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Analysis of *Tieghemella heckelii* x *Theobroma cacao* L. Interaction in Traditional Agroforestry Systems in Western Cote d'Ivoire

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Abstract: Agromorphological and productivity parameters and incomes of cocoa companion trees assessment was studied to identify the ecological interaction between *Tieghemella heckelii* (makoré) and cocoa (*Theobroma cacao*) trees in Cote d'Ivoire. To this end studies have been carried out in rural areas in the locations of Duekoué and Taï. This work was conducted on the cocoa trees around the makoré trees over three distances around the tree (10, 20, and 30 m). Several parameters related to morphology, productivity, biomass, and CO_2 stock were determined, for the two speculations. Results indicated that the trees of makoré used have the same characteristics (size, DBH, biomass, and CO_2 stock). However, a difference in the shape of the fruit and/or the seed (weight of the fruit, length, and width of the seeds) and the number of seeds contained in the fruits was observed, thus reflecting a variability of individuals. Moreover, the density and yield of cocoa trees increased with distance. Indeed, cocoa trees located 30 m from the makoré trees recorded the highest rates of healthy pods. The rate of rotten and gnawed pods was similar for all distances considered, and cocoa trees located 20 m from the makoré trees were the most vigorous. Additionally, the biomass and the CO_2 stock were high for large diameter and tall cocoa trees, especially the cocoa trees located 20 and 30 m from the makoré trees.

Keywords: *Tieghemella heckelii*, *Theobroma cacao*, Agroforestry, Biomass, Productivity

1. Introduction

Cote d'Ivoire is the world's leading producer of cocoa beans, the marketing of which occupies an important place in the economy of this country [1]. The expansion of cocoa farming had negative consequences on the environment. Indeed, the country has experienced one of the fastest rates of deforestation in the world since its independence. From 16 million hectares of forest in the 1960s, Cote d'Ivoire today finds itself with less than 2.5 million hectares [2]. This deforestation has not only contributed to the loss of biodiversity but also to the disruption of the rainfall regime, thus limiting agricultural productivity [3]. So, according to Vroh, B. T. A. [4], the ecologically sustainable, socially acceptable, and economically profitable alternative to conventional agriculture would be agroforestry.

Defined as all land use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same land management unit, in a spatial or temporal arrangement ICRAF [5], agroforestry helps diversify producers' incomes and maintain agricultural production capacities, thus extending the environmental, economic, and social benefits of rural communities [6]. It's practiced all over the world and largely in temperate zones. In Cote d'Ivoire, certain perennial crops such as cocoa behave very well vis-à-vis of agroforestry practices. However, most cocoa farms in the country are monocropping in full sun or sometimes associated with trees without a real logic of association [7]. In these cropping systems, yields decline rapidly, due to numerous reasons, such as: the rapid decline in soil fertility, competition for water, increased pressure from pests harbored by trees and the proliferation of diseases such as black pod, due to humidity caused by excessive shade [7-9, 3]. Thus, the lack of knowledge of good agroforestry practices urges producers to perpetually move in search of new forest land. However, by adopting appropriate agroforestry techniques, cocoa farming can be carried out sustainably on the same soil type. Also, according to FAO [8], efficient agroforestry systems take advantage of the positive interaction between their different elements, so that the value of the final product is great compared to this same value in the absence of trees, while the risks of crop failure and dependence on chemical inputs are reduced.

From a technical point of view, it is necessary to associate the appropriate species with cocoa trees to gain satisfactory results. To this end, in rural areas, cocoa trees are generally associated with some forest species such as makoré (*Tieghemella heckelii*) which is among the threatened species in Cote d'Ivoire [10-12]. Among these forest species, makoré is the most appreciated tree by farmers in the South-west of Cote d'Ivoire as a multipurpose tree whose oil extracted from the seeds is highly valued by the local population [10, 13]. The species can be planted in open sites, grows fairly quickly, and the structure of its top is relatively open, which allows good penetration of light, making it eligible for agroforestry programs [14, 15]. However, research on this speculation remains embryonic [13, 16]. It is therefore necessary to carry out studies on the cocoa-makoré association to better understand the interaction of this cropping system on the productivity of cocoa farms, because the choices of species to be used in agroforestry systems must consider the ecological status of the species, but also the strata occupied by these species [17].

