AGRONOMIC EVALUATION OF TRADITIONAL AGROFORESTRY SYSTEMS BASED ON RUBBER TREE (*HEVEA BRASILIENSIS*) IN THE WEST-CENTRAL OF CÔTE D'IVOIRE.

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For several decades, agroforestry has been seen as a tangible solution to fight against the degradation of the forest cover. However, some farmers remain reluctant to adopt this system. It's in this context that the present study was carried out to evaluate the performance of the traditional rubber tree-based agroforestry system. To carry out this research, four experiments have been realized on two rubber tree plots, one immature plot and the other mature in Daloa, Central-Western of Côte d'Ivoire. In the immatutre plot, the effect of two forest species: kapok tree (*Ceiba pentandra*) and akpi tree (*Ricinodendron heudelotii*) on the growth of rubber trees was studied. As for the mature plot, the study focused not only on the growth and the production but also on the impact of the kapok tree on the sensibility of rubber trees to dry notch. A total of nine (9) treatments on the immature plot and eleven (11) treatments on the mature plot were tested using a one-tree plot design. The results showed that the forest species studied have only influenced the growth in diameter and the production of rubber trees located less than three meters from their proximity. However, the forest species had not affected the sensibility of rubber trees to dry notch. So, this study shows that the traditional agroforestry systems based on rubber trees don't constitute a danger to rubber cultivation and can be considered as a beneficial practice for the sustainable management of agricultural and forestry resources.

Abstract

1 Introduction: -

Changes in the natural environments of tropical regions lead to the forest degradation and the transformation into savannahs strongly influenced by human activity. These changes affect the structure and composition of plants of initial conditions of soil, climate and flora (Brookfield & Padoch, 1994). In Côte d'Ivoire, forest cover has fallen from nearly 16 million hectares around 1960 to 2 million hectares today. This is equivalent to 9.2 % of forest cover, against over 20% in the 1960s FAO, 2023). So, to ensure sustainable management of natural resources, it's essential to use agroforestry practices (windbreaks, improved fallows, intercropping, silvopastoral systems...). Agroforestry consists of combining trees with crops (food or cash) and/or livestock in a specific spatial and temporal arrangement (Nair, 1991). It is one of the oldest methods of agricultural production, long practised on almost every continent (Nair, 1993). In Côte d'Ivoire, this system is applied to important crops such as cocoa to limit the damage caused by their expansion into the forest canopy. Rubber cultivation is also very important in Côte d'Ivoire, with 1.3 million tonnes produced in 2022 from an area of 600,000 hectares. This makes Côte d'Ivoire the leading rubber-producing country in Africa and the third largest in the world (Marc, 2023). In addition, rubber cultivation is one of the main causes of the degradation of Ivorian forest cover (N'guessan, 2022). Faced with this deforestation, the government of Côte d'Ivoire has implemented several policies to slow down the phenomenon and restore the country's forest cover. In addition, the international REDD+ mechanism constitutes one of these policies, aims to achieve a forest cover rate of at least 20% in 2030 (REDD+ CI, 2018) through practices such as agroforestry. However, to this day many farmers remain skeptical of the idea of combining woody species with their rubber plantations for fear of seeing their rubber production fall. It's with this in mind that the general aim of this work is to contribute to the reconstitution of Côte d'Ivoire's forest cover through the impact assessment of rubber trees based on agrosystems on the vigour, rubber production, and health status of rubber trees.

Materials and methods :-

Study area

The study was carried out in Séria and Békipréa, villages located respectively to12.5 and 8.5 km from Daloa. Daloa is a town in the west-central of Côte d'Ivoire (Figure 4). It's the capital of the Sassandra-Marahoué district and the chief town of the Haut-Sassandra region. At 6° 52' 00" north latitude and 6° 27' 00" west longitude, the vegetation of Daloa department is composed of semi-deciduous forests to the south and west, and wooded savannah to the north and east (Guillaumet, 1971). The climate of the Daloa department is humid tropical, with four distinct seasons, including two rainy seasons and two dry seasons. The average temperature is 26°C, with an average rainfall of 941.6 mm per year (Aude & Nico, 2024).

