Rubber agroforestry systems (RAS) for a sustainable agriculture.

Agroforestry systems based on rubber trees.

Workshop GPSNR 2023 with rubber planters in Côte d'Ivoire

English version for external sharing[1]

Yamoussoukro, October 2023

By Dr Eric Penot (CIRAD UMR Innovation, France), Dr Maria Wang Mei Hua, and Jean Pierre Akichi (APROMAC)

Mission carried out in October 2023 and report in February 2024, Montpellier

[1] Participant names redacted from this version for confidentiality purposes.

1 Introduction: Agroforestry Practices with Rubber (Rubber Agroforestry Systems - RAS): The workshop organized by APROMAC in Yamoussoukro

We extend our gratitude to APROMAC for organizing this fruitful three-day meeting with rubber producers.

1.1 Objectives

The overall objectives of this session with rubber producers from Côte d'Ivoire are:

- To share technical information on existing RAS worldwide to illustrate examples achievable under the specific climatic and pedological conditions of Cambodia.
- To inform farmers and benefit from their experience with RAS, especially in intercropping.
- To identify the constraints and opportunities for RAS development in various socio-economic environments and the impact of local markets on RAS potential.
- To identify RAS cultivation models suitable for local farmers.
- To identify conditions for further potential actions (demonstration plots, farm trials).
- To share farmers' perceptions of RAS and conditions for developing opportunities.

For GPSNR, the objectives are:

- To gather data on the best evidence and practices on agroforestry for natural rubber systems globally, nationally, and regionally.
- To disseminate the compiled educational material to APROMAC member producers and their communities, where possible.
- To organize pilot workshops (in Indonesia, Cambodia, and here in Côte d'Ivoire) for smallholder members of GPSNR and their communities to present agroforestry concepts and practices and provide guidance and answers to the following questions:
  a) What is possible to develop in your specific region or location, and how can it be achieved?
  b) What is the market availability and demand for specific products in your region?
  c) How can agroforestry investments benefit smallholders economically, environmentally, and socially?

The initial target countries in 2022 were Indonesia and Cambodia. In Indonesia, agroforestry possibilities and practices vary significantly across the country's main rubber-producing regions, with smallholders showing keen interest. It's crucial to blend or merge more traditional concepts like jungle rubber with evidence-based structured agroforestry forms.

In Cambodia, there's no historical development of RAS by local farmers, except for some intercropping during the immature period. Most rubber areas have few other perennial crop opportunities (pepper, banana, cashew nuts).

The situation in Côte d’Ivoire is similar to Cambodia, with no RAS development. Additionally, there are no significant climatic constraints (a dry season of 3 to 5 months leading to potential severe water competition between rubber and associated trees as in Cambodia, Burma, or eastern Sri Lanka), meaning not all potential RAS models need to consider climatic constraints as of now.

The participant list is detailed in Annex 1. A consent form (Annex 2), a guide or introduction to rubber agroforestry (Annex 3), and a survey questionnaire (Annex 4) was given to all participants. All documents distributed to participants were in French. An analysis of the agroeconomics of rubber systems in Côte d'Ivoire by CIRAD in 2020 is included (Annex 4). Annex 5 is a technical summary of the survey responses by workshop participants.

1.2 Workshop Organization

The workshop was organized by APROMAC in Yamoussoukro with 50 producers (all from APROMAC) and 12 individuals representing plantation companies (SAPH, SOGB, etc.), APROMAC, and other institutions.

After two presentations on agroforestry practices during immature and mature periods, and a presentation on a prospective economic modeling trial with a rubber-based agroforestry system conducted for the FTA project in 2021, two exchange sessions were held to discuss possibilities in the Ivorian context.

The two seminars planned by GPSNR in 2023, in Côte d’Ivoire and Indonesia, are funded by Bridgestone.

The workshop's program is as follows:

The workshop program for Côte d'Ivoire is as follows:

DAY 1: 25 OCTOBER 2023 (Wednesday)

Time	Programme	Items needed	Personnel needed
Arrival – 2:30 PM	**Registration** Consent Forms Participants Survey	Registration forms Consent forms Survey form Pens	Facilitators to help with registration, consent form, and survey
2:30 – 3 PM	**Introduction** - Organizers, Dr. Eric, Dr. Maria introduce themselves & about the workshop - Self introductions by all participants	Sound system	Representatives from APROMAC, SIPH, other involved agencies to introduce themselves
3–5PM	**What is Agroforestry?** We discuss what participants understand about agroforestry, and give definition **Presentation on Agroforestry during Immature Period** by Dr. Eric Penot with Q&A (during/after) * **Short break** during presentation when appropriate	Projector Sound system	Tech support Refreshments support

DAY 2: 26 OCTOBER 2023 (THURSDAY)

Time	Programme	Items needed	Personnel needed
8:30 AM – 10:30 AM	**Small group discussion**: Smallholders' Experience with Agroforestry during Immature Period 5 groups of 10?	Seats arrangement for small groups Paper and stationery for writing reflections	Facilitator for each small group discussion (participants can self-select among themselves)
10:30 – 11 AM	Break		Refreshments support
11 – 12:30 PM	**Whole group sharing** - challenges and opportunities for agroforestry during immature period	Flipchart stand / Whiteboard for writing Marker Pens	
12:30 PM – 1:30 PM	Lunch		

1:30 – 3 PM	**Presentation on Agroforestry during Mature Period** by Dr. Eric Penot	Projector Sound system	Tech support
3 – 3:30 PM	Break		Refreshments support
3:30 PM – 4:30 PM	Continuation of presentation / Q&A session / Briefing about tomorrow's programme of presentations by smallholders	Projector Sound system Template	Tech support

DAY 3: 27 OCTOBER 2023 (FRIDAY)

Time	Programme	Items needed	Personnel needed
8:30 AM – 10:30 AM	**Smallholder Presentations** – smallholders present about their farm situation, ideas/plans for agroforestry, available markets. Encouraged to bring drawing/sketches of their land, photos and videos Feedback will be given by Dr. Eric & other participants	Flip chart / Whiteboard + Marker pens for drawing / writing Projector Sound system	Tech support Facilitators to record information
10:30 – 11 AM	Break		Refreshments support
11 – 12:30 PM	**Smallholder Presentations (continued)**	Flipchart stand / Whiteboard + Marker Pens Projector Sound system	Tech support Facilitators to record information
12:30 PM – 1:30 PM	Lunch		
1:30 – 3 PM	**Discussion about smallholder presentations / Presentations from agency officers (if relevant, e.g. about tree planting policies)**	Projector Sound system	Tech support Facilitators Relevant agency officers
3 – 3:30 PM	Break + Exit Survey	Exit survey form Pens	Refreshments support Facilitators for exit survey form
3:30 PM – 4:30 PM	Spoken feedback from participants about workshop Conclusion & Thanks!	Flipchart Sound system	Tech support Facilitators to record information

2 The Workshop

2.1 Composition of Participants

The list of participants can be found in Annex 1.

The characteristics of the 50 planters are as follows:

- Average age of participants: 53 years (ranging from 37 to 75).
- Ethnicity: A wide variety of ethnic groups represented from all regions of Côte d'Ivoire: Abidji, Agni, Baoulé, Bété, Brong, Sénoufo, etc., from 33 different communes.
- Participation in a cooperative: 30 out of 50.
- Family size: 2-30, with an average of 7.9 people.
- Average net income from rubber: 30,000 FCFA – 2,500,000 FCFA, with an average of 751,139 FCFA (approximately 1140 euros/year).

The 50 producers are primarily medium to large planters with an average of 38 hectares, of which 28 hectares are in production (see attached table based on 32 respondents), implying that most use hired labor for tapping. The FTA survey of 2019 showed that the average for small producers was 5 hectares of rubber trees per family.

Rubber Surface Area of Producers:

	Total Area (ha)	In production (ha)	Immature (ha)
Average	38.61	27.90	10.544
Min	1.5	0.5	0
Max	1100	850	250

- **Age of plantations**: ranges from 1 to 35 years. A significant number of producers had immature plantations, an opportunity for developing intercropping.
- **Planting density**: the majority with 6x3m (n=42) but also 4x4, 4.5x4.5, 4.75x4.75, 4x7.5, 5x3, 7x2.8, 7x3.
- **Clones**: predominantly GT1 with few leaf diseases and shading between 80 and 90%. The second most used clone is IRCA 41. 7 producers do not know their clone.

Clone	Producers
GT1	51
IRCA18	3
IRCA41	18
IRCA217	3
IRCA230	3
PB217	5
PB235	3
PB260	6
RRIC100	2

- **Weed maintenance is primarily manual, with 12 out of 50 using herbicides** (Glyphosate). Only 3 utilize Pueraria as a cover crop.
- **The tapping frequency is either** D3 or D4.
- **For labor,** 11 producers have 1 family worker (MOF = Main d'Oeuvre Familiale = family worker), and 30 have between 2 to 11 MOF. Almost all have hired workers (1-15), indicating that hired labor (MOS = Main d'Oeuvre Salariée, external daily paid labor) is becoming scarce.
- **The terrain of plantations**: 42 on flat land, 20 on slopes, and 10 in low-lying areas prone to flooding.
- **Soil types** are mainly clay (36) and/or sandy (35), with 7 being stony.
- **The reasons for interest in** agroforestry include economic reasons: improving income (gross margin per hectare) (7), preserving the ecosystem (6), avoiding deforestation, and returning to a wooded situation.

Expectations of the program:
The main themes are: acquisition of knowledge on agroforestry, agroforestry agricultural practices adapted to the local context, improvement of income through diversification, sharing local and external knowledge, etc.

Local experience on agroforestry:
Participants were asked about their level of prior knowledge of agroforestry (scale of 1-4):

Self-assessment of prior knowledge/experience	No. of respondents
1– No knowledge	11
- Some knowledge, but no experience - Unsure of how to 2practice	20
- Some knowledge, some experience - Sufficient 3knowledge to practice agroforestry, or just started practicing agroforestry	5
4- Experienced, ready to teach others	3
*Various combinations of ratings (*e.g. 2,3,4 or 2,4 or 3,4)	11
No response	17

11 individuals reported having partial knowledge and experience with agroforestry. Most have engaged in intercropping during the immature phase (banana, vegetables, yams...). Some have attempted to establish high-value timber trees, such as Hevea + Fraké, Bété wood, acacia, teak, and cedar.

Participant Engagement

Compared to the Indonesian workshop where producers had experience with Rubber Agroforestry Systems (RAS), Ivorian farmers had a situation similar to Cambodian smallholders with little to no experience with RAS, but they showed a clear interest in the subject. Most farmers have no experience with permanent RAS, but some have limited experience with intercropping during the immature phase. Many took notes during the discussions.

Extension agents and the APROMAC team contributed to fostering discussions among the farmers. The general discussion was open and highly effective. Each participant signed a consent form (see Annex 2).

2.2 Results of discussions with producers

After two presentations on agroforestry practices during immature and mature periods, and a presentation on a prospective economic modeling trial with a rubber-based agroforestry system conducted for the FTA project in 2021, two exchange sessions were held to discuss possibilities in the Ivorian context.

2.2.1 Day 1: Definition of agroforestry systems. Agroforestry practices during the immature phase.

Five groups presented the results of their one-and-a-half-hour discussions.

Group 1: 13 people

1 to 3 years: 93% (12) engaged in intercropping: Plantain banana, yam, staple crops, taro.

Reasons for adoption include: generating additional income, employing local labor , and ensuring food production.

Selected plants: Plantain banana for up to 5 years.

The absence of intercropping is linked to a lack of local labor and available time.

Group 2:

Intercropping for 100% of group members.

The duration of intercropping ranged from 6 months to 3 years with the following plants: okra, eggplant, chili, peanut, cassava, beans; banana.

Reasons for adoption include: generating additional income, employing local labor (LL), ensuring weed control for optimal growth of rubber plants, and ensuring food production.

Problems include: presence of pests (requiring phytosanitary treatments for associated crops), harvest theft, and issues with availability of local labor (mainly hired workers for the planters in our sample).

Group 3: 13 people

Intercropping for 83% of group members.

The main crops are cassava and plantain banana.

Some unsuccessful attempts were made with cocoa.

Reasons for adoption include: same as for groups 1 and 2.

A particularity: cocoa and staple crops are planted in clearings or in areas where rubber trees have died.

Problems: In the case of cassava: if a portion is not harvested, it becomes a focus for diseases.

Group 4: 12 people

Intercropping for 60% of group members.

Associated crops include: plantain banana, cassava, yam, coffee. Choice based on consumption preferences: yam in the North, cassava in the South, bananas everywhere.

Constraints: Maintenance issues such as damage to rubber tree stems during maintenance, uprooting of rubber tree stems along with cassava plants, excessive banana growth.

Intercropping was not encouraged by supervisors between 1980 and 2000.

Group 5: 12 People

100% engaged in intercropping.

Associated crops include: yam, cassava, taro, various staple crops, and banana.

Reasons for adoption include: One of the main reasons is to ensure food self-sufficiency: for the family and for hired labor, and to reduce maintenance costs.