2. Materials and Methods

2.1. Plant Material

This study was carried out in two regions of western Cote d'Ivoire: the Guemon and the Cavally, specifically in the locations of Duekoué and Taï, highlighted in figure 1.

Figure 1. Study sites.

2.2. Plant Material

The plant material used for this study consisted of makoré (*Tieghemella heckelii*) and cocoa (*Theobroma cacao*) trees.

2.3. Method

2.3.1. Experimental Design

Kouakou, K. et al. [18] modified and adapted method was used to conduct our study. Concentric circles of 10, 20, and 30 m radius were delimited around the makoré trees in the cocoa orchard in 2019-2020.

2.3.2. Data Collection

Various parameters were collected within each circle in each location.

(i). Morphological Characterization of Makoré Trees

It consisted in carrying out dimensions in relation to the shape of the trees like the diameter at the breath height (DBH) at 1.30 m from the ground of companion trees, the diameter at the collar of cocoa trees, and the height of the trees (makoré and cocoa trees).

(ii). Tree Biomass

This parameter was calculated using the formula:

$$AB = 0.0509 \times (D \times (DBH2) \times H)$$

With: AB = aboveground tree biomass (t/ha), H = tree height (m), D = wood density (g.cm^3),

DBH = diameter at the breath height or diameter of 1.30 m from the ground (cm). The density of the wood considered for makoré is 0.69 g.cm^3 [19].

(iii). Carbon Stock of Cocoa and Makoré

The calculation of the biomass made it possible to determine the carbon stock of the cocoa and makoré trees according to the relationship:

$$Stock\ of\ CO2 = ATB \times 0.50$$

with ATB = aerial tree biomass (t/ha).

(iv). Fruits and Seeds Characteristics

The length, width, weight, and number of seeds per fruit of makoré fruits and seeds were determined.

(v). Cocoa Density

The cocoa density was determined by counting the cocoa trees neighboring the companion trees (makoré) in the radius of 10, 20, and 30 m.

(vi). Cocoa Trees Vigor

The vigor of the cocoa trees was determined from measurements of the diameter at the collar and the height of each cocoa tree according to the formula of [20].

$$Vigor = D2 \times H$$

with: H= height of the cocoa tree and D = diameter at the collar of the cocoa tree.

(vii). Productivity of Cocoa Trees

Cocoa plants productivity was determined at each distance of 10, 20, and 30 m from the companion trees. The number of healthy, gnawed, and rotten pods were counted per tree and according to distance. Thus, the production potential of cocoa trees, the rate of rotten, and gnawed pods, were calculated according to the following formula:

$$Rotten\ pod\ rate = (number\ of\ rotten\ pod)/(total\ number\ of\ pod) \times 100$$

$$Bitten\ pod\ rate = (number\ of\ bitten\ pods)/(total\ number\ of\ pods) \times 100$$

$$Production\ potential = \frac{number\ of\ healthy + rotten + gnawed\ pods}{total\ number\ of\ pods} \times 100$$

2.3.3. Statistical Analysis

All collected data were subjected to an analysis of variance (ANOVA), at the significance level of 5%, using SAS 9.4 software. When the probability was $P \geq 0.05$, we deduce that there is no significant difference between the means, on the other hand, when $P < 0.05$, there is a significant difference between the different means. When a significant difference is observed, the test of the smallest significant difference was carried out to discriminate the treatment responsible for this difference.

3. Results

3.1. Characteristic of Makoré Trees

The analysis of variance revealed that all the makoré parameters (height, DBH, biomass, and CO_2 stock) did not vary ($P > 0.05$), regardless of the locality. These parameters were therefore similar in each of the localities (Table 1).

3.2. Biomass and CO_2 Stock of Cocoa Trees

The analyzed parameters (stem diameter, height, vigor, biomass, and CO_2 stock) were significantly influenced ($P< 0.05$) by the distance from the makoré trees (Table 2). In addition, the test of the smallest significant difference showed that the diameter at the collar of the cocoa trees located 30 and 20 m away were greater with 38.72 and 37.93 cm, respectively, than that of the trees located at 10 m from the makoré (35.45 cm). It was the same for the height of the cocoa trees. Indeed, the cocoa trees neighboring the makoré between 20 and 30 m possessed much greater heights with 4.52 and 4.51 m, respectively compared to that of the cocoa trees located at 10 m (4.21 m).