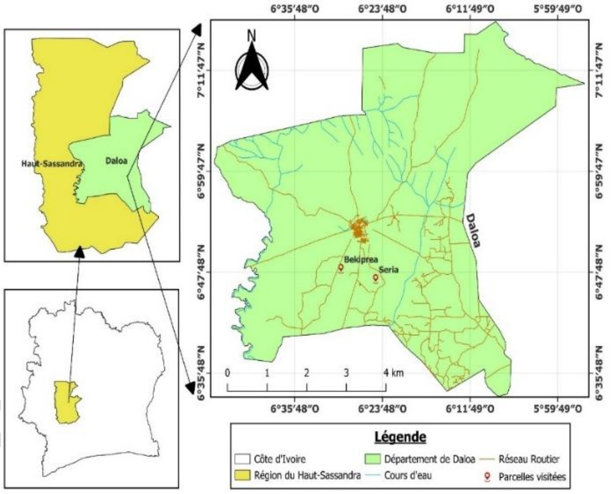


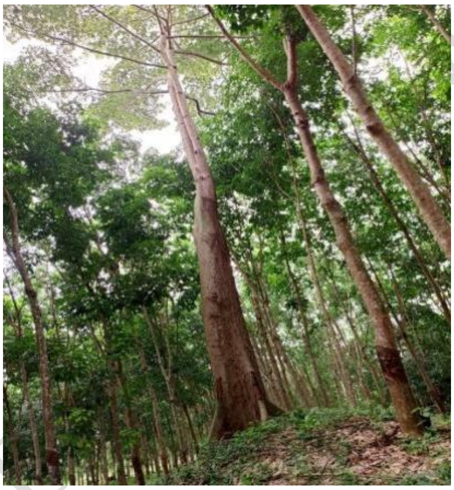
Figure 1 :- Location of the area of study

Plant material

The plant material was consisted of *Hevea brasiliensis*, two plants of *Ceiba pentandra* (Figure 2) and one plant of *Ricinodendron heudelotii* (Figure 3).

Figure 2 :- A *Ceiba pentandra plant in association with rubber trees in production (12 years).*

Figure 3 :- A plant of *Ricinodendron heudoletii* in association with immature rubber trees (4 years old).



Study methods :-

Experimental device

The experiments were carried out on two rubber tree plots: an immature plot located in Séria and a mature plot in production in Békipréa. Each plot was planted at a density of 555 plants per hectare (6 m × 3 m). The rubber trees in the immature plot were 4 years old, while those in the mature plot were 12 years old. The experiment followed a "one-tree plot design", where each rubber tree constituted a replication. On the immature plot, two trials (Trial 1 and 2) were set up, each comprising nine treatments. The rubber trees were associated with specific forest species: a kapok tree (*Ceiba pentandra*) for Trial 1 and an akpi tree (Ricinodendron heudelotii) for Trial 2. The kapok tree had a circumference of 2.7 m at 1.5 m from the ground, a height of around 17 m and a crown 10 m in diameter. The akpi tree had a circumference of 2.5 m, a height of around 18 m and a crown 12 m in diameter. On the mature plot in production at Békipréa, two trials (Trials 3 and 4) were also carried out, with eleven treatments each. The rubber trees were associated with a kapok tree in both trials. The one in Trial 3 had a circumference of 2.8 m, a height of about 20 m and a crown diameter of 12 m, while the one in Trial 4 had a circumference of 3.4 m and a crown diameter of 12.4 m for a similar height. In each plot, treatments were defined according to the distance separating the rubber trees from the associated forest species, as detailed in Tables 1 and 2.

Table 1:- Characteristics of treatments on immature rubber tree plots

Treatments	Distance between rubber trees and forest species (m)
T1	0 – 3
T2	3 – 6
T3	6 – 9
T4	9 – 12
T5	12 – 15
T6	15 – 18
T7	18 – 21
T8	21 – 24
T9 (control treatment)	Over 24

Table 2:- Characteristics of treatments on mature rubber tree plots

Treatments	Distance between rubber trees and forest species (m)
T1	0 - 3
T2	3 – 6
T3	6 – 9
T4	9 – 12
T5	12 – 15
T6	15 – 18
T7	18 – 21
T8	21 – 24
T9	24 – 27
T10	27 – 30
T11 (Control treatment)	over 50

Measured parameters :-

Rubber tree circumference

The measurements of rubber trees circumference were taken at 1.70 m from the ground using a tape measure and expressed in cm.

Rubber production

The fresh rubber production (FP) was evaluated by weighing (Figure 10). Fresh weight (FW) was transformed into dry weight of rubber (DW) using the following relationship:

D.W. = F.P. x 0,6

The dry rubber production was expressed in grams per tree per tapping (g/t/t).