Table of Intercropped Plants during the Immature Period

1	Yam Livestock Miscellaneous food crops Taro	Banana Plantain	
2	Okra Eggplant Pepper Peanut Cassava Bean	Banana Plantain	
3	Cassava	Banana Plantain	Cocoa in the clearings
4	Cassava Yam	Banana Plantain	Coffee
5	Yam, Cassava, Taro, Miscellaneous food crops	Banana Plantain	

2.2.2 Day 2: Agroforestry Practices in Mature Period

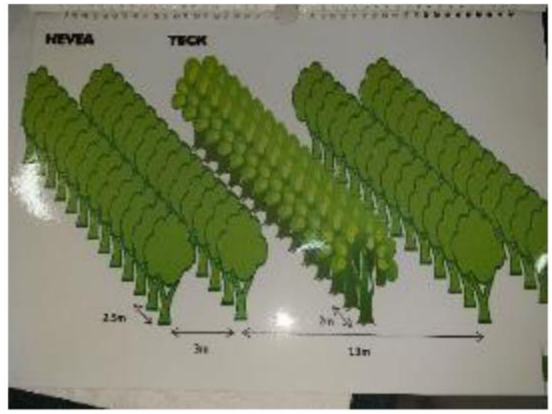
None of the producers have experience with Agroforestry Systems (RAS) during the mature period. It is interesting to note the following points:

- Extension services stemming from large plantations have always favored monoculture and technical training. The result is quite remarkable, as the average production stands at 1700 kg/ha/year (according to FTA surveys in 2019), and the overall technical level of producers is high.
- Rubber producers are often also cocoa producers, and some have certain experience with agroforestry practices with cocoa, but these experiences are not applicable to rubber trees.
- The conditions for developing "traditional" agroforestry practices (as seen in Thailand or Indonesia) have historically not been met, hence the significant prevalence of specific monoculture with significant technical results.
- There are potentially markets for fruits and timber, but they are still limited, which has not facilitated the emergence of endogenous agroforestry systems.
- The majority of rubber plantations are in good health in terms of plant health, with a relative absence of leaf diseases (compared to situations in Indonesia or Sri Lanka, for example). Shading during the mature period is significant, ranging from 80 to 90% with clones such as GT1 and PB 260. Such shading levels prohibit any associated plants with rubber trees in normal planting densities and virtually limit production to zero.
- Therefore, it is crucial to present the benefits of double-density planting systems and wide inter-rows to allow for optimal combinations of crop associations, which represents a small local revolution as these systems are entirely unknown, despite being tested since the early 1990s in research stations in Côte d'Ivoire.

Hence, there are no historical, traditional, or socio-technical conditions conducive to the development of agroforestry practices during the mature period. However, intercropping practices during the immature period are known and quite commonly used.

A roundtable discussion was conducted to try to identify the few existing experiences of RAS.

SOGB has conducted interesting and conclusive trials with teak associated with rubber trees, which has been the subject of a publication by APROMAC on the matter.



A private company has planted 100 hectares of Agroforestry Systems (RAS) near the Anguedédou forest.

Concerning the cola tree: The cola tree has been preserved and sourced from the original forest within the RAS, but research at Bimbresso has shown that the cola tree is a focal point for Fomes once dead. Therefore, it is important to destroy it as soon as signs of the disease appear or once it is dead to limit its spread. Fomes is a significant issue in Côte d'Ivoire.

Regarding avocados: Avocado has a significant potential market in Côte d'Ivoire. While it has been planted, excessive shading has greatly limited its production.

Trees more or less suited to shading have been identified by producers, such as the akpi or djansang. Djansang is a nut from a fruit tree in the tropical forest, taxon *Ricinodendron heudoletii* or *Ricinodendron africanum* (Bail.).

Ricinodendron is a genus of plants in the Euphorbiaceae family, described in 1864 by Müll. Arg. Currently, it comprises only one species, native to tropical Africa, with its geographical distribution ranging from Senegal and Liberia to Sudan, Tanzania, south to Mozambique, and Angola. *Ricinodendron heudelotii*, also known as Njansang, Musodo, Erimado, Corkwood, Akpi, and Essessang, is a fast-growing tree from West and Central Africa, whose nuts (akpi) are used as flavoring and thickening agents.

The bark of Djansang is traditionally used to treat gonorrhea, cough, leprosy, hernia, dysentery, elephantiasis, and syphilis. The extract from this bark is used to treat yellow fever, anemia, toothaches, and malaria.

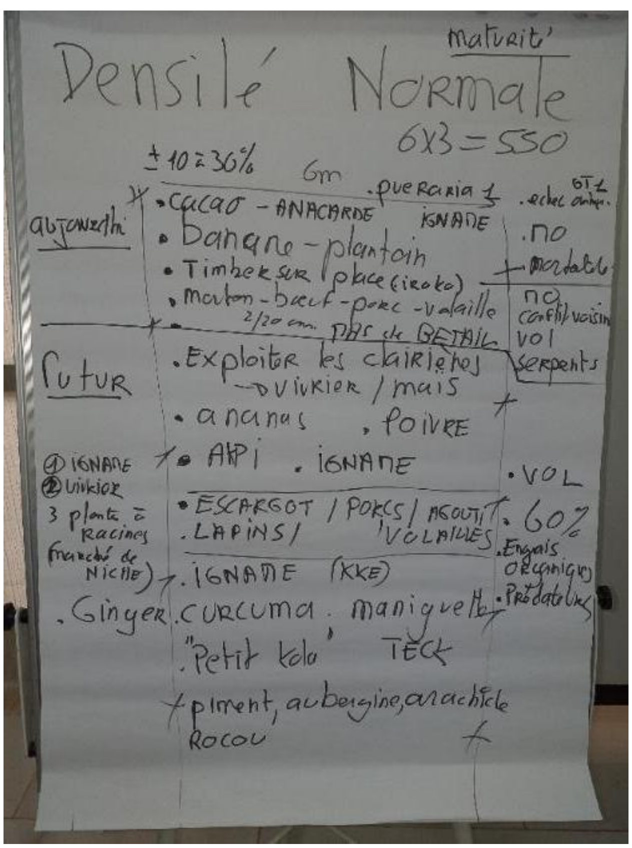
The roots are also used for treating constipation in Nigeria and Côte d'Ivoire, and, when mixed with the bark, for dysentery. The bark itself is used for elephantiasis (Sierra Leone), pain relief, preventing miscarriages (Liberia), as well as for gonorrhea, painful menstruation, and as an antidote for toxins (Gabon).

It is a natural "antibiotic" locally used for certain conditions such as diabetes, hypertension, and the seeds are also used to enhance the flavor of local dishes. There is demand for it, and the current price ranges from 4 to 5000 FCFA per kilogram.

2 Results of Group Discussions

We have compiled the results of the discussions on the two possible cropping systems: normal planting density and double spacing.

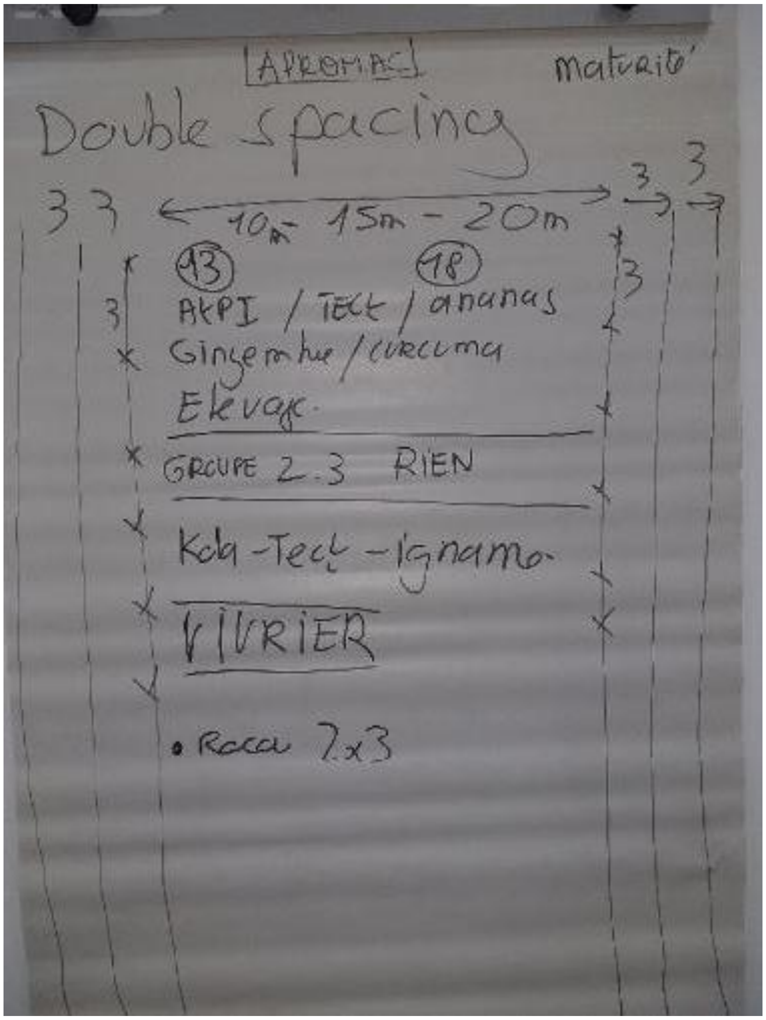
2.21 Pratiques agroforestières en densité de plantation normale



Potential crop associations primarily depend on the shading rate, which is generally very high in Côte d'Ivoire, often exceeding 80%.

There is limited potential for such associations in Côte d'Ivoire unless developing shade-tolerant species for which there is currently no market demand in the country.

2.2.2 Agroforestry Practices in Double Spacing Planting Density



The species proposed in double spacing planting density mainly include: pineapple, ginger, turmeric, livestock, food crops (yams), akpi, annatto, etc., which are linked to local markets, as well as timber species with significant local demand and a 30-year cycle adapted to the rubber tree cycle, such as teak. Additionally, the cola tree is proposed as a fruit-bearing tree in this system.

2.2.3 Day 3: Overall Discussion with Producers

Immature Period

Many producers have already successfully experimented with various crops during this stage. Therefore, it is a well-known area and easily adaptable based on local markets and opportunities.

Mature Period

The presentation of the prospective simulation works for rubber trees with fruit trees (presented in Annex 5) has sparked varied reactions among producers: interest or lack thereof in fruit production or timber, with a clear preference for certain crops. It suggests the development of small-scale productions such as akpi, turmeric, small-scale poultry farming (chickens), beekeeping; yams seem to be an excellent candidate as an associated crop due to high local demand and the advantages of this crop, which can be stored for up to 8 months and provides flexibility in marketing.

Timber production can be based on the following species: teak, iroko, fraké, framiré, mahogany, for which there is confirmed local and international demand.

SOGB has already conducted rubber tree + teak trials, which seem particularly profitable, yielding 100 m3 of wood at 15 years at 60,000 FCFA per m3.

Another GIZ project has tried a technique based partly on a different density at 3 w 3 x 8 meters with teak and banana intercropping, as well as cocoa (an idea considered uninteresting as cocoa will not produce under these conditions).

It would be interesting to compile all these past experiences and synthesize them with the producers. A search for innovation could thus be conducted within the framework of a Master's student internship.

Given the current good health of rubber tree foliage in Côte d'Ivoire, the potential future of agroforestry systems with rubber trees relies on the adoption of double spacing systems with at least 400 rubber trees/ha to avoid yield decreases exceeding 10%. While these systems are known to researchers, they are not familiar to current development estates (e.g., SAPH, etc.). Development could only occur with targeted and precise information (derived from discussions with producers considering local markets) on these systems to be provided to producers for future production. This would require significant efforts from current extension structures and producer representatives (APROMAC).

On aging or normally planted old plantations, only shade-tolerant plants have a chance of production, including turmeric, cardamom, ginger, and tomatocochus.

SAPH emphasizes the potential competition between rubber trees and associated crops. However, numerous trials conducted worldwide and farmer plots developed in Thailand, Indonesia, Sri Lanka, and India show that if suitable associations are adapted, competition is not a problem except in marginal areas with high water competition or those susceptible to becoming so in the global context of climate change.

Conclusion

A series of on-farm trials using a participatory approach would be necessary to identify the most suitable agroforestry systems within a network of reference farms. Additionally, demonstration plots of wide-spacing systems could be established within the same network and monitored. These plots could then serve as examples for interested farmers during future plantations.

The network of reference farms could be developed among members of the APROMAC network.

An in-depth economic analysis over several years (e.g., 10 years) would be needed to assess the results in terms of gross margin per hectare and labor productivity compared to monoculture. It would also be essential to identify lucrative markets, both local and international, for the produce.

Annexs

Annex 1: List of Participants

No	Institution/Role
1	COOPHESA
2	FPHCI
3	FPHCI
4	FPHCI
5	FPHCI
6	FPHCI
7	FPHCI
8	FPHCI
9	FPHCI
10	FPHCI
11	FPHCI
12	FPHCI
13	FPHCI/Area President or Sector Chairman
14	FPHCI/Area President or Sector Chairman
15	FPHCI/Area President or Sector Chairman
16	FPHCI/Area President or Sector Chairman
17	FPHCI/Area President or Sector Chairman
18	FPHCI/Area President or Sector Chairman
19	FPHCI/Delegate
20	FPHCI/Delegate
21	FPHCI/Delegate
22	FPHCI/Delegate
23	FPHCI/Delegate
24	FPHCI/Delegate
25	FPHCI/Delegate
26	FPHCI/Delegate
27	FPHCI/Delegate
28	FPHCI/Delegate
29	FPHCI/Delegate
30	FPHCI/Delegate
31	FPHCI/Delegate
32	FPHCI/Delegate
33	FPHCI/Delegate
34	FPHCI/Delegate
35	FPHCI/Delegate
36	FPHCI/GPSNR Member
37	FPHCI/GPSNR Member
38	FPHCI/GPSNR Member
39	FPHCI/GPSNR Member
40	FPHCI/Manager

41	FPHCI/Manager
42	FPHCI/Manager
43	FPHCI/Manager
44	FPHCI/Manager
45	FPHCI/Manager
46	FPHCI/Manager
47	FPHCI/Manager
48	FPHCI/Manager/GPSNR Member
49	FPHCI/Manager/GPSNR Member
50	FPHCI/Manager/GPSNR Member
51	CCP/Head of Department: Quality Hygiene Security Environment
52	CHC/CSPV
53	EXAT/Sector Head
54	FIRCA/CP Hevea
55	SAPH/CDAT
56	SAPH/Tapping Department
57	SOGB/Plantation Director
58	TRCI/Plantation Director
59	APROMAC /Director of Technical Operations
60	APROMAC/Executive Secretary
61	APROMAC/RCG
62	Translator

Annex 2

Participant Information Sheet (You may keep this sheet for your reference)

Project title: Rubber Agroforestry Workshop in Côte d'Ivoire
Researchers involved: Dr. Eric Penot (consultant, CIRAD), Maria Wang Mei Hua (consultant, independent)
Local project partners: APROMAC, SAPH/SIPH
Organizer: GPSNR
Funder: Bridgestone, APROMAC

Introduction and purpose:

Workshop Objectives: (1) To share the latest technical information on rubber agroforestry with participants; (2) To create a space for participants to share their own experiences; (3) To understand participants' perceptions on rubber agroforestry; (4) To identify constraints and opportunities, including special concerns for female, youth and minority participants.