Regarding the vigor of the trees, the test of the smallest significant difference indicated that cocoa trees located at 20 m from the companion trees were more vigorous (0.124) than the trees located at 30 m from the makoré (0.121). As for the cocoa trees located at 10 m, the vigor of the trees was intermediate between the two previous values (0.123).

Finally, the analyzes revealed that the cocoa trees located at 20 and 30 m from the makoré had greater quantities of biomass and CO_2 stock than the cocoa trees located 10 m away. Thus, the biomass extended from 141.43 t/ha for the trees located 10 m away, to 168.42 t/ha for those located 20 m away and to 178.66 t/ha for the cocoa trees located at 30 m from the makoré. As for the stock of CO_2, the trees located 10 m from the makoré stocked an average of 70.71 tC/ha of CO_2. The trees located at 20 and 30 m stored 84.21 and 89.33 tC/ha of CO_2, respectively.

3.3. Characteristic of Makoré Fruits

Seven parameters were used to study makoré fruits according to their locality: length, width, weight of the fruits, number of seeds per fruit, length, width, and weight of the seeds (Table 3).

Results indicated that there was a significant interaction (P < 0.05) between the weight of the fruits, the number of seeds per fruit, the length, and the width of the seeds. Indeed, the makoré trees from the locality of Duekoué showed a higher average fruit weight than those of the locality of Taï. The makoré fruits of Taï contained more seeds than those of Duekoué. In addition, makoré seeds from Duekoué were longer and wider than those from Taï.

Finally, no significant difference (P > 0.05) was observed in the length and width of the fruits, and the weight of the seeds, for both localities.

Table 1. *Characteristics of makoré plants according to locality.*

Parameters	Locality		Statistics		
	Duekoué	Taï	CV (%)	*F*	*P*
Height (m)	23.81^{a*}	27.41^{a}	29.17	0.73	0.5378
Diameter at the Breath Height (cm)	176.07^{a}	218.66^{a}	38.7	2.46	0.0762
Biomass (t/ha)	903.47^{a}	1116.71^{a}	132.60	0.37	0.7723
CO_2 stock (tC/ha)	451.73^{a}	558.35^{a}	132.60	0.37	0.7723

* For each parameter, the values with the same letters on the lines are statistically equal.

Table 2. *Characteristics of cocoa trees according to the study distance.*

Parameters	Distance around makoré trees (m)			Statistics		
	10	20	30	CV (%)	F	P
Collar Diameter (cm)	35.45^{b}	37.93^{a}	38.72^{a}	32.42	27.97	< 0.001
Height (m)	4.21^{b}	4.52^{a}	4.51^{a}	32.11	20.34	< 0.001
Vigor	0.123^{ab}	0.124^{a}	0.121^{b}	30.76	5.10	0.061
Biomass (t/ha)	141.43^{b}	168.42^{a}	178.66^{a}	93.94	21.83	< 0.001
CO_2 stock (tC/ha)	70.71^{b}	84.21^{a}	89.33^{a}	93.94	21.83	< 0.001

* For each parameter, the values with the same letters on the lines are statistically equal.

Table 3. *Characteristic of makoré fruits according to localities.*

Parameters	Locality		Statistics		
	Duekoué	Taï	CV (%)	F	P
Length of fruit (cm)	9.49^{a*}	8.84^{a}	11.10	3.32	0.074
Width of fruit (cm)	6.67^{a}	6.24^{a}	18.40	1.04	0.312
Weight of fruit (g)	265.49^{a}	212.50^{b}	27.91	7.73	< 0.001
Number of seed	1^{b}	1.20^{a}	22.74	3.78	0.0037
Length of seed (cm)	6.65^{a}	5.83^{b}	7.56	10.52	< 0.001
Width of seed (cm)	3.40^{a}	3.11^{b}	8.31	4.77	0.0007
Weight of seed (g)	43.07^{a}	31.90^{a}	85.07	0.68	0.6680

* For each parameter, the values with the same letters on the lines are statistically equal.

3.4. Cocoa Density

The table 4 showed that the density of cocoa trees increased significantly (P<0.001) with the distance around the makoré trees. It is estimated an average around 38 cocoa trees for cocoa trees located at 10 m around the makoré trees, 94 for cocoa trees at 20 m apart, and 125 for cocoa trees located at 30 m from makoré trees.