The dry notch rates

The Dry notch is a disease characterized by the total or partial absence of latex flow in rubber trees. The length of the dry notch was measured using a tape measure. The percentage of dry notch was determined as follows:

DNR (%) = (SNL / TNL) x 100

DNR: Dry Notch Rate, SN**L**: Sick Notch Length, **TNL**: Total Notch Length

Statistical analysis

The data collected were analyzed using a one-factor analysis of variance (ANOVA), performed with Minitab_21.2 software. This analysis, performed with a threshold of 5%, allowed us to compare rubber trees in terms of circumference, production and dry notch rate. To determine significant differences between the different parameters, the Newman-Keuls test was applied, also with a threshold of 5% to classify the means.

Results :-

Circumference of rubber trees

The average circumferences of immature rubber trees in trials 1 and 2 are shown in Table 3. They vary from 22.10 cm (T1) to 34.36 cm (T9, control) for the trial 1, and from 27.30 cm (T1) to 40.10 cm (T9) for the trial 2. In both trials, the treatment 1 (T1) recorded the lowest average circumference, while the highest circumferences were observed with the treatment 5 (34.36 cm) for the trial 1 and the treatment 7 (45.13 cm) for the trial 2. There were no significant differences between the average circumferences of the different treatments

Table 3 :- Average circumferences of immature rubber trees by treatment (Trials 1 and 2)

Treatments	Average circumferences (cm)	
	Trial 1	**Trial 2**
T1	22,10a	27,30a
T2	28,17a	32,52a
T3	33,50a	35,02a
T4	32,57a	35,84a
T5	34,36a	38,67a
T6	33,20a	37,74a
T7*	-	45,13a
T8*	-	33,60
T9 (Control treatment)	32.57a	40,10a
p	0,554	0,361
F	0,85	1,16

Numbers with the same letter are not statistically different at the threshold of 5 % according to the Newman-Keuls test. *There were no rubber trees at these distances in trial 1.

The average circumferences of mature rubber trees in Trials 3 and 4 are shown in the Table 4. They varied from 36.35 cm (T1) to 58.52 cm (T11, Control treatment) for the trial 3, and from 39.33 cm (T1) to 62.69 cm (T11) for the trial 4. In both trials, the treatment nearest to the kapod tree (T1) recorded the lowest average circumference, while the highest was observed with the treatment 11 (T11, Control treatment) for the trial 3 and the treatment furthest away (T0) for the trial 4. There was a significant difference between the mean circumferences of the different treatments.

Table 4 :- Average circumferences of mature rubber trees by treatment (Trials 3 and 4)

Treatments	Average circumferences (cm)

	Trial 3	Trial 4
T1	36,35a	39,33c
T2	49,50ab	54,49abc
T3	50,92ab	57,23ab
T4	49,60ab	56,13ab
T5	57,48ab	53,25abc
T6	55,40ab	55,71ab
T7	53,23ab	54,20ab
T8	51,00ab	52,75abc
T9	56,19ab	50,61bc
T10	57,47b	52,60abc
T11(Control treatment)	58,52b	62,69a
p	0.026	0,001
F	2,24	3,18

Numbers with the same letter are not statistically different at the threshold of 5 % according to the Newman-Keuls test.

Rubber production from mature rubber trees

The average of dry rubber yields for each treatment are shown in Table 5. They vary from 0 g (T1) to 168.4 g (T11, Control treatment) in one case, and from 0 g (T1) to 202.5 g (T11) in the other. In both situations, the rubber trees nearest to the kapok tree (T1) showed the lowest rubber yields, while the rubber trees furthest away (T11, Control treatment) showed the highest yields. A significant difference was observed between the average rubber yields of the different treatments.

Table 5 :- Average production of dry rubber (g/a/s) of mature rubber trees by treatment (Trial 3)

Treatments	Average production of dry rubber (g/a/s)	
	Trial 3	Trial 4
T1	0b	0b
T2	93,8ab	103,6ab
T3	95,0ab	114,6 ab
T4	115,0ab	141,4 ab
T5	124,3ab	168,2 ab
T6	145,0ab	128,5 ab
T7	116,1ab	132,3 ab
T8	121,4ab	164,8 ab
T9	152,3ab	131,9 ab
T10	159,5ab	131,3 ab
T11(Control treatment)	168,4a	202,5a
p	0,036	0,032
F	2,13	2,08

Numbers with the same letter are not statistically different at the threshold of 5 % according to the Newman-Keuls test.