Research Objectives: (1) To understand participants' perceptions and experiences of rubber agroforestry and of the workshop; (2) To collect baseline data on participants' existing knowledge and practices of rubber cultivation and agroforestry.

Rationale: (1) To monitor and evaluate effectiveness of this workshop; (2) To improve the quality of future trainings; (3) To improve agroforestry knowledge and dissemination.

Research Methods: semi-structured survey, participation observation, note-taking, and informal conversations by researchers during the workshop; analysing written material (document analysis).

Output: After the workshop, we will write a report which will be sent to GPSNR. The anonymised outputs of this project may contribute to broader research projects on agroforestry.

Participation:

Your part in this investigation is to participate in a rubber agroforestry workshop, which includes a written survey, group discussions, presentations, and providing comments via written or verbal methods. The written survey will ask you about your rubber plantation, your current practices, and your existing knowledge and practice of agroforestry.

Your participation is voluntary and you can choose to withdraw at any time without consequences. Your participation in the workshop is financially supported by GPSNR through a grant provided by Bridgestone and APROMAC. The workshop will take place over 3 days. With your approval we may contact you again to conduct a follow up survey or interview.

Use of information:

The information collected from this study will be recorded via audio recorder / on paper / on a computer. Paper records will be transformed into digital records to be stored electronically. The information collected will be used to better understand participants' perceptions and experience with rubber agroforestry, and for monitoring and evaluation by GPSNR and project partners to assess effectiveness of the training and improve future trainings.

A report of the workshop will be written by the consultants for GPSNR. The report will be shared internally within GPSNR, CIRAD, the funders, and local project partners. GPSNR may choose to make the report or parts of the report available to members of the public who request it.

Anonymised data may be shared with external research partners for the purpose of scientific studies.

Your personal data (e.g. phone number) will not be shared outside the two researchers involved, GPSNR, the funders, and the local project partners.

Contacts:

If you have any further questions or concerns about this study, please use the contact information below. Thank you for reading this information – please ask any questions if you are unsure about what is written here / you have heard here.

Dr. Maria Wang Mei Hua
WhatsApp: +60142734182
Email: wang.mh.maria@gmail.com

Dr. Eric Penot
Email: eric.penot@cirad.fr

CONSENT FORM

- I confirm that I have read or have been told and understood the information sheet and the researcher has answered any queries to my satisfaction.
- I consent to being a participant in the Rubber Agroforestry Workshop.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences. If I exercise my right to withdraw and I do not want my data to be used, any data which have been collected from me will be destroyed.
- I understand that I can withdraw from the study any personal data (i.e. data which identify me personally) at any time.
- I understand that anonymized data (i.e. data which do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that the information I provide will be anonymized before any dissemination. This also covers direct quotes. The information will not be traceable to me.
- I consent to my answers being recorded on paper and/or in electronic format.

PRINT NAME:

____

Participant signature:

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Date:

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Annex 3

Introduction to Rubber Agroforestry[1]

(translated from French ver. 1.0.1 : Oct 2023)

Agroforestry with rubber is a sustainable and innovative farming system that combines the cultivation of Hevea brasiliensis with other complementary crops, fruit trees or valuable timber species, shrubs, or livestock on the same plot of land. This integrated approach offers numerous benefits, including income diversification, improved soil fertility, increased biodiversity, enhanced economic resilience through diversification, and potentially reduced environmental impacts compared to conventional monoculture rubber plantations.

The idea is to maintain rubber production at productivity levels close to those of monoculture while adding additional production from complementary fruit or timber trees and/or crops. Agroforestry models can be based on the classic rubber planting density (with 500-550 trees per hectare) or with a modified planting design that allows for wider spacing between rubber tree rows (double spacing and wide intercropping systems).

Why Agroforestry with Rubber?

Traditionally, rubber cultivation has often been associated with monoculture plantations, where vast areas of land were dedicated solely to single-species cultivation. Although this approach can generate substantial latex production, it presents significant drawbacks, such as vulnerability to pests and diseases, soil degradation, and limited income diversification for farmers. The low rubber prices since 2012 and their high volatility over the past 40 years have made diversification of income necessary.

Agroforestry with rubber encourages the cultivation of various crops, livestock, and/or trees alongside rubber trees to maximize land use, optimize family or external labor and diversify income. Agroforestry can offer an astonishing variety of products, ranging from commercial food crops like coffee, cocoa, and tea, to herbs and spices, vegetables, flowers, nuts, fruits, resin, timber, and honey. This diversity enhances the economic and ecological resilience of the system. Agroforestry encourages farmers to be creative and adaptable, and it can be practiced on rubber plots of any size!

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1 This guide was prepared for GPSNR by consultants Dr. Maria Wang (wang.mh.maria@gmail.com) and Dr. Eric Penot (eric.penot@cirad.fr). It is intended to serve as a general reference. The authors, their institutions, GPSNR, and their funders are not responsible for any results or losses arising from the advice presented in this document and during the training.

The transition to agroforestry with rubber requires careful planning and adaptation to local environmental conditions and markets. In rubber agroforestry, different species must interact in a mutually beneficial or non-detrimental way, especially concerning maintaining rubber productivity. For example, nitrogen-fixing shrubs can improve soil fertility for rubber trees. It is also crucial to avoid penalizing rubber production under severe climatic constraints in areas with long dry seasons like Cambodia, Myanmar or eastern Sri Lanka. This is an exciting approach with many potential benefits.

Types of Agroforestry with Rubber

There are various types of rubber agroforestry. To simplify, rubber agroforestry can be categorized as follows:

1. Intercropping during the immature period (years 1-3, 4-6)
2. Intercropping during the mature period (from the 6th year)
3. Rubber with livestock
4. "Jungle rubber" or rubber agroforestry based on seedlings (non-intervention approach)*

Most farmers will be interested in options 1-3, which require more intensive management but also offer more predictable yields.

Box 1: What is Jungle Rubber?

Traditional jungle rubber is a unique system where non-clonal rubber plants were planted in forests using slash-and-burn or intercropping ("sisipan") in Indonesia. This practice is rare today, and most jungle rubber areas have been replaced by clonal rubber and oil palm plantations.

Jungle rubber can also result from abandoning the management of monoculture plantations, leading to the natural regeneration of shrubs and trees similar to a secondary forest. Useful plants can be harvested alongside latex (as seen in Nigeria).

Among the types of agroforestry with rubber, **jungle rubber is the best system for indigenous biodiversity** and requires little management and inputs. However, it may not be economically attractive to farmers due to its very low economic productivity.

Advantages of Agroforestry with Rubber

1. **Economic Resilience**
Diversifying crops and income sources can protect farmers from price fluctuations and market uncertainties associated with rubber production alone. Besides rubber, farmers can harvest valuable timber and non-timber products such as resins, nuts, fruits, spices, and medicinal plants, which improve overall income. Cover crops can reduce the need for weeding and provide food for livestock.

2. **Improved Soil Fertility**
The inclusion of nitrogen-fixing trees and organic matter from companion crops enhances soil fertility and structure, as well as soil microbial diversity, reducing the need for synthetic fertilizers and preventing soil erosion.

3. **Enhanced Biodiversity and Conservation**
Agroforestry with rubber can promote biodiversity by providing additional habitats for various plant and animal species. A structurally and functionally diverse environment tends to support a greater diversity of pollinators, beneficial insects, and wildlife.

Additionally, cultivating native species such as valuable timber trees or rare and endangered indigenous trees can contribute to the preservation of native tree biodiversity and even restore unique ecosystem services to support other native flora and fauna species.

4. **Climate Change**
Although it has not been definitively proven that agroforestry systems with rubber offer a significant advantage over monocultures in terms of climate resilience, it is likely that agroforestry systems with rubber can offer some benefits. Agroforestry with rubber maintains moist soils and provides shade for other crops, potentially creating a cooler environment within the plot. Adding more woody species like trees to rubber plantations can increase the total amount of carbon stored in the system and offer opportunities for carbon credits. However, the additional amount of carbon sequestered depends on various factors such as the use of latex and wood, the plantation cycle duration, and how the trees are harvested.

5. **Land Conservation (Indirect)**
By maximizing the use of existing agricultural land, agroforestry with rubber can reduce deforestation and the expansion of cultivated land into ecologically sensitive areas. This indirectly contributes to preserving existing natural habitats and biodiversity.

Key Principles of Rubber Agroforestry

1. **Adaptation to rubber trees and local environmental conditions**: Choose species adapted to your specific climate and soil conditions. To avoid loss of latex yield, avoid planting intercrops that will shade mature rubber trees. The species that compete with rubber trees for water or increase the risk of disease/damage to rubber trees should be avoided.

2. **Adaptation to local markets : Assess market demand for intercrops in your area to ensure profitability and sale of associated products. Also consider market access and additional costs**

and labor required. Successful implementation often involves a phased approach, with gradual integration of intercropping to minimize risks.

3. **Implement Good Agricultural Practices (GAP) for Rubber Trees**: Do not neglect Good Agricultural Practices (GAP) for your rubber trees, particularly tapping techniques! GPSNR has developed a detailed GAP manual that provides lots of useful, expert-verified information. 2 The GAP manual covers useful practical knowledge such as tapping techniques, disease management, soil preparation and proper use of stimulation.
   - 3.1 **Improving the quality and techniques** of tapping should be the top priority, whether you implement agroforestry in your rubber plantation or not.
   - 3.2 **Low-frequency tapping** (for example, tapping every three or four days with proper stimulation) can free up labor for agroforestry activities without reducing yield.
   - **3.3** Plan for **appropriate spacing** and layout to ensure that intercrops do not compete with rubber trees for resources such as light, water, and nutrients. To avoid loss of latex yield, **refrain from planting intercrops that will shade mature rubber trees, and avoid planting intercrops within one meter of rubber trees.**
   - 3.4 Choose a **rubber clone** that suits your needs (for example, less bushy clones like PB 260 to reduce shading; disease-resistant clones). In Thailand, agroforestry has been successfully implemented with clones RRIM 600 and RRIT 251. Other countries like Indonesia are testing superior rubber clones such as IRR 112 and IRR 118 in agroforestry systems with promising results. Similarly, the Rubber Research Institute of Cambodia is developing high-yielding clones suitable for Cambodian soils. Therefore, when possible, please **consult your country's rubber research institute** for the latest information on the best clones for your region and to obtain these clones.
   - 3.5 **Crop rotation** should be considered to avoid soil depletion and disease accumulation, especially during the immature period. This is particularly important for root crops.

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2. GPSNR Good Agricultural Practices (GAP) Manual (free download): https://sustainablenaturalrubber.org/reports/

3. For more information on rubber agroforestry in Thailand, please contact: rafs.thailand@gmail.com | RAFS Foundation

4. https://www.e3sconferences.org/articles/e3sconf/pdf/2021/81/e3sconf_rubis2021_03006.pdf

Implementation of Agroforestry with Rubber Trees

Before implementing an agroforestry system with rubber trees, please consider the following questions. Proper planning and management are essential for a successful rubber agroforestry enterprise.

First, think about your **agroforestry goals**:

- **Improving soil health and reducing weeds?** You may want to plant cover crops, grasses, and shrubs that provide ground cover.

- **Food security?** You may want to plant your favorite staple foods, fruits, or vegetables.

- **Short-term additional income?** You may want to choose crops with low start-up costs that you can harvest and sell within 1 to 2 years.

- **Medium-term investment?** You may want to choose crops with assured demand and high profitability in the market. You can consider integrating small animals.

- **Long-term investment or retirement income?** You may consider integrating timber.

- **For medium and long-term investments**, you should ask yourself: Are you willing to invest in labor, time and skills to grow and harvest intercrop crops?

Some **physical criteria** to consider when choosing plants include:

- Which plants are suitable for planting in mature rubber plantations with normal spacing and more shade?
- Which plants need more light to produce economic yields (and are therefore more suitable for wider spacing design)?
- Which plants are suitable for the water, soil, and climate conditions of your farm?
- How long does it take for plants to produce a harvest (short-term, medium-term, long-term)?

Once you have considered your goals, capabilities, and the physical suitability of your farm, it's time to consider the following steps. Feel free to **consult local agricultural experts and extension services** to identify the most suitable intercrop species for your specific goals and location.

Plantation Design

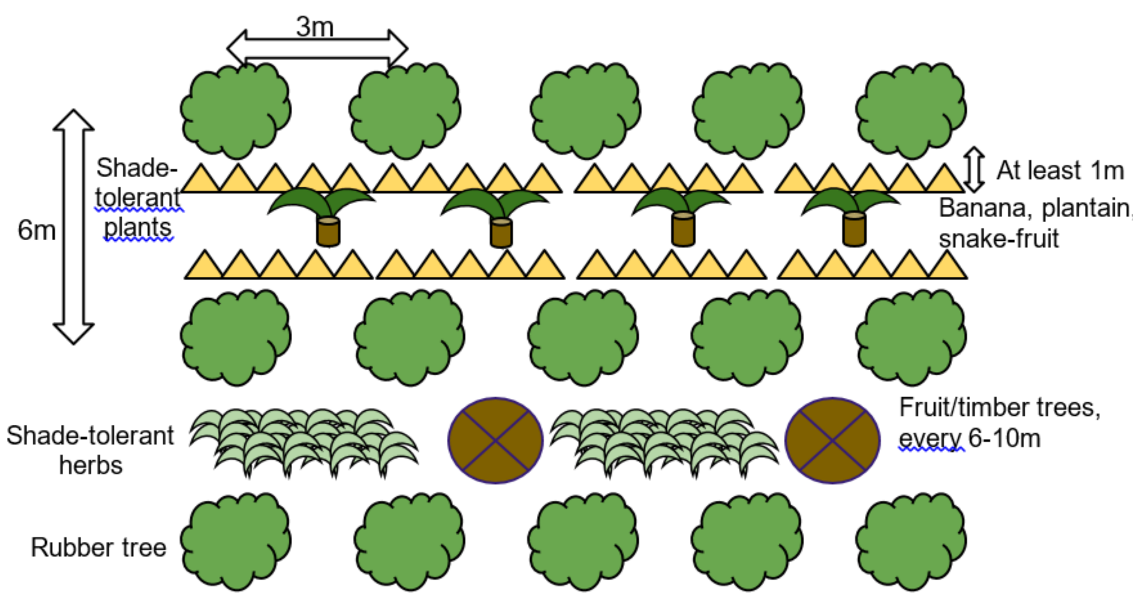
1. **Normal Spacing (6x3m or 7x3m, ~ 555 trees or ~ 476 trees per hectare)**

Most farmers already have rubber trees growing with normal spacing. You can still plant intercrop crops or trees with adequate spacing between them. There will then be more shade for intercrop crops, making these crops less productive. However, the overall gross margin per hectare will probably be higher than a pure rubber monoculture.