3.5. Effect of Distance on Cocoa Trees Productivity

Results revealed a significant interaction (P<0.001) between cocoa trees yield and distance around makoré trees (Table 5). The highest yield was observed in cocoa trees of 30 m away from the companion tree, followed by cocoa trees located 20 m away. Finally, the lowest yields were observed in the cocoa trees at 10 m from the makoré trees.

The rotten and gnawed pods rates values in Table 5 showed that the distances had no influence (P>0.05) on these parameters. Furthermore, there was a significant interaction (P<0.05) between the distance and the rate of healthy pods. Cocoa trees located at 30 m from companion trees had a higher rate of healthy pods (36.22%) than that of cocoa trees located 10 m from makoré trees (26.16%). As for the cocoa trees located at 20 m, the rate is intermediate between the two previous values (31.62%).

Table 4. *Effect of study distance on cocoa tree density.*

Parameters	Distance around makoré trees (m)			Statistics		
	10	20	30	CV (%)	F	P
Density of cocoa trees	38.15^{c*}	94.19^{b}	125.74^{a}	47.43	31.91	< 0.001

*For each parameter, the values with the same letters on the lines are statistically equal.

Table 5. *Effect of distance on cocoa tree productivity.*

Parameter	Distance around makoré trees (m)			Statistics		
	10	20	30	CV (%)	F	P
Cocoa yield	76.74^{c*}	264.31^{b}	470.05^{a}	124.52	9.22	< 0.001
Healthy pods (%)	26.16^{b}	31.62^{ab}	36.22^{a}	44.71	3.48	0.0355
Rotten pods (%)	8.80^{a}	10.08^{a}	10.85^{a}	67.82	0.64	0.5305
Gnawed pods (%)	5.30^{a}	6.22^{a}	7.19^{a}	85.09	0.86	0.4285

* For each parameter, the values with the same letters on the lines are statistically equal.

4. Discussion

It appears from this study that the height and the diameter (DBH) of the makoré trees are statically identical in all the localities. Results obtained correspond to those of the description of makoré made by Bonnéhin, L. [10]. Authors described the makoré as a tree that can reach 55 m in height and 250 cm in diameter. Thus, the trees that were used to carry out this study, having not yet reached this height, we could say that they are still at the young, or adult stage.

In terms of makoré fruits, we noted that the number of seeds contained in the fruits was not proportional to their weight. Additionally, the fruits of low weight observed at Taï contained more seeds than those of Duekoué despite their high weight. This therefore testifies to a varietal diversity of the trees. Assi, B. F. [21] also observed a morphological diversity of cashew nuts (weight, thickness, etc.), due to the inter-varietal genetic mixing of cashew trees during pollination. As a result, the “solitary” character of the makoré seeds from the locality of Duekoué, allowed them to grow (in length and width) more efficiently than the seeds of Taï, grouped in the fruits.

Cocoa density over three distances (10, 20, and 30 m) around the makoré trees was studied. Distance has an influence on the density of cocoa trees neighboring the companion trees. The change in cocoa density observed was due to the increase in the area occupied by these trees in the various sub-plots set up. However, the average densities observed for each distance could correspond to the expected densities, considering the spacing of 3×2.5 m recommended in the establishment of cocoa farms [22]. The position of most companion trees at the edge of the field would have reduced the areas of the different sub-plots, thus reducing the cocoa density for the three distances. In the description of cropping systems associating makoré, Bonnéhin, L. [10] revealed that makoré was planted at the edge of the field, in the space between perennial crops and agricultural tracks, by farmers in the Southwest of Cote d'Ivoire. In view of the different densities obtained, makoré could be associated with the cocoa tree, without causing its death, unlike certain species such as *Spathodea campanulata* which has a negative impact on the development of the cocoa tree, expressed by the absence of cocoa under the canopy of this tree [23].

The increase in yield of cocoa trees with distances could be linked to their densities. Indeed, the different yields obtained are proportional to the densities; the yield increases with the density. Also, the use of heterogeneous plant material (mixture of improved and unimproved varieties) in the establishment of farmer plots could be a cause of yield variation. To this end, the work of Kouadio, V. P. G. et al. [9] in a farmer environment, revealed that the so-called "Ghanaian cocoa" varieties (improved and/or hybridized varieties) are much more productive than the "French cocoa" varieties. Thus, given their large surface area, cocoa trees located at 30 m from companion trees could contain many improved varieties than the other distances.

