values recorded in the 10 m radius (145.77 kg for biomass and 72.89 t C/ha for carbon stock) were higher than those in the 20 m radius (131.47 kg for biomass and 65.73 t C/ha for carbon stock). Analysis of variance of cocoa biomass and carbon stock showed significant differences (P < 0.05) (Table 4).

Table 3: Biomass and carbon stock of *Garcinia kola* trees

Variables	Means	Guéyo			Buyo	*P* = .05
		Konankro	Kouamékro	Wenedougou	Wonsealy	
Biomass (kg)	195.82	880.16a*	64.16b	561.8a	73.32b	0.0001
Carbon stock(t C/ha**)**	97.91	440.08a	32.08b	280.92a	36.64b	0.0001

*In the same column, means followed by the same letter are statistically identical at the 5% threshold (Student-Newman-Keuls).

Table 4: Biomass and carbon stock of cocoa trees

Radius	Biomass (kg)	Carbon stock(t C/ha)
0-10 m	145.77a*	72.89a
10-20 m	131.47b	65.73b
Means	135.69	67.84
P = .05	0.035	0.035

*In the same column, means followed by the same letter are statistically identical at the 5% threshold (Student-Newman-Keuls). P: probability (0.05).

3.3. Potential yield of *G. kola* and cocoa fruits

With an average of 29.36 for the number of fruits and 2433.95 g for fruit mass. The highest values were observed in Kouamékro, precisely on tree 4, which recorded 29 fruits and a mass of 6141.3 g.

The lowest values were also found in Kouamékro, with 4.86 fruits for tree 3 and a mass of 908.3 g for tree 1 (Table 5). Analysis of variance revealed significant differences between localities for these parameters (P < 0.05).

With an average of 1078.6 for cocoa yield, 0.5925 for the rate of gnawed pods and 19.609 for the rate of rotten pods. The highest values were observed within the 20 m radius for cocoa yield (1477.4) and rotten pod rate (20.798). As for the rate of gnawed pods, the highest values were found within a 10 m radius.

The lowest values are found within the 10 m radius for the redemption rate (679.8) and rotten pod rate (18.420). The lowest values for the rate of gnawed pods were found within a

20 m radius. Analysis of variance revealed significant differences between localities for these parameters (P < 0.05) (Table 6).

Table 5: Potential yield of*Garcinia kola*

Code of *Garcinia kola*	**Average number of fruits**	**Average fruit weight (g)**
Kouamékro 1	5.188b*	908.3b
Kouamékro 2	27.833a	1512.9b
Kouamékro 3	4.867b	1167.7b
Kouamékro 4	29.35a	6141.3a
Kouamékro 5	10.50b	1698.7b
Wonsealy 2	24.86a	1415.3b
Means	29.36	2433.95
P = .05	0.0001	0.0001

*In the same column, means followed by the same letter are statistically identical at the 5% threshold (Student-Newman-Keuls). P: probability (0.05).

Table 6: Potential yields of cocoa

Distance to *Garcinia kola*	**Number of pods**	**Rate of gnawed pods(%)**	**Rotten pod rate(%)**
0-10 m	679.8a*	0.6475a	18.420a
10-20 m	1477.4b	0.5375a	20.798a
Means	1078.6	0.5925	19.609
P = .05	0.0001	0.6639	0.3312

*In the same column, means followed by the same letter are statistically identical at the 5% level (Student-Newman-Keuls). P: probability (0.05).

4. Discussion

The degradation of forest cover linked to extensive cocoa cultivation has led the Ivorian government to adopt a strategy of sustainable cocoa production through the implementation of its replanting program based on agroforestry with the integration of forest fruit tree species, including *Garcinia kola*. In this work, the influence of *G. kola* on the carbon sequestration capacity and yield of cocoa trees was studied in traditional agroforestry systems. The aim is to promote the species in the new cocoa-growing strategy without it having a negative impact on yield, and to generate additive gains for cocoa producers. In this study, our results on the dendrometric characteristics of *G. kola* doesn't reveal a significant difference between localities. This result is justified by the similarity of the ecological parameters of the two localities of the study. Indeed, these localities are a part of the Nawa region, with an evergreen forest and have an average rainfall between 1,300 and 1,600 mm/year. The ecological conditions of the region seem favorable to the good growth of the species, despite the invasion of cocoa plantations.

G. kola is a rainforest tree that can also be found in fallow land or cocoa plantations (Kouamé *et al.,* 2008). Codjia*et al.*, (2018) consider that rainfall and vegetation type are not sufficient to explain the non-significance of morphological parameters from one locality to another. Pedoclimatic conditions, planting, previous crops, age, etc. should also be considered.