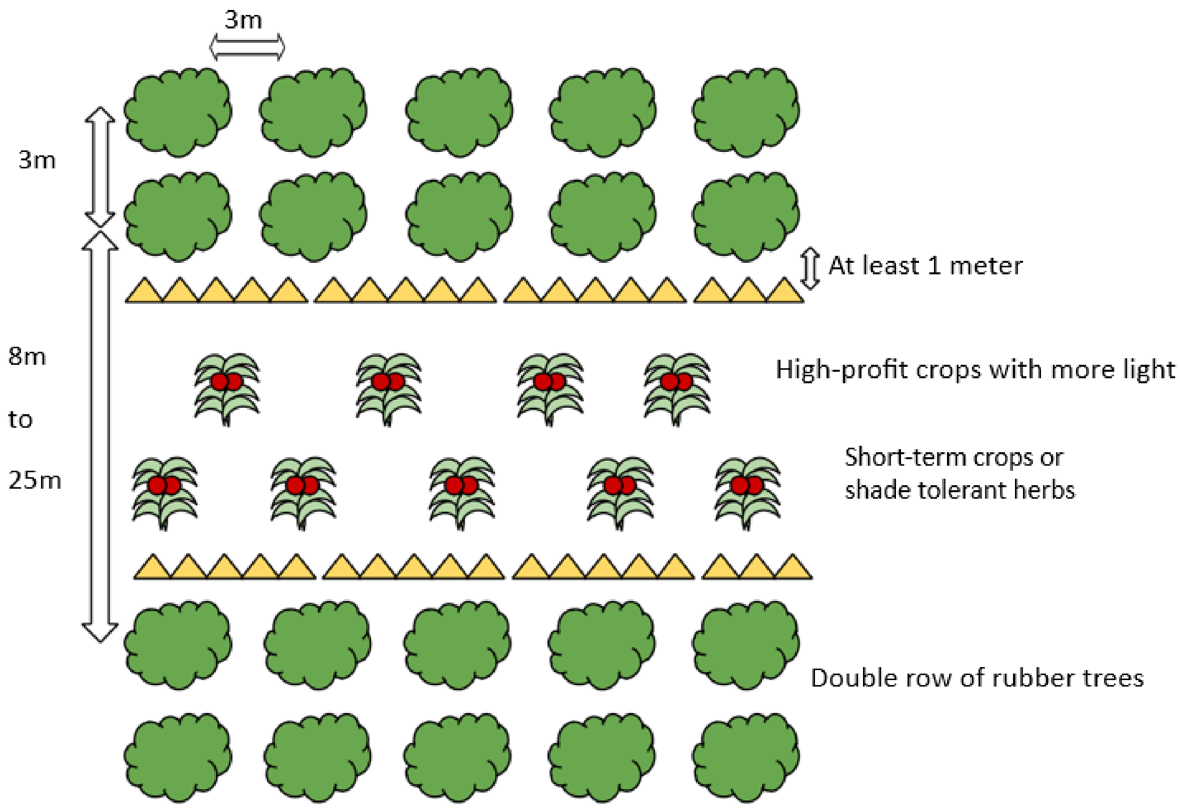
2. **Wider Spacing: Double Row Rubber Trees (3x3m) with wider inter-row spacing (8-25m)**

Density: 238-450 trees per hectare: the optimal density is around 400 trees/ha
This is a newer innovation. Wider spacing between rows allows more light to reach intercrop crops, but it also means fewer rubber trees. For example, an inter-row spacing of over 13 meters corresponds to less than 400 rubber trees per hectare.
The profit from intercrop crops should be sufficiently high to offset potential losses due to the reduced number of rubber trees (less than 10% of production). However, production loss is limited if the number of trees per hectare does not fall below 400. Intercrop crops should fetch a good price and have a stable market to ensure a profitable margin per hectare. Thus, an economic evaluation is recommended before implementing this type of plantation design. If planned correctly, available land can be optimized for multiple crops, thus generating higher profits.

Example of a possible agroforestry design for rubber tree cultivation with a normal planting density:



Example of a double row of rubber trees with a wider inter-row spacing:



The choice of intercropping crops

Many types of crops have been grown with rubber trees worldwide. When choosing plants, consider your agroforestry goals, markets, local climate, and soil conditions.

Here are some examples of commonly intercropped crops, but there are many other examples not mentioned here that can be grown with rubber. Be creative! For example, consider plants that can meet a niche market in your country for export (e.g., marigolds in Thailand for religious purposes, traditional medicinal herbs for export, agarwood for the perfume industry).

Cover crops - Legumes, grasses (for cattle feed)

Many species of cover crops have been tested in rubber plantations. They should be planted at the same time as rubber. Generally, they will almost disappear after the immaturity period of rubber. Some common species of cover crops are:
Pueraria phaseolides, Mucuna spp, Stylosanthes guianensis, Flemingia macrophylla.

Annual/half-annual sun-loving crops:

Annual/half-annual sun-loving crops are suitable for short-term intercropping during the immaturity period when rubber trees are still young. They should be planted during years 1-3.

Vegetables: Since vegetables are highly perishable, choose vegetables that you can sell in local markets. Some vegetables tolerate shade and can be planted with mature rubber. In Thailand, pakliang is a popular vegetable commonly planted in rubber plantations.

Cereals/legumes: Rice, upland rice, corn, cowpea, peanut, soybean, etc. can all be planted during the immaturity period.

Tubers: Generally, it is less recommended to grow tubers intercropped with rubber due to possible interference with roots. For example, cassava is a popular tuber in many tropical countries. However, intercropping cassava for more than 12 months can promote root rot disease. Cassava belongs to the same family as rubber and competes for minerals and nutrients with rubber. Cassava can also deplete soil fertility and therefore requires fertilization.
Sugarcane: A classic in eastern Sri Lanka with success.

Bamboo: Only in old irrigated lands like old rice fields in Thailand, as bamboo competes with rubber for water. However, you can consider planting bamboo around boundaries (it's not really agroforestry but a hedge system).

Annual/half-annual shade-tolerant crops (can be planted in years 4-6, or earlier):

Common examples: banana, plantain, pineapple (shade for pineapple should not exceed 60-70%).

Medicinal herbs, spices, mushrooms

Can be planted from the first year or after the third year if they tolerate shade.

Common examples: Cardamom, ginger, turmeric, chili, mushrooms

Shade should not exceed 60% for the following species: pepper, vanilla

Fruit and nut trees

The number of timber trees you can intercrop in your rubber plantation will depend on local climatic and physical conditions (e.g., water availability, soil fertility). Under good climatic and soil conditions, you can plant up to 250 fruit trees per hectare. All types of fruit trees can be planted as long as you have a market to sell them. Shading should not exceed 75% for each tree. Some studies note that yields of intercropped cash crops and fruit trees may decrease after several years due to shading by the rubber canopy, becoming unprofitable.

There are many examples of tropical fruit trees and nut trees that have been planted with rubber: durian, rambutan, duku, longan, jackfruit, mango, salak (a type of palm, also known as salacca or salak), cashew, macadamia nuts, stinky beans (a family of legumes consumed as vegetables, e.g., petai/sator, jengkol); as well as lemon trees, oranges, and other citrus fruits.

Recommended only with wide spacing between trees: Coffee and cocoa - note that yields start to decrease significantly with more than 30% shade.

Timber trees

Timber trees can be integrated into rubber agroforestry systems to provide long-term income (e.g., retirement income) upon harvest, offering both ecological and economic benefits. Consult local authorities before cultivating timber trees, as you may need specific permits to grow and harvest timber on your land.

Timber trees can be planted from the first year, with a few banana trees to provide shade if necessary (e.g., for Dipterocarps). Some common examples of timber trees that can be intercropped with rubber: teak (Tectona grandis), mahogany (Swietenia spp.), rosewood (Dalbergia spp.), local woods (iroko, sapelli, etc.).

Some fast-growing trees can be planted but will need to be cut earlier as they may compete with rubber. For example: Gmelina arborea, Paraserianthes falcataria, Albizia lebbeck, Acacia mangium.

Rubber with Livestock

Stingless bees have been successfully integrated into rubber plantations in Thailand and Indonesia. Other small livestock that could be suitable for rubber agroforestry include ants (a delicacy in Thailand), bees, and edible snails. In Nigeria, rubber farmers have integrated bees, snails, and rabbits as part of a diversification strategy. Fish and poultry farming are also possible in rubber plantations (although this is not considered agroforestry unless there is an ecological interaction with the rubber trees).

Keeping large animals such as cows, sheep, and goats in rubber plantations is possible on an extensive basis, but they can damage the trees. Therefore, this is not widely recommended. Instead, you can grow grass in your rubber plantation and harvest it to feed your large animals.

Final Remarks

These documents aim to assist you in your journey into rubber agroforestry. They offer general advice but do not guarantee success. It is essential to consult with local experts for professional advice, as agriculture is a combination of art and science, with variable circumstances. Always use your best judgment when implementing new farming practices.

We wish you a fruitful experience in rubber agroforestry!

Annex 4

Survey for the GPSNR Rubber Agroforestry Workshop – *translated from French*

Adapted from a basic questionnaire of the Rubber Agroforestry Sustainability Foundation (RAFS) (2023).
For more information: rafs.thailand@gmail.com | https://www.rafsfoundation.org/index.php

Registration Information

Name :____________________________

Age : _____________________________

Gender : __________________________

Ethnicity (Indigenous/Minority) : ___________________________

Primary Occupation : ___________________________

Address (City/ District/ Province) : ________________________________

Telephone : ________________________________

Email : ______________________________

GPSNR Member ? [Yes/ No]

Member of an Agricultural Cooperative ? [Cooperative Name : ___________________________]

Institutional Affiliation [If any] : ___________________________

Ecomomy

Household size : __________________________

Total net household income (per month or per year, please specify):

From the rubber tree ? _________________

From other agricultural activities? ______________________

From off-farm/non-agricultural activities? __________________________

Information about Rubber Plantation and its Management

1. Rubber Plantation Size (ha) : _____________________________
    a. Production Area (ha) : ____________________________
    b. Non-Production Area (ha) : _____________________________
2. Age of Rubber Trees : _________________________
3. Spacing between Rubber Trees (m) : _____________________________
4. Rubber Clone Used : _____________________________

5. Weed Management: How do you manage weeds?

Weed Management	Frequency per year, cost, labor required, etc.
No weeding	
Herbicides	
Manual weeding	
Cover cropping / Intercropping	
Livestock	
Other	

3. Labor needs :
   a. Frequency of tapping? : ___________________
   b. Number of family members working in the rubber plantation (including yourself)? : ________________________________
   c. Number of external paid workers working in the rubber plantation? : ________________________________
   d. Number of sharecroppers? : _______________________
   e. Any other details you'd like to share about the labor needs? : ____
4. Describe the terrain of your rubber plantation (flat, lowland, steep slopes, etc.)

____

5. Describe the soil characteristics of your rubber plantation (clayey, sandy, acidic, etc.) ____

Knowledge and Practices in Agroforestry

1. What does "agroforestry" mean to you?

____

2. Why are you interested in agroforestry?

____

3. What are your expectations from this program?

____

4. Evaluate your knowledge and experience in agroforestry (with any crop), on a scale of 1 to 4:

(Tick one box)

1 - No knowledge

2 - Some knowledge, but no experience - Uncertain about how to practice

3 - Some knowledge, some experience - Sufficient knowledge to practice agroforestry, or just started practicing agroforestry

4 - Experienced, ready to teach others

5. For those who answered 3-4 (have experience in agroforestry):

a) How many years of experience in agroforestry do you have, and with what type of agroforestry (which crop)?

____

b) Who taught you agroforestry? Tick one box

[Self-taught / Friends / Parents / Government / Other: __________________________________]

Feedback on the GPSNR Agroforestry Workshop (Anonymous):

1. On a scale of 1 to 5, please rate your satisfaction with the workshop?
(1 = Very dissatisfied; 5 = Very satisfied)

Very dissatisfied 1 2 3 4 5 Very satisfied

2. Would you recommend this workshop to others?

3. What did you find most useful in this workshop?

4. What suggestions do you have to improve future workshops?

Annex 5

Agroeconomic characterization of rubber activity systems in Côte d'Ivoire

Noe Biatry, Eric Penot, 2020.

The study presented was conducted as part of the "Forest Trees and Agroforestry" project, which seeks to analyze how family rubber plantations can adapt and remain viable in the face of natural rubber price volatility. It took place in Côte d'Ivoire with 152 rubber growers surveyed in December 2019. The analysis is mainly based on quantifying economic performance at two levels: the cropping system and the activity system. Characterization of agricultural farm structures has highlighted several differentiation factors (share of rubber in income and natural rubber selling price), used to create a typology of farms. Eight model farms representative of the sample were created to compare their operations and performances. Through economic modeling using the Olympe software, different scenarios were tested to assess the impacts of price variations, changes in labor types, and the implementation of rubber-based agroforestry systems. The results show that farms still have many productivity reservoirs, and their agronomic and economic performances are heterogeneous. Payment at the official price, the use of family labor, and the adoption of agroforestry systems could be strategies used by growers to meet their needs.