In addition to the yield, the cocoa trees located 30 m from the makoré trees have a high rate of healthy pods (36.22%), unlike the cocoa trees located 10 m away, which have the lowest rate (26.16%). With a healthy pod rate of approximately 32%, the distance of 20 m appears to be the intermediate distance of variation in the healthy pod rate. However, the rate of rotten and gnawed pods did not vary, regardless of distance considered. Indeed, the treatment and monitoring of cocoa trees is done in a homogeneous way. As a result, certain cultural practices (density of plants, sanitary harvest not practiced, etc.) or certain environmental factors (rainfall, humidity, etc.) could be the cause of pod rot [7]. In addition, the complexity of certain agroforestry systems (system comprising many local species), promotes the proliferation of rodents, feeding on the mucilage of cocoa beans, after having perforated the pods [9].

The diameter and height of cocoa trees located 20 and 30 m from makoré trees have values much greater than those of cocoa trees positioned 10 m from makoré trees. This may be due to the influence of some species associated with cocoa farms. In addition to makoré, several woody and non-woody species are most often associated with cocoa trees, which can thus have an impact on the growth and development of cocoa trees, through the shade they provide. The work of Deheuvels, O. [24] also revealed that agroforestry systems with a dense and complex canopy (very high level of shade) include very tall cocoa trees (7.5 m), unlike agroforestry systems with a high density of cocoa trees (5 m), with a high density of Musaceae (2.5-5 m) and a complex and sparse canopy (5-7.5 m). These agroforestry systems also had a lower shade rate than those with a dense and complex canopy.

The relationship between the height and the diameter of the cocoa trees made it possible to deduce the vigor. It shows that despite the small height and small diameter of the cocoa trees located 10 m from the makoré trees, these cocoa trees have an intermediate vigor (0.123) between the cocoa trees positioned 20 m (0.124) and 30 m (0.121) from the makoré trees. The vigor of cocoa trees is therefore weakly influenced by the distance around the associated trees.

The largest quantities of biomass and CO_2 stock observed in cocoa trees located 20 and 30 m from the makoré trees could be explained by their morphologies (significant height and diameter at the collar). Indeed, although having the highest cocoa densities, authors like Essola, E. L. C. [25] and Kouamé, A. P. S. [26] attested that the density of trees hardly implies a high quantity of biomass or CO_2 stock. Hence, according to Kouamé, A. P. S. [26] the parameters influencing the biomass are the height and the diameter (DBH) of the trees. Our results are in agreement with those of the author, who revealed in the arboretum of the National Center of Floristic of Cote d'Ivoire that biomass and carbon sequestration increase with the diameter and the height of seedlings. Thus, the invariability of the height and diameter of the makoré trees would therefore have had an influence on the biomass and the stock of CO_2, which also remained invariable. However, characterized by low density, large heights and diameters, makoré trees recorded the highest amounts of biomass and CO_2 stock, compared to cocoa trees. Similar results were obtained by Essola, E. L. C. [25] indicating that the lowest carbon stock values were recorded in cocoa trees, despite their high density (about 10 times more than that of associated trees) in the field.

5. Conclusion

Makoré trees involved in this study had the same characteristics (size, DBH, biomass, and CO_2 stock). However, there was a difference in the shape of the fruit and/or the seed (weight of the fruits, length, and width of the seeds) and the number of seeds contained in the fruits, thus testifying to a varietal diversity of the individuals. Additionally, the density and yield of cocoa trees increases with the distance around the makoré trees (10, 20 and 30 m). The cocoa trees located 30 m from the makoré trees recorded the highest rates of healthy pods. However, the rates of rotten and gnawed pods were similar for all distances. Also, the cocoa trees located 20 m from the makoré trees were the most vigorous. Lastly, the biomass and the amount of CO_2 stock were high in cocoa trees with large diameter and high height in particular, cocoa trees located at 20 and 30 m from the makoré trees. Makoré could thus be associated with the cocoa tree for a sustainable cocoa based agroforestry system.

6. Recommendations

In order to deepen this topic, some follow-up actions can be envisaged such as: i) repeat this study during the short and the large cocoa harvest seasons to confirm current results, ii) study the influence of climatic variability on the behavior of makoré by dendrochronological analyses, iii) characterize makoré pests capable of harming the cocoa trees, iv) conduct this study on young and mature cocoa farms over several years in order to know the benefits of the tree on the farms age, v) domesticate *Tieghemella heckelii* and densify cocoa-based agroforests, and vi) evaluate the tree income to producers.

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