Biomass and carbon stocks are essential for implementing climate change mitigation strategies. Across all the areas surveyed, the average carbon stock estimate was 97.91 t C / ha, with a total biomass quantity of 195.6 kg. Carbon stock estimation studies in agroforestry systems carried out in several countries with varying climates and soils condition by Montagnini& Nair (2004), Albrecht & Kandji (2003), Zapfack et al., '(2016) have estimated the carbon stock potential of cocoa agroforestry systems at between 12 and 228 mg C ha^{-1}. Dixon (1995) estimated that, considering above-ground biomass and soil, an interplanted agroforestry system could store between 1.1 and 2.2 mg C annually over 50 years. Our values are lower than those reported by Dixon (1995) and Alrecht& Kandji (2003). It should be noted that carbon fluxes are highly variable, due to differences in soil and climatic conditions, management methods, vegetation types and ecosystem use (Henry *et al.*, 2011. Vroh et al., 2015). Various factors may influence the variability of tree biomass. In humid tropical zones, tree biomass is mainly influenced by trunk diameter, crown diameter and wood density. The capacity of agroforests to store carbon also depends mainly on the forest species of which they are composed, environmental factors and tree-specific factors (Tsoumou*et al.,* 2023; Henry, 2011). As for *G. kola* production, a significant difference was observed between trees. With an average number of fruits of 29.36 and a mass of 2433.95 g, the most productive tree (29 fruits and a mass of 6141.3 g) was identified in the Guéyo zone. This could be due to the age of the tree. These assertions corroborate that of Codjia*et al.*, (2018) who in a survey conducted in south-east Benin on the geographical distribution of *G. kola* revealed that the productivity ofthis tree species depends on its age and the pedoclimatic conditions in which the species grows.

With regard to the interaction between *Theobroma cacao* and *Garcinia kola*, the results obtained showed a variation in density and yield of cocoa trees depending on the radius (10 m and 20 m). We observed a low density in the 10 m radius with 34 cocoa trees for a production of 679 pods, compared to a high density in the 20 m radius with 82 cocoa trees for a production of 1,477 pods. Our results revealed also, that cocoa trees within the 10 m radius of *G. kola* trees had a higher biomass and carbon sequestration rate than those within the 20 m radius. This observation is justified by the nature of the cocoa tree, which is an ombrophilous plant and, its natural state, occupying the lower strata of rainforests (Lobão*et al.,* 2007). Under the shade of *G. kola*, cocoa trees are more photosynthetically active, enabling them to produce biomass and sequester carbon. According to De Almeida (2007), cocoa plants show increasing rates of photosynthesis as photosynthetically active radiation (PAR) increases, reaching values of 20-30% of PAR in full sun, and decreasing for exposures above 30% of global radiation (De Almeida et valle, 2008). This causes competition between the two species (for light and nutrients) leads to the drop in cocoa yield observed in our study. These results are in line with those of Somarriba *et al.* (2013), who argue that cocoa trees located close to associated trees are subject to pressure from companion trees, leading to lower cocoa yields.

Garcinia kola would therefore have a positive influence on biomass production and the capacity of cocoa trees to sequester carbon. These results are in line with those of Saj *et al.* (2013), who showed that agroforestry increases CO_2 capture while reducing greenhouse gas emissions, and also contributes to other ecological services such as conservation. No significant difference was observed in the rate of rotted and gnawed pods. *G. kola* therefore appears not to be a vector of diseases that could cause cocoa pod rot. Furthermore, the species does not seem to preferentially harbor animals (rodents) that attack cocoa pods. These results are in line with those of Coll (2009), who asserts that in CAFS, trees and other associated plants provide a strong potential for pest regulation. Cocoa replantation in the context of climate change can be achieved by increasing carbon sequestration in cocoa agroforestry systems.

5. CONCLUSION

Cocoa agroforestry systems are types of plant formations that have been modified by human activities such as agriculture. The choice of species for restoration and sustainable cocoa production is a key step in the success of agroforestry models. This study revealed that *Garcinia kola* trees influenced the biomass and/or productivity of cocoa trees depending on their positioning around *G. kola* trees. The presence of *G.kola* on cocoa trees had a negative influence on cocoa density and yield. The 10 m radii showed low density and low pod production compared with the 20 m radii. Yields of cocoa trees located close to *G. kola* were also low compared to those far from it. Our work has shown that stands of cocoa and associated *G. kola* have different contributions depending on their proximity. This complementarity in terms of carbon sequestration capacity and productivity is an asset that can be exploited to create replicable agroforestry models.

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