FTA funded field surveys of rubber growers conducted by CIRAD in December 2019 in Côte d'Ivoire, to characterize agricultural farm structures, practices, and economic situations, with the aim of comparing them with systems observed in other rubber-producing countries such as Thailand, Indonesia, and Vietnam.

Natural rubber in Côte d'Ivoire: an overview in 2019.

During the economic liberalization of the 1990s, the Ivorian state disengaged from many economic sectors, including the rubber sector, notably reducing its stake in SAPH and privatizing SOGB and the historical plantations of Anguédédou, Bettié, and Cavally (Brindoumi Atta, 2015). During the same period, the areas under village plantations steadily increased until they eventually surpassed those of industrial plantations in the 2000s (Ruf, 2012). Thus, between 1990 and 2010, Ivorian rubber production increased from less than 100,000 tons, dominated by industrial plantations, to over 200,000 tons, relatively evenly split between industrial and village production (FAO, 2020).

From 2010 onwards, this production accelerated significantly, driven by the village sector, and in 2018, more than 90% of planted areas were in village plantations, with the country's total rubber production reaching 624,000 tons (APROMAC, 2020).

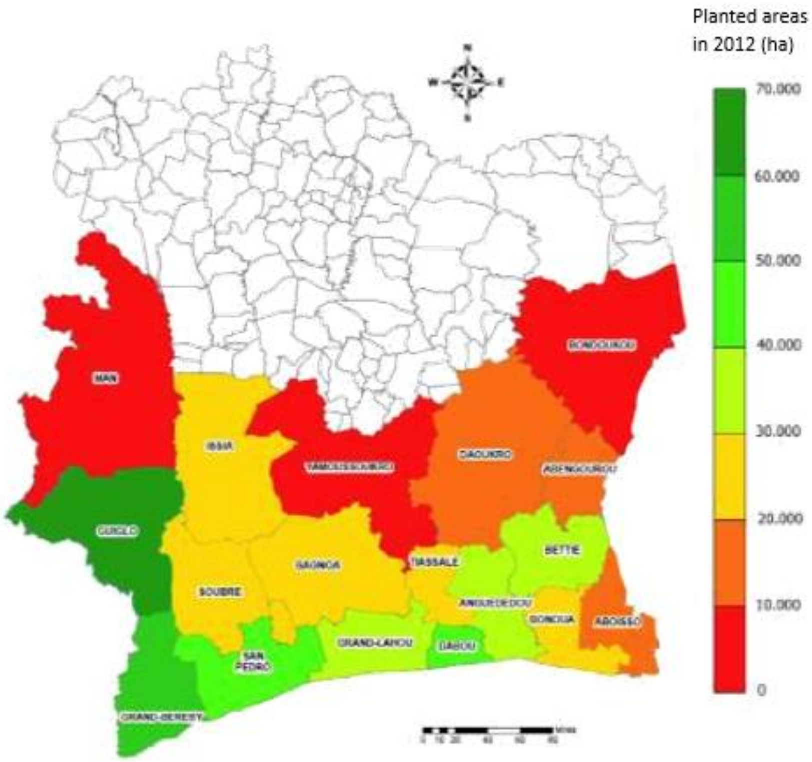


Figure 1: Distribution of rubber-planted areas by region (Benoist and Leconte, 2020)

Furthermore, new regions that were previously inaccessible to industrial plantations are gradually converting to rubber cultivation (Figure 1). Traditionally present in the southern region of Côte d'Ivoire, rubber-planted areas are increasingly expanding in the central part of the country, notably in the regions of Man or Yamoussoukro. This "rubber fever" could even continue to the northern part of the country, provided that climatic conditions remain suitable (Läderach et al., 2013).

With 780,000 tons produced in 2019, Côte d'Ivoire is the leading producer of natural rubber in Africa and the sixth globally, accounting for about 5% of global production. The market is dominated by Thailand and Indonesia, representing 37% and 25% of global production respectively, according to the International Rubber Study Group (IRSG, 2020).

Rubber plantations in Côte d'Ivoire are characterized by a predominant and rapidly expanding village sector, accounting for approximately 550,000 hectares of plantations in 2019, representing over 90% of the planted areas at present. Agro-industrial rubber plantations thus make up less than 10% of the planted areas, among which SAPH and SOGB plantations account for approximately 80%. Rubber processing in Côte d'Ivoire mainly involves its primary processing, for the production of rubber bales. In 2019, 570,000 tons of rubber were processed and exported, mainly to the European market.

In order to support the increase in planted areas and consequent rubber production, new processing units have been established in recent years, while existing units have expanded their processing capacities. However, the increase in these capacities has been slower than the growth in plantation production, which was 624,000 tons in 2018 and between 780,000 and 810,000 tons in 2019 (APROMAC, 2020; IRSG, 2020). In this situation, a growing fraction of the produced coagulum, between 25 and 30% of production in 2019, could not be processed domestically and were directly exported as cup lumps. Furthermore, finished product processing units are extreme marginal in Côte d'Ivoire, and in 2013 they processed less than 1,000 tons of rubber, representing approximately 0.3% of national production (Marty et al., 2013).

The establishment of rubber plantations in Ivorian village settings has followed a different history from the systems present in Asia, resulting in differing characteristics of rubber cultivation systems. Some commonalities are found, such as the frequent presence of food intercrops (cassava, yam, peanut, plantain, maize) during the early years (1-4 years) of rubber tree growth or the planting density, notably 6x3m, and the clones used (GT1 and IRCA 18 are predominant in Côte d'Ivoire).

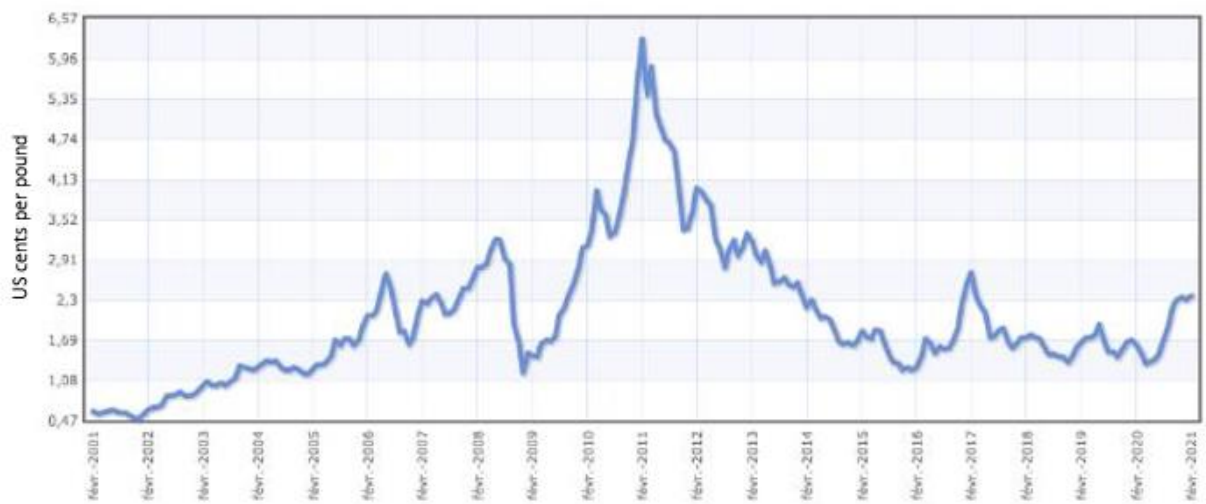
However, one can quickly notice the absence of crop associations in mature rubber plots in Côte d'Ivoire. Fruit trees or timber-producing trees, sometimes associated in Indonesia or Thailand, are not present, or very few, in Ivorian rubber systems. Thus, the typical plot is a monocultural clonal rubber plantation, with interrows maintained by mechanical or chemical weeding until the rubber canopy covers the ground. Fertilizer application may sometimes be carried out during the immature period of the tree, and fungicides are used when certain diseases attack the trees, notably white root disease (Rigidoporus lignosus or fomes), a root disease of rubber trees that is most developed in Côte d'Ivoire (Michels, 2005).

This form of family agriculture, composed of farmers generally owning 2 to 5 hectares of rubber (often coupled with cocoa to ensure regular income), is characterized by complex logics, involving personal choices related to household needs and their own strategy concerning the production system (Gasselin et al., 2015). These logics strongly influence production, and it is therefore fundamental to analyze them in order to understand the reasons that drive these "small farmers" to adopt certain cultivation modalities, but also to project themselves to determine the medium-term trajectory of their farming operation, in a particular economic and ecological context. These reasons may involve other performance indicators: yield is no longer necessarily the reference criterion for system productivity, but the valorization of labor (monetary unit/hour of work) becomes the focus.

One key explanation lies in the significant difficulty of replanting cocoa on itself in certain areas of Côte d'Ivoire, due notably to the emergence of diseases (swollen shoot virus), soil pH becoming more acidic, and the lack of water and nutrients in the soil horizons already explored by the previous cocoa (Ruf, 2008). In this situation, rubber cultivation becomes an often-ideal alternative for farmers: faced with land saturation phenomena, it is increasingly difficult to find forest plots to clear for cocoa cultivation. The rapid development of rubber cultivation systems is thus explained not only by the attractiveness of having a high monthly income, but also by an ecological need to change perennial crops.

Over the past 15 years, natural rubber prices have experienced significant fluctuations (Figure 2): after two peaks in 2006 and 2008, they collapsed in 2008-2009, reaching a minimum of 1.21 USD/kg for SMR20 (Standard Malaysian Rubber) in December 2008. They then quickly rebounded to reach a new historical peak in 2010-2011, before falling again and stabilizing at a level generally considered low by industry stakeholders, despite a slight recovery in 2017.

Figure 2: Graph of current natural rubber prices on the global market (SICOM, Singapore)



In Côte d'Ivoire, the rubber market strictly follows the global market trend, unlike cocoa, the country's predominant cash crop, whose price is set by the government for the current year. The rubber processing companies purchase the planters' harvests at the price stated each month by APROMAC (Association of Natural Rubber Professionals of Côte d'Ivoire) (Figure 5). This price in CFA francs is obtained after currency conversion, by estimating the Dry Rubber Content (DRC) in the latex, by imposing a FIRCA (Interprofessional Fund for Research and Agricultural Advisory) tax, and applying a slight quality discount of 3% on the world price.

Another major factor affecting the impact of the global market is the presence of more or less formal intermediary collectors between the planter and the processing plant, which reduces the purchase price of latex by almost half (150 CFA francs) compared to the announced price of 285 CFA francs in December 2019 by APROMAC.

The objective of comparing different agricultural operations is to understand their functioning and strategies, to enable the future operation of an innovation platform on these systems. Ultimately, the goal is to propose alternatives adapted to planters to better address current economic constraints. However, since each operation has specificities, offering "tailor-made" solutions is impossible. The analysis of agricultural operations allows them to be classified into a typology, according to key characteristics related to the level and structure of household income. A typology also has the advantage of being easily presentable to producers, as they can "recognize themselves" in a model and potentially compare themselves.

The determination of techno-economic indicators is based primarily on the terms and definitions used in management, in "The Basics of Economic Calculations for the Evaluation of SCV Systems in Madagascar" (Penot and Husson, 2010). At the level of the cropping system, the following data are of interest: yields, gross margin per unit of cultivated area, and the valuation of family labor (i.e., the gross margin produced per unit of family labor).

At the level of the activity system, the economic analysis takes into account:

- Net Agricultural Income or Result, which is the sum of the net margins of all productions

- The origin of agricultural income, i.e., the net margin of each type of agricultural production (rubber, cocoa, fruits), expressed as a ratio of the sum of net margins

- Net Total Income (NTI), which is the sum of net margins (NM) and non-agricultural income

- Cash Balance, which is the NTI minus all family consumption and expenses

Calculated from the techno-economic evaluation of activities, these indicators allow for comparison between activity systems.

Finally, a prospective analysis testing scenarios of structural and economic changes was conducted using the Olympe software. A scenario is a "hypothetical sequence of events constructed to draw our attention to causal processes and decision-making" (Gallopin, 2002). This could be, for example, a drop in prices of a specific crop, a climatic hazard impacting production, or a sudden financial need due to personal constraints.

<u>Box 1: Presentation of the Olympe Software (Penot, 2007)</u>

Olympe is a software developed by Inra/Esr, in collaboration with IAM/Montpellier and Cirad. It is a modeling and simulation tool for the functioning of agricultural operations based on systemic analysis, following the definitions of cropping systems, livestock systems, activities, and production given by Jouve et al. (1997).

It offers the possibility to carry out a functional modeling of farm systems detailed and precise enough to allow the identification of income sources and production costs, the economic analysis of profitability based on technical choices and production types, and the monthly analysis of labor needs.

It provides:
- Standard results (income statement, balance sheet, cash flow),
- Customized output statements built by the user,
- Graphs.

In addition to automated basic calculations, it is possible to create custom variables, indicators, and output tables of data, both for cropping systems, livestock systems, or activities as well as at the overall farm level.

Olympe allows the construction of scenarios based on assumptions about changes in technical routes, diversification, price volatility, or the impact of dry years or climate-related problems. It can also test the "robustness" of a technical choice or the farm against a series of hazards.

The study area is primarily the southern region of Côte d'Ivoire, encompassing the areas that have gradually converted to rubber cultivation (see Figure 3).

Figure 3: Map of surveyed villages (OpenStreetMap)

For the sake of accurately representing the reality of the rubber sector in Côte d'Ivoire, there was very little sorting done when selecting the types of farms to survey: it can be estimated that the situation is generally representative of the range of farms observed in family rubber farming in Côte d'Ivoire. Thus, one-third of the farms in the sample are still in the immature phase of rubber growth, as well as many young productive plantations, between 7 and 12 years old.