Dry notch rate

The dry notch rate of the trials 3 and 4 are shown in Table 6. The different dry notch rates obtained for these trials were statistically equivalent and practically nil.

Table 6 :- Dry notch rate of rubber trees per treatment in the trials 3 and 4

	Dry notch rate (%)	
Treatments	**Trial 3**	**Trial 4**
T1	0,00a	0,00a
T2	0,00a	0,14a
T3	0,00a	0,00a
T4	0,00a	0,00a
T5	0,00a	0,04a
T6	0,00a	0,00a
T7	0,00a	0,00a
T8	0,00a	0,00a
T9	0,00a	0,00a
T10	0,00a	0,00a
T11(Control treatment)	0,03a	0.00a
P	0,69	0,208
F	0,73	1,36

Numbers with the same letter are not statistically different at the threshold of 5 % according to the Newman-Keuls test.

Discussion :-

The results obtained in the production plot showed that the kapok tree had a strong influence only on the rubber trees located less than three meters of them. Rubber trees located within a radius of more than 3 m from the kapok trees showed better growth and did not seem to be influenced by the presence of the kapok trees. This weak growth in the thickness of the rubber trees nearer to the kapok trees can be explained by the shading caused by the kapok trees on the rubber trees. Kapok trees have greater crown heights and diameters than rubber trees. The shade created by the Kapok trees therefore prevents the rubber trees to receive sufficient light for photosynthesis, which is a very important phenomenon for the growth of the rubber trees in view of the plant biomass they produce. To the phenomenon of photosynthesis limitation which hinders the growth of rubber trees can be added the factors of nutritional and hydric competition between the kapok trees and the rubber trees. These results corroborate those of (Keli et al.,1992) who argue that at least one of these factors (water, mineral elements and light) is at the base of the poor growth observed in rubber trees associated with other crops. In the case of immature rubber trees, the results showed that there was no significant difference between treatments, for any of the trees were associated with the rubber trees (kapok tree or akpi tree). This low impact of associated forest species on the growth of immature rubber trees could be explained by the fact that, at this young age, the needs of rubber trees (in terms of light, water and nutrients) are quite low. The light, water and nutrients available on the plot are therefore sufficient to satisfy the growth needs of the rubber trees. There is therefore no marked competition between the young rubber trees and the associated forest species. These results are confirmed by Taiz & Zeiger (2002), who argue that the needs (water, light, mineral elements) of plants differ according to their stage of development and therefore the needs (water, light, mineral elements) of immature plants are lower than those of adult plants. Concerning the rubber production, the results also showed that the kapok trees associated with the rubber trees had a negative impact on the rubber production of the rubber trees located very close to them, meaning within a radius of less than three meters. These rubber trees recorded the lowest average rubber production. It should also be noted that rubber trees less than three meters away were not tapped, as they were deemed too small to be tapped. According to standards, trees must reach a circumference of 50 cm at one meter from the ground to be tapped (Obouayeba et al., 2002). However, the rubber trees near of the kapok trees have an average circumference of around 39 cm. Moreover, the low average circumference of rubber trees in treatment 2 (3 - 6 m) could also be one of the reasons for the low rubber productions observed. Rubber production was significantly correlated with rubber tree circumference (Soumahin, 2010). These results concur with those of (N'guessan, 2022) who, in an agromorphological characterization of a Rubber Tree-Teak agroforestry system, observed low rubber production in rubber trees that were close to teaks. In terms of the average rate of dry notch, the results obtained showed that kapok trees had no impact on the health of the rubber trees, as the average rate of dry notch obtained over the entire experimental plot was practically nil (Okoma et al., 2009).

Conclusion :-

This study was carried out in the context of sustainability, while evaluating the performance of traditional agroforestry systems rubber trees. At the end of this study, it was found that the kapok tree and the akpi tree had no impact on the growth of immature rubber trees. However, for the mature rubber trees, the kapok tree association induced a reduction in growth and a drop of rubber production of the rubber trees located less than 3 m from them. Finally, kapok trees associated with rubber trees have no influence on the rate of dry notch of rubber trees. Forest species such as kapok tree (*Ceiba pentandra*) and akpi (*Ricinodendron heudoletii*) can therefore be associated with rubber trees without causing major damage to rubber trees. However, a minimum distance of 3 m must be maintained between the forest species and the rubber trees.

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Conflicts of interest

The authors declare no conflict of interest regarding the publication of this article.

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