Data collection was conducted through individual interviews with farm owners, following a questionnaire developed by Éric Penot and Jérôme Sainte Beuve (CIRAD).

The construction of the typology is based on determining discriminant factors between farms. These factors are used to classify each farm into a specific class (called a "type") and then more precisely into a subclass (called a "subtype") in order to refine the differences within the same type.

After classifying the farms into each type and subtype, the objective is to merge all the farms in a class into a single representative farm for that class. All model farms were created based on the results of the surveys, while ensuring compatibility with existing preliminary surveys (Ruf, 2008; Ruf, 2013). From 99 farms, we thus move to 8 representative medium-sized farms. This step is necessary for modeling, as it simplifies the data entry process. Although the model farms may not necessarily correspond to a farm that can be found in reality, they best summarize the diversity present within each created subtype.

The modeling objective is to subject the model farms to a certain type of event: these scenarios are exploratory and by no means predictive of the future. They reflect the situation in which the farms could potentially find themselves.

The interface of the Olympe software (Figure 7) shows the succession of steps necessary for modeling farms, from left to right (Attonaty et al., 2009). After defining the units, existing costs and products, the different cropping systems are created in "Workshops". The model farms corresponding to each subtype are then established in the "Farmers" interface, with the possibility of creating variants for each of them. The "Random" function allows for variations in prices and quantities of products and costs, and it is used for simulating prospective scenarios over 10 years.

Elaboration of the scenario for the establishment of an agroforestry system based on rubber trees

Associations of crops with rubber trees are generally of two types: annual food crops can be planted between the rows of young rubber trees during the immature period for the first 3 or 4 years, or perennial crops (fruit trees, timber trees, coffee, cocoa) can be installed and continue to produce during the tapping period of the rubber tree (Snoeck et al., 2013). The choice was made to focus on the association between rubber trees and perennial crops, to show that even though the rubber tree is in the production phase, it is still possible to diversify crops within the plantation. Thus, the scenario "AFS Fruit Trees" was designed, which places fruit trees in the inter-row spaces of the rubber trees.

The fruit trees chosen to model this scenario were selected based on their presence rates in the plots of cocoa farmers during a previous study on agroforestry in Côte d'Ivoire (Sanial, 2015). Thus, the cocoa tree, orange tree, mango tree, and avocado tree were selected. Yields and costs of these crops are extracted from the "Agronomist's Handbook" (CIRAD and GRET, 2006). The production of fruit trees was reduced by 50% compared to a conventional plantation, to account for the shading effect of rubber trees on fruit trees.

A variant of the scenario was created by integrating teak trees into the plantation. This crop requires little maintenance and has the advantage of being exploitable at the same time as the rubber tree plot is cut. The data are extracted from a teak planting guide by the Ivorian National Agronomic Research Center (CNRA) (N'guessan et al., 2012).

The assumptions necessary for the implementation of this scenario in an agroforestry system (AFS) are respectively agronomic, economic, and social:

- The implantation of other trees does not impact rubber production as long as the density of other trees remains below 200 trees/ha (Penot, 2001). This neutral effect on rubber tree yield has been observed in other countries (Indonesia, Thailand) but remains to be confirmed in the case of the chosen fruit trees.
- Market structural conditions can meet the demand for fruits. In view of a doubling of the Ivorian population by 2050, and a strong trend towards urbanization, the fruit market must be viable.
- Assimilation by farmers and tappers of agroforestry crop systems techniques. Historically, companies do not recommend associating other crops with rubber trees, so stakeholders in the sector must participate in the implementation of this type of system.

The list of proposed scenarios is as follows:

AFS Fruit Trees: implementation of an association of rubber trees with fruit trees on the plantation. The yield remains the same, and the fruit trees (cocoa tree, orange tree, mango tree, avocado tree) are managed by hired labor. The number of fruit trees is 140 per hectare, with 30 cocoa trees, 40 orange trees, 30 mango trees, and 40 avocado trees.

AFS Fruit Trees Timber: implementation of an association of rubber trees with fruit trees and timber trees on the plantation. The yield remains the same, the fruit trees are managed by hired labor, and the timber trees are harvested and sold at the end of the rubber tree cultivation cycle. The number of fruit trees is halved compared to the "AFS Fruit Trees" scenario, and 70 teak trees per hectare have been added instead.

Economic Recovery: gradual increase in the price of natural rubber, from 1.4USD/kg to 3USD/kg. The demand for natural rubber is significant, especially in emerging markets where the transportation sector is booming (China, India). The industry is structured, and the gap between the official price and the "tracker" price gradually narrows.

Economic Crisis: continuation of the decline in the price of natural rubber, following price levels similar to those reached during the financial crisis of 2008 or the Covid-19 crisis. The industry remains unstructured, and the gap between the official price and the "tracker" price remains significant.

Labor Shortage: drop in the supply of qualified labor for tapping. The price paid per kilogram of cup lump gradually increases, impacting the expenses of rubber planters.

Transition to Family Labor: in response to low prices and labor shortages, tapping is done by the planter or their family, with the aim of reducing rubber cultivation expenses.

Transition to Official Price: planters whose cup lumps are paid at the "tracker price" are paid at the official price, to observe the difference that their entry into a more structured and standardized industry makes.

Only the first two scenarios concerning agroforestry systems are presented in this summary.

Some of the scenarios are dynamic with changes (prices, expenses) over the years, while others simply show structural adjustments (changes in labor type, buyer) within the operation but do not change over time. Some scenarios are not applicable to all operations: for example, a planter who sells their production at the official price cannot be modeled according to the "Transition to Official Price" scenario.

Presentation of results

Based on the typological factors identified, the farms have been classified into 4 types (named A, B, C, and D) and 8 subtypes (named A1, A2, A3, B1, B2, C1, C2, D1) (Table 1).

A: 50-100% of the income comes from rubber.	B: 1-49% of the income comes from rubber.	C: 0% rubber in the income (immature).	D: Large rubber plantation (>25 ha).
A1: 100% rubber in income	B1: Official selling price (285 FCFA)	C1: Large cocoa plantation (> 5ha)	D1: Managerial type rubber/cocoa plantation
A2: Official selling price (285 FCFA)	B2: Tracker selling price (150 FCFA)	C2: Small cocoa plantation (< 5ha)	
A3: Tracker selling price (150 FCFA)			

Table 1: Presentation of the farm typology

The 99 selected farmers for this analysis are distributed as follows:

- Type A: 50 to 100% of rubber cultivation in agricultural income - 26 farmers:
    - A1: 6 farmers
    - A2: 10 farmers
    - A3: 10 farmers
- Type B: 1 to 49% of rubber cultivation in agricultural income - 46 farmers:
    - B1: 12 farmers
    - B2: 34 farmers
- Type C: 0% of rubber cultivation in agricultural income, cocoa cultivation - 24 farmers:
    - C1: 11 farmers
    - C2: 13 farmers
- Type D: Large-scale plantation > 25ha of patronal type
    - D1: 3 farmers

Farm A1, with 100% rubber cultivation, is managed by a young farmer (34 years old) who decided to invest in rubber since the planting wave of 2004. The rubber surface is not very large (2.9 hectares) but is optimized: the yield is the best in the database (1500kg dry/ha/year) and the farmer follows the official selling price by selling directly to the processing plants. Expenses are rather modest, and the cash balance exceeds 1 million francs despite a low agricultural land area.

Farm A2 is a typical case of a farmer who has already well advanced in transitioning from cocoa to rubber. He is of average age for a farmer (50 years old) and established his plantation in 2003, during the first wave of rubber planting. His rubber yield remains good for a village plantation (ranking second among other subtypes), and he understands the selling mechanisms by selling his production at the official price. His area under cash crops is 7 hectares, representative of a typical farmer who has many dependents with relatively high expenses. His cocoa, nearing the end of its cycle (very low operational costs), allows him to diversify his income.

Farm A3 is owned by the oldest farmer in the database (58 years old). Without any fallow land available for rubber planting, he replaced old and unproductive coffee and cocoa trees with rubber. As a result, his cocoa area is smaller, but his yields are higher despite low allocated expenses. He belongs to the same rubber planting wave as type A2. His rubber yield is slightly lower, but the main difference is that he sells his rubber latex to "pisteurs" intermediaries at a much lower price. To compensate, he employs fewer wage laborers for tapping, thus reducing rubber expenses.

Farm B1 established its rubber plantation in 2009, when global prices were starting to be high. Wanting to maximize the potential of cocoa trees, the farmer only converted a small portion of his agricultural land to rubber. His 6 hectares of cocoa continue to have a decent yield for a village plantation. However, despite rubber representing only 14% of the agricultural land area, it accounts for 22% of the income because the farmer can expect to be paid at the official price due to significant cocoa revenues. His cash balance is the highest among village rubber producers.

Farm B2 also begins rubber planting when global prices rise after 2009. Its agricultural land area is smaller than B1, totaling 6 hectares. The farmer relies on his 4 hectares of cocoa to generate income but must sell his latex at the "pisteur" price of 150 FCFA. Similar to Farm A3, the farmer employs fewer wage laborers for tapping to reduce expenses.

Farm C1 belongs to the third wave of planting, particularly in response to very high prices in 2011. This new plantation, only 6 years old, is not yet productive and relies almost exclusively on strong cocoa income, thanks to significant land (9 hectares) and decent yields. It is the type of farm where the preceding fallow period is the most important, also indicating available land. Its cash balance is the highest of all types, especially considering its significant agricultural land area.

Farm C2 resembles Farm C1 but with much more limited land for rubber planting. Thus, the predominant previous crop is cocoa, and cocoa areas are three times smaller than those of type C1. Limited by land constraints and relying only on a single source of income, farmer C2 has the lowest income, which he tries to offset with low expenses as well. It is the farm with the lowest cash balance, likely awaiting the ability to tap rubber to increase income.

Note that type C represents younger farmers on average, in their forties instead of their fifties like the other types. It can be assumed that they have relatively recently gained decision-making rights over the land and are therefore organizing their transition to rubber.

Farm D1 is very specific and goes beyond the scope of village agriculture. The farmer owns 26 hectares of agricultural land and is relatively old (57 years old). He favored rubber considering it more profitable than cocoa but still maintains old cocoa trees to have additional sources of income. His rubber yield is decent, and he sells at the official price because he can economically afford to wait during the payment delay by the factory. He outsources tapping, paying his tappers more than average (around 70 FCFA/kg). He is the highest spender, the highest earner, and has the highest cash balance.

The gross margin per hectare of rubber is indicative of the economic performance of the cropping system implemented. There are significant differences in margin (Figure 15) depending on the chosen type.

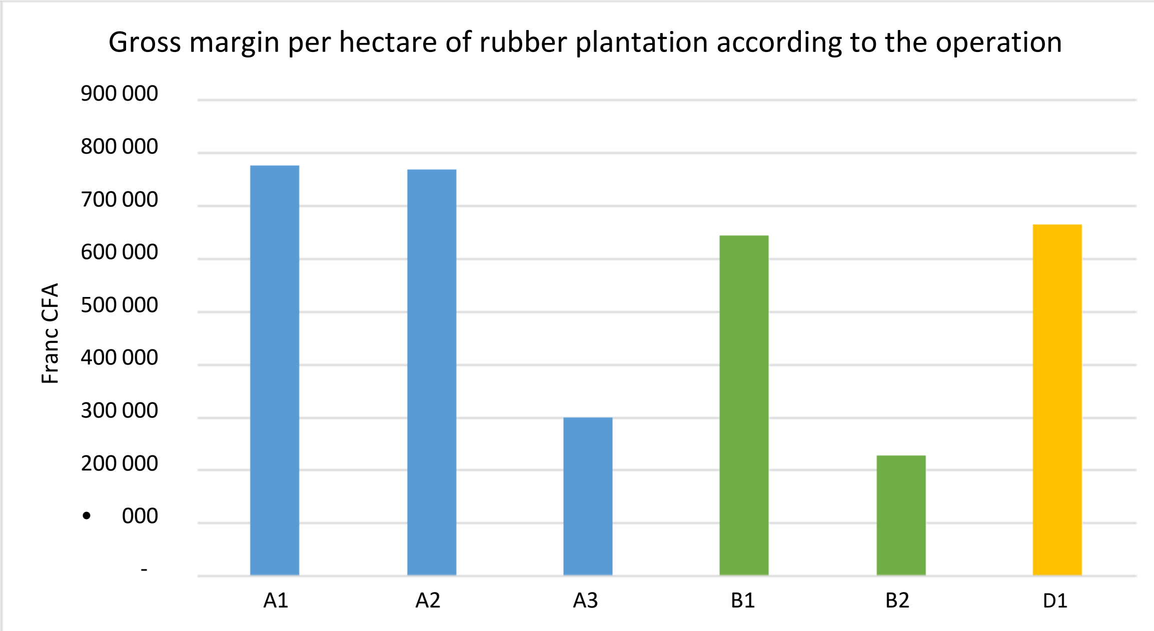


Figure 4: Comparative Gross Margins per Hectare of Rubber Plantation

Gross margin is primarily determined by two factors: selling price and yield. Expenses in rubber cultivation consist of over 90% payment of waged labor for tapping, which also depends on the yield.

Thus, one hectare of rubber trees at planter B2 generates a gross margin of 227,800 FCFA per year, while at planter A1, the gross margin is 775,840 FCFA, which is 3.4 times more. The economic performance of types A3 and B2 is mainly reduced by the low selling price; they alone represent 44 planters from the sample of 99 planters. When compared with the 'village planters' category (types A1, A2, A3, B1, B2) of 72 planters, A3 and B2 characterize 61% of the planters.

When comparing agronomic performances, it is noticeable that when agricultural income predominantly depends on rubber, the yield reported by the planter is more significant (Figure 5). The yield of planter A1 (1550 kg dry/ha/year) is 30% higher than that of planter B2 (1070 kg dry/ha/year) knowing that rubber cultivation represents 100% of A1's agricultural income, and only 24% for B2.

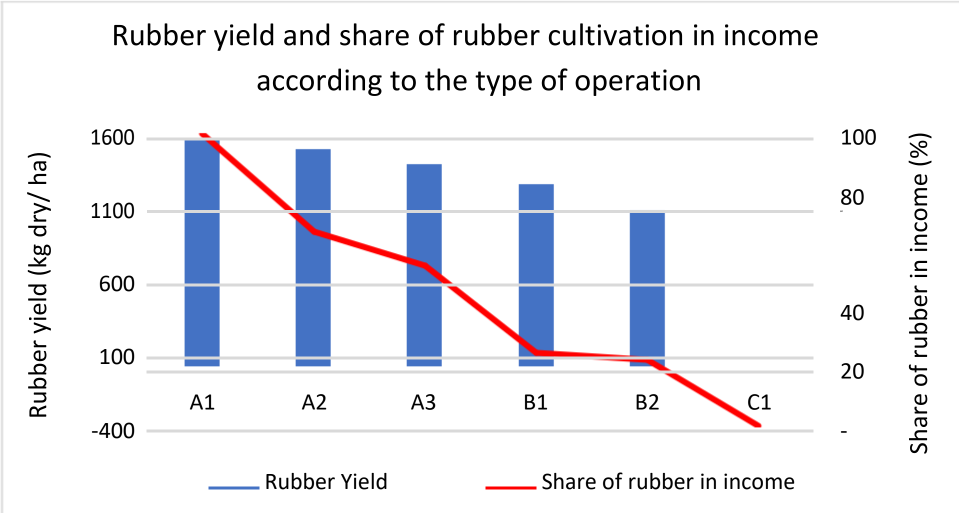


Figure 5 : Relation entre rendement et part de l'hévéaculture dans le revenu par type d'exploitation

Several reasons can explain these differences: the level of interest in rubber cultivation, the technical mastery of tapping, the planter's decision to tap the trees moderately considering the prices practiced, or the quality of the plant material and the age of the rubber trees.

This phenomenon is also notable with cocoa cultivation, where yield decreases with the share of cocoa cultivation in income. The chart and corresponding data are presented in Annex 9.

1.1.1. Labor Productivity Favorable to Rubber

By agroeconomic convention, for this comparison, it is assumed that all the work is performed by family labor. Each crop (rubber and cocoa) is assigned three hypotheses of annual labor quantity per hectare, representing high and low estimates based on the literature (Table 2).

	Rubber 105 JT/ha/an	Rubber 95 JT/ha/an	Rubber 85 JT/ha/an	Cacao 85 JT/ha/an	Cacao 75 JT/ha/an	Cacao 65 JT/ha/an
A1	7389	8167	9128	-	-	-
A2	7315	8085	9036	3574	4050	4673
A3	2847	3146	3516	4490	5089	5872
B1	6122	6767	7563	4394	4980	5746
B2	2170	2398	2680	4748	5381	6209
C1	-	-	-	4902	5556	6411
C2	-	-	-	4302	4876	5626

Table 2: Valuation of the workday by type of operation according to several hypotheses

It is observed that when the planter sells his cup bottoms at the official price (A1, A2, B1), the valuation of the workday (JT) is higher for rubber than for cocoa. However, planters A3 and B2 achieve better valuation of the workday in their cocoa farms. When comparing the lowest workday valuation for a "official price" planter (B1 6122 FCFA/JT for 105 days worked) with the highest for a high-performing cocoa planter (B2 6209 FCFA/JT for 65 days worked), there is almost equality, having taken the most unfavorable hypothesis for rubber (105JT), and the most favorable for cocoa (65JT).

Labor productivity is an important indicator for the planter and the decisions he makes. This difference might explain why half of the surveyed planters are more interested in rubber than in cocoa. Those who sell at the official price directly observe the economic benefits of rubber compared to cocoa and assert that rubber is a crop of the future. Those selling at the tracker price prefer to refocus on cocoa, considering rubber less interesting.

Prospective Modeling and Scenarios

The proposed economic modeling concerns types A and B as they belong to the category of family planters whose income partly comes from rubber cultivation.

Rubber - Fruit Tree Agroforestry Systems

It should be noted that the scenario for the implementation of an agroforestry system (SAF) is based on numerous assumptions, presented in section 2.4.4.

The yields and selling prices are as follows:

- Orange trees: 40 trees/ha with a production of 1250 kg sold at 115 FCFA/kg
- Cocoa trees: 30 trees/ha with a production of 300 kg sold at 350 FCFA/kg
- Mango trees: 30 trees/ha with a production of 900 kg sold at 110 FCFA/kg
- Avocado trees: 40 trees/ha with a production of 1000 kg sold at 95 FCFA/kg

The yields have been reduced by 50% compared to what is reported in the literature to simulate the effect of light competition induced by the rubber trees. The prices have been chosen arbitrarily but are minimized to avoid yielding extravagant economic performances. The costs are relatively significant, involving inputs used and especially hired labor that takes care of the maintenance and harvesting of the fruit trees.

The net agricultural income is positively impacted by the implementation and exploitation of fruit trees within the rubber plot (Figure 6). The fruits provide a new source of diversification for the planters and help achieve the threshold of 2,500,000 FCFA in net agricultural income.

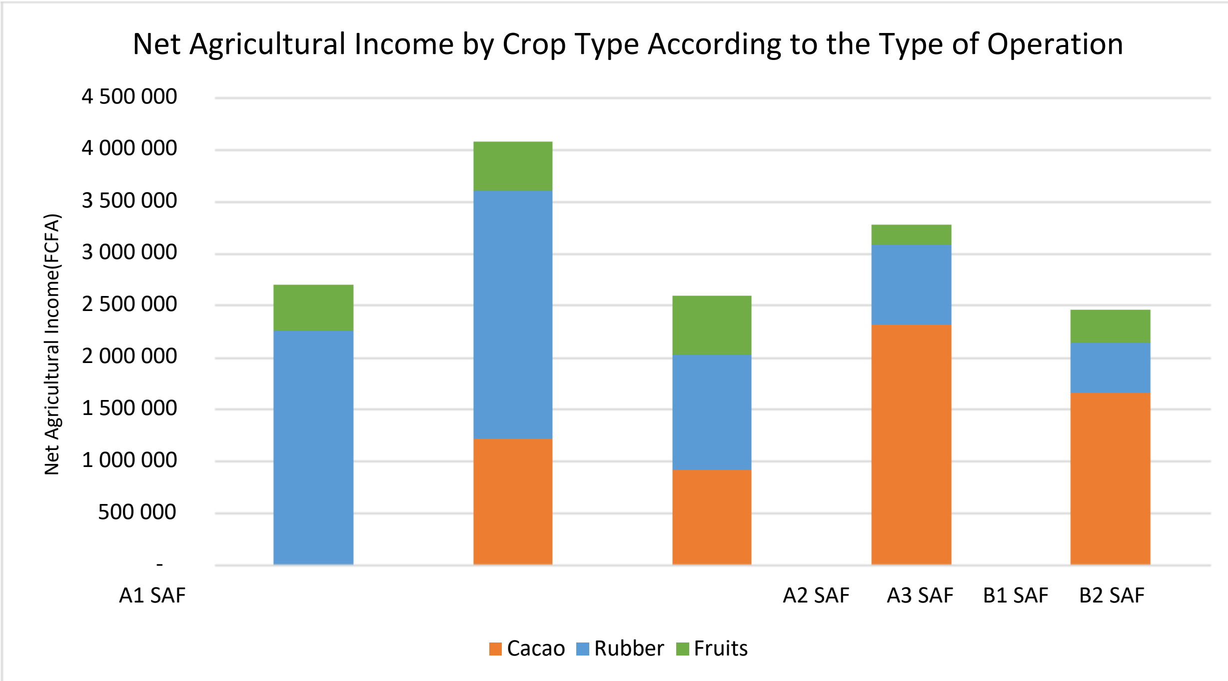


Figure 6: Histogram of Net Agricultural Income by Crop Type According to the Type of Operation

The sale of fruits (oranges, mangoes, avocados, cola nuts) brings in 154,000 FCFA per hectare, thus increasing the gross margin of farms. The proportion of each fruit in the revenue source is quite similar: 33% for orange trees, 24% for cola nuts, 22% for mangoes, and 21% for avocados. The sub-types that sell cup bottoms at the "tracker" price (A3 and B2) have a relatively reduced gross margin per hectare, and adding fruit trees increases this margin by 52% and 68% (Table 3).

Nevertheless, it is certainly the types based on rubber, and which are already present in official sales circuits (A1 and A2), where the establishment of this agroforestry system would be most likely.

Type and subtype	Gross Margin per hectare of rubber in monoculture	Gross Margin per hectare of rubber under Agroforestry Systems with Fruit Trees	Differential (%)	Current agricultural revenue	Agricultural revenue from Agroforestry Systems with Fruit Trees	Differential (%)
A1	775 840	929 840	19,8	2 249 936	2 696 536	19,8
A2	768 085	922 085	20,0	3 596 064	4 073 464	13,3
A3	298 900	452 900	51,5	2 021 931	2 591 731	28,2
B1	642 830	796 830	24,0	3 086 910	3 271 710	6,0
B2	227 800	381 800	67,6	2 133 009	2 456 409	15,2

Table 3: Comparison of Economic Performance between Current Systems and the Agroforestry Scenario

Rubber-based agroforestry offers a "neutral" crop association for the rubber tree: unlike cocoa-based agroforestry systems, where shading can sometimes reduce the cocoa tree's production potential, here the rubber tree is not penalized by the introduction of fruit trees, as it continues to dominate the canopy. It is the fruit trees that are impacted in their production levels, and they may have a shorter lifespan than in traditional plantations.

<u>Case Study: The Typical Farm A2</u>

The choice was made to focus on the study of planter A2: it is the most "balanced" operation, in the sense that the areas of rubber and cocoa are almost identical. It especially represents the possible future of a large number of farms: agricultural income primarily depends on rubber, with cup bottoms sold at the official price, and cocoa cultivation allows for maintaining a source of diversification in the face of price volatility. It is the type on which the most scenarios are plausibly testable, with different variants (Figure 7).

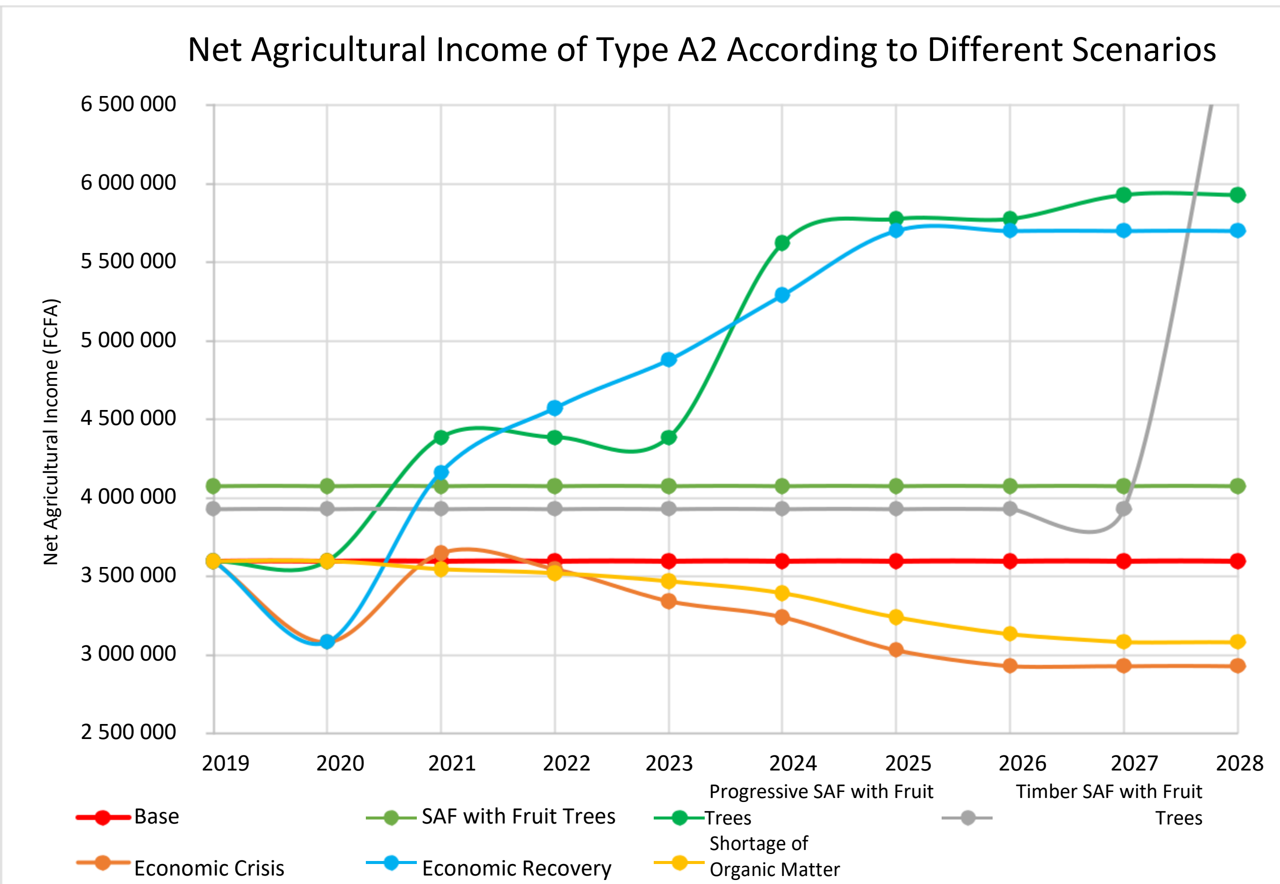


Figure 7: Graph of the net agricultural income of farm A2 according to different scenarios

We notice that starting from the baseline situation in December 2019 (red curve), the magnitude of income increase in the optimistic scenarios (economic recovery, agroforestry systems) is more significant than the decrease in income in the pessimistic scenarios (economic crisis, shortage of salaried labor). In other words, when agricultural income drops, the magnitude is around -20%, whereas when it increases, the magnitude is around +60%. This is explained by the low price of natural rubber considered at the time of the surveys: it seems more plausible in the future to double the official price of the cup lump (570 FCFA/kg), rather than to halve it (142 FCFA/kg).

On the other hand, if we focus on the year 2028, where the scenarios 'economic crisis' and 'shortage of salaried labor' have the most significant impacts on the farm, the agricultural income loss is 600,000 FCFA during the modeled economic crisis and 500,000 FCFA during the labor shortage. This order of magnitude of income difference is similar in the 'SAF Fruitiers' scenario, where the generated gain is approximately 500,000 FCFA. We can thus deduce that if the scenarios of price drop and increased costs occur on a type A2 farm where the agroforestry system has been implemented, the agricultural income would then be comparable to the base A2 farm. The adoption of an agroforestry system providing an additional source of income is therefore an effective strategy to cope with periods of economic difficulty. It allows the planter to raise their income level and be less sensitive to the fluctuation of cup lump prices. However, it requires a need for salaried labor to take care of both the rubber tapping and the maintenance of fruit trees.

The first variant of the 'Progressive SAF Fruitiers' scenario shows a dynamic situation, different from the simple structural adjustment shown by the 'SAF Fruitiers' agroforestry scenario. While maintaining exactly the same rubber-fruit tree system implemented in the baseline scenario, the area under rubber cultivation increases over time, occupying the 7 hectares of the farm by 2027. The transition to rubber is thus complete in 10 years, and the association with fruit trees has been established and mastered. Agricultural income increases significantly each time a part of the farmer's utilized agricultural area (UAA) is converted to rubber. In 2021, the model shows that 1.5 hectares of SAF Fruitiers rubber has entered production in place of an aging cocoa plantation, then 2.5 hectares in 2024. For each hectare of cocoa converted to SAF rubber-fruit trees, agricultural income increases by 17% when the rubber becomes suitable for tapping.

We observe that agricultural income generally follows the magnitude of the 'economic recovery' scenario, even though the price is constant at 285 FCFA/kg in the 'Progressive SAF Fruitiers' scenario. In 2028, the implementation of SAF over the entire area of the farm generates higher income than an increase in the price per kilo to 490 FCFA while maintaining the same area distribution (about 3.5 hectares of rubber and cocoa). Agricultural income is around 6 million FCFA, or more than 850,000 FCFA of gross margin per hectare. The gross margin per hectare of the baseline A2 farm (without any scenario), for all crops combined, was 500,000 FCFA.

The second variant of the 'SAF Fruitiers - timber' scenario refers to the cultivation system described in 2.4.4 (Modeling and Simulated Scenarios) with the addition of teak trees to the rubber-fruit tree agroforestry system. It is based on the intention to produce a more valuable species than rubber, while being harvestable at the end of the rubber cycle (around 35 years). The year of tree felling (modeled here in 2028) is logically characterized by a high income, with more than 7 million FCFA of agricultural income. The production of 35-year-old teak was estimated at 30m^3/ha, with a price of 40,000 FCFA/m^3. Meanwhile, the fruit trees also provided a source of diversified agricultural income during the rubber production period, despite their number being halved due to the introduction of teak.

It is necessary to take into account that yield data in cubic meters per tree (within a rubber plantation), and especially price data on the local market, are very variable and difficult to obtain reliably. For example, trees are often sold standing, and a logging company takes care of the felling work. Furthermore, the sale of rubberwood is not accounted for in this variant to avoid biasing the comparison with other scenarios. The usefulness of this scenario is to show that various associations are possible, depending on the farmer's preferences: in the case where interest in fruit trees is low, alternatives are possible by planting timber-producing trees to be harvested at the same time as the end of the rubber cycle.

The case study of farm A2 provides information on the potential future income level of a rubber farmer. Assuming the transition from cocoa to rubber continues, type B farms will soon resemble type A farms in terms of rubber plantation area. Similarly, if the sector becomes more structured, types A3 and B2 will become similar to type A2 by selling their production at the official price. The economic performance of farm A2 is the most interesting from the perspective of a balanced rubber-cocoa farm. The net agricultural income is over 3,500,000 FCFA, equivalent to 300,000 FCFA per month (approximately 550 USD), which is more than double the average Ivorian salary.

With this level of income, significant transformations occur within the household: the farmer can afford more expensive means of transportation, the family dwelling can be expanded, and the farmer's descendants can pursue higher education by moving towards urban centers. Therefore, rubber farming serves as a lever for changing social class, provided it is properly managed.

Method Critique

The farms were modeled without accounting for yield variations over time for both rubber and cocoa. There was no correlation between the age of the rubber trees and the yield of cup lumps, and the age of the cocoa trees was unknown. Therefore, the methodology was adapted to this constraint by fixing the yields as constant over time. Part of the rubber plots had reached the "production plateau" at around 12 years, where the yield is constant, but this was not the case for other younger farms resulting from the 2007-2010 planting wave. On Olympe, perennial crops were thus classified as annual crops due to the impossibility of establishing different production phases according to the years.

The development of prospective scenarios is based on an intuitive method, arbitrarily fixing certain structural conditions. Particularly at the price level, it is very difficult to reliably predict the evolution of natural rubber and cocoa prices. As commodities traded on the global market, they are subject to speculation, and the magnitude of a price rise or fall can sometimes be poorly estimated. This methodological critique is inherent to foresight science, which relies on "weak signals," i.e., elements of environmental perception (opportunities or threats) that are subject to anticipatory listening (called monitoring).

Comparison of Results with Literature

The latest scientific studies concerning the internal economy of village rubber farmers are those written by François Ruf, particularly in 2008 and 2012.

The 2008 study, "Support for Village Rubber Farming," proposes a per-hectare analysis of a clonal rubber monoculture system under different price assumptions (430 and 330 FCFA/kg). In this example, the yield of 1800 kg dry/ha/year is higher than that of the various types presented in the typology. Nevertheless, the same order of magnitude is found for one hectare of rubber, with a gross margin of 770,000 FCFA per hectare under a price assumption of 330 FCFA/kg. The gross margin per hectare rises to 1,070,000 FCFA in the case of a price of 430 FCFA/kg, which is generally similar to the performances presented in the prospective "economic recovery" scenario. In this article, it is noted that operational costs are higher than in the work presented: in addition to the cost of salaried labor (tappers), there are costs for fungicide paste and weeding.

The 2012 study, "The Adoption of Rubber, Prices, Mimicry, Ecological and Social Change," shows the interest of farmers in rubber by comparing the economic performances of cocoa farming and rubber farming. Using the prices of three different years (2008, 2009, and 2010), the economic advantage of rubber farming over cocoa farming is confirmed. Even in 2010, when the price of cocoa is higher (1150 FCFA/kg) than that presented in this study (750 FCFA/kg), a low price of natural rubber (below 260 FCFA/kg) is required for cocoa farming to economically compete with rubber farming.

The price in 2009 is roughly identical to that of December 2019, the date of the surveys related to this work, namely 272 FCFA/kg. The study calculates a valuation of a workday at 10,570 FCFA for a rubber farming system, which is even higher than the best assumption presented in section 3.3.3.

Conclusion

This study sought to determine the new significance of rubber farming in the incomes of Ivorian family farmers traditionally focused on cocoa farming. Rubber's role is becoming increasingly central in the agricultural landscape of perennial crops in Côte d'Ivoire, and this trend continues to persist. The reasons for this adoption are multifaceted, encompassing not only economic but also ecological factors. The analysis of the results showed the significant productivity reservoirs of small rubber plantations in Côte d'Ivoire. From selling at the official price to implementing agroforestry systems, rubber farming systems have considerable leeway to continue innovating and improving productivity. Different levels of priority have been established: it seems more relevant to address the current problems faced by farmers before establishing or promoting new rubber farming systems.

The possibilities for implementing rubber-based agroforestry systems are numerous, and those presented in this work are just a simple part. The farmers themselves are often the source of innovation processes, and a participatory approach would be necessary to understand their choices and potential reluctances to adopt new farming systems. Historically, there has not been a local tradition of rubber agroforestry systems; nevertheless, the fact that some cocoa producers already use agroforestry practices in cocoa farming shows that they are willing to adopt such practices if the agro-economic and ecological benefits are present.

The diversification of income for better resilience to the volatility of natural rubber prices is the main asset of the "SAF Fruitiers" scenario described, and this type of system could meet the international promotion goals for sustainable rubber farming. Therefore, it is necessary to continue research on these systems, studying their agronomic, economic performances and their social impacts on family farming.

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Annex 6
Summary in English

__Summary of Participants and Survey Responses from Cote D'Ivoire Agroforestry Workshop__

Participants: 50 smallholders/planters and 8 extension officers from various institutions (Please refer to Annex 1 for detailed Participant List).

Gender representation: 7 women, 51 men

Total survey respondents: 57

Age: 37-75, average age is 53.2.

Ethnicity/Indigenous/minority representation:

A range of ethnicities were reported: Abidji, Agni, Baoulé, Bété, Brong, Sénoufo, Indigenous (Unspecified), and Minority (Unspecified). While all specified ethnic groups are indigenous to Cote d'Ivoire as a whole, within Cote d'Ivoire certain ethnic groups traditionally inhabit specific regions of Cote d'Ivoire (e.g. North, East, Southwest). When they move to a different part of the country, they may not be considered "indigenous" in that locality. However, they may then be considered a "minority" in the new locality.

Geographical representation: Good, participants from 33 different townships from all across the country.

Participation in Cooperatives: Most participants were involved in some kind of cooperative, only 20 answered no.

Household size: 2-30. The average (excluding the one household with 30 members) is 7.9

Income from rubber (net): 30,000F – 2,500,000F (Average 751,139 F)

The range reflects the diversity of respondents (acreage of rubber), as some are estates.

Income from other sources:

32 respondents reported having income from other agricultural sources (cocoa, livestock, oil palm are the most common sources mentioned) and 20 from non-agricultural sources (varied).

Rubber hectarage:

	All rubber area (ha)	In production (ha)	Not in production (ha)
Average	38.61	27.90	10.544
Sum	2123.82	1534.4	579.92
Min	1.5	0.5	0
Max	1100	850	250

Rubber age: Ranged from 0-35. A significant number of respondents (n=43) have rubber not in production, which presents an opportunity for implementing intercropping during immature period.

Spacing: Majority of respondents plant rubber trees with spacing of 6x3m (n=42). Other spacings: 4x4, 4.5x4.5, 4.75x4.75, 4x7.5, 5x3, 7x2.8, 7x3.

Clones: Majority of respondents use GT1. The second most common clone was IRCA41. 7 respondents used multiple clones but did not specify which ones.

Clone	Number of respondents reported using
GT1	51
IRCA18	3
IRCA41	18
IRCA217	3
IRCA230	3
PB217	5
PB235	3
PB260	6
RRIC100	2

Weeding:

Most participants use manual weeding method. Frequency of weeding varies (from once to four times a year, most commonly is twice a year). The cost also seems to vary quite a lot, and seems to be significant.

Herbicide was only reported to be used by 12 respondents. Glyphosate and roundup were mentioned.

3 respondents used *Pueraria* as a cover crop.

Tapping Frequency:

D3 or twice a week is the most common.

Labour:

11 respondents reported having family labour of 1 (likely themselves), 30 have family labour of 2-11. Almost all respondents hire workers (1-15). 30 have no sharecroppers, 25 have sharecroppers (1-7 sharecroppers). Some commented that farm workers are increasingly rare.

One plantation director reported family labour of 250 and hired labour of 200 for 1100ha of rubber (850 in production, 250 not in production).

Terrain:

Respondents reported flat terrain (n=42), slopes (n=20, but only 3 with steep slopes), lowland (n=10).

Soils:

Mostly clay (n=36) and/or sandy (n=35) soils. Sometimes gravel or stony (n=7), acidic (n=4).

Reasons for interest in agroforestry:

Majority gave economic reasons (increase or diversify revenue, productivity). Some mentioned climate change (n=7) and nature (n=6; e.g. preserve biodiversity/nature/ecosystem, help environment, avoid using forest land). Three mentioned sustainability or all three pillars of sustainability (economic, environmental, and social). Six were more motivated by knowledge (.e.g to know different crops, to learn, to increase knowledge).

Expectations for Programme:

Common expectations are: increase knowledge (generally, for applying in practice, and technical information), increased profit, spreading awareness and sharing knowledge with others beyond workshop, e.g. to help small producers.

Prior knowledge/experience:

We asked participants to rate their knowledge and experience with agroforestry (with any crop), on a scale of 1-4:

Self-assessment of prior knowledge/experience	No. of respondents
1 – No knowledge	11
2 - Some knowledge, but no experience - Unsure of how to practice	20
3 - Some knowledge, some experience - Sufficient knowledge to practice agroforestry, or just started practicing agroforestry	5
4 - Experienced, ready to teach others	3
*Various combinations of ratings (*e.g. 2,3,4 or 2,4 or 3,4)	11
No response	17

11 respondents answered with a combination of ratings – indicating some knowledge, perhaps some experience in certain types of agroforestry, but less experience in other types.

Most have experience with intercropping rubber with food crops (e.g. banana, yam, vegetables).
A few have tried intercropping with timber.
Of note is a government project that started in since 2020, that intercropped rubber with timber trees: Hevea - Fraké - Bois Bété - acacia - teak - cedrela (6 species)

They learned about agroforestry from various sources, most commonly themselves (9), sometimes through friends or family (5), or from other organisations (APROMAC, FIRCA, forestry department, Ministry of Water and Forestry, FPHCI, German Organisation, GPSNR, INADES-Formation, L'Anader, SAPH, O.N.G.).

Feedback about workshop

58 participants responded to the anonymous exit survey. Nearly all participants would recommend the workshop to others.

Satisfaction rating	**Count**
1	2
2	0
3	6
4	24
5	26
Total	58