FROM JUNGLE RUBBER TO RUBBER AGROFORESTRY SYSTEMS

History of Rubber Agroforestry Practices in the World

Éric Penot, editor

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Cover: Agroforestry system based on rubber, ananas and durian in double spacing design in Myanmar in 2019 during immature period (© É. Penot, Cirad).

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Acknowledgments

This book is dedicated to the memory of Dr. Afs Budiman, chairman of GAPKINDO from 1993 to 2001. Budiman was a close friend of the author and played a key role in the development of RAS (Rubber Agroforestry Systems) in the 1990s through both his personal involvement and funding of the very first research actions in 1994. He was a strong supporter of RAS as a way of diversifying rubber farmers' income, improving farm resilience and making the Indonesian rubber sector sustainable. He always helped and supported funding for research. The RAS research program (SRAP, Smallholder Rubber Agroforestry Project 1994/2007) and most of the ideas reported in this book were discussed, shared and promoted by Budiman. He passed away in 2009 and the agroforestry research team will always remember his exceptional personality.

We would like to thanks all researchers, students (16), technicians, extension agents, farmers, and any persons involved in agroforestry activities I met in the last 30 years that held us to define originally the SRAP project in Indonesia and later on all the studies implemented in many countries (Indonesia, Thailand, Cambodia, Vietnam, Myanmar, Sri Lanka, Colombia, Brazil and Côte d'Ivoire mainly), to understand the "who and what" of agroforestry practices.

We would like to thank in particular Ms Daphne Goodfellow who implemented the complete English editing of this book.

Foreword

Rubber Agroforestry Systems (RAS) have been developed by local farmers in Southeast Asia (Indonesia, Thailand and Malaysia) as soon as the 1920s initially through the development of jungle rubber. Jungle rubber is a very practical and easy way to develop at very low cost non clonal rubber (seedlings) plantations with forest regrowth. Jungle rubber was the main smallholding rubber cropping system until 1950s. Then, for political reasons, clonal plantations with a better productivity were developed though national planting programs in the 1950s in Malaysia, in the 1960s in Thailand and later on in the 1970s in Indonesia. In the 1990s, jungle has disappeared in Malaysia and Thailand when in Indonesia, jungle rubber was still covering 3 million ha for 70% of the rubber national production. In 2023, most of the jungle rubber has disappeared or is not anymore tapped, replaced by monoclonal plantation.

However, in some countries, some local farmers continue to adopt or develop agroforestry practices, basically associating rubber with various number and types of plants and trees in both immature and mature period, in order to increase global productivity at plot level and to diversify sources of incomes to increase farms' resilience. These countries are India, Sri Lanka, Indonesia and Thailand and to a lesser extend Columbia and Brazil. In other countries, more recent rubber booms or lack of history and knowledge about agroforestry limited rubber development to monoculture with good success as well.

In this book, we try to explain what have been the historical and societal conditions for agroforestry to develop in these countries, in particular Thailand and Indonesia. The interest for local farmers to develop agroforestry systems is still very important: incomes diversity to tackle with low rubber prices and with positive environmental externalities. Long periods of low rubber prices since the 1990s increase interest of many farmers for agroforestry practices.

In 2024, environmental concerns, cropping systems sustainability and more globally positive externalities are largely taken into account not only by farmers but also by governments, research and extension bodies as well as most Non Gouvernmental Associations (NGOs).

There is evidently a future for RAS in the current world with global economic uncertainty. However, this is still relatively difficult for most farmers to develop agroforestry practices in countries with no local knowledge and know-how such as Vietnam, Cambodia, Myanmar, China, as well as central America and Western Africa. We listed all constraints for agroforestry adoption.

This is mainly now a political decision for governments to allocate funds to promote agroforestry where it could be possible and locally adapted. RAS is not the perfect "panacea" for agricultural economic rubber development but it might help in many situations depending on farmers situations and strategies as well as local existing markets for the various associated products such as fruits, timber, food, resins, spices, medicinal plants, rattan and other plants.

The objective of this book is to provide evidence of RAS interest and constraints as well as an analysis of local historical evolution of RAS in order to understand how to develop potentially such systems in other countries. Crop diversification is still a very important component for most farmers strategies in the world, and some crops in monoculture might also be in concurrence with rubber (oil palm, pepper, fruit trees…). In agroforestry systems, the objective is to find complementary between crops within one plot. The book integrates various sources from the author and associated researchers and students, written between 1994 and 2024 that have been updated. All original sources dans dates will be precised.

The introduction presents the rubber world and the definition of the agroforestry concept. Chapter 1 presents the original development of jungle rubber based on the use of seedlings as the main agroforestry system in Southeast Asia and the development in the 1990s of the RAS concept (Rubber Agroforestry Systems) based on the use of clonal planting material. Chapter 2 illustrates the development of RAS in Indonesia and Thailand and the way to develop it through "innovation platforms". Chapter 3 presents the current state of RAS in the world. Chapter 4 displays current expectations of RAS, impacts and contribution to today's main challenges on biodiversity, eco-systemic services, environmental concerns, externalities and impact on farmers' income. The conclusion suggests some potential tracks and perspectives for further agroforestry development in the very next future.

I personally strongly believe that if historically famers develop on their own such adapted agroforestry systems in some countries, there is still a future for these very flexible and locally adapted agroforestry systems in many different situations in the tropical world where rubber is present, depending now on government's willingness to tackle with farmers objectives and global environmental concerns.

Introduction

Éric Penot, Joseph Adelegan, Lekshmi Nair, Hugo Lehoux, Adrien Perroches, Lucie Poline, Jerôme Sainte-Beuve

⏩ Rubber in the world

The place of rubber

This section has been originally partly published in a Cirad report for AFD using IRSG data in Penot et al. (2020)[1].

Natural rubber is a key product for the global economy because its elasticity and strength have never been perfectly reproduced in synthetic rubber. Natural rubber is extensively used in the tire industry, whose growth due to increasing transport by car, truck and plane, has a direct impact on the demand for rubber (Sainte-Beuve, 2015). As a result, in one decade, rubber plantations grew by more than 2 million hectares to reach 12 million hectares worldwide (Figure I.1).

World production of natural rubber (2017) reached 13.5 million tons, while synthetic rubber production accounted for 15.06 million tons (IRSG, 2018). The vast majority of natural rubber is produced in Asia (Figure I.2)[2].

The order of the top 10 rubber producing countries has remained virtually unchanged since the 2000s, but in the decade 2007 to 2017, annual world production increased from 10.1 to 13.55 million tons (Figure I.3).

The top 25 producing countries can be classified in five groups based on their annual production (Table I.1). The following pages describe the increase in production in each of these groups.

1. Éric Penot, Philippe Thaler, Yann Nouvellon, Bénédicte Chambon, Jérôme Sainte Beuve, 2020. Revue de la littérature sur les Standards de la Filière Hévéa. Rapport AFD. 41 p.
2. Partial source: IRSG data and report by Hugo Lehoux, Adrien Peroches, Lucie Poline, Éric Penot, Jérôme Sainte-Beuve. Rubber in the world. Rubber growing throughout the World. Overview of production dynamics, market and value-chain sustainability challenges. FTA project. Montpellier, 2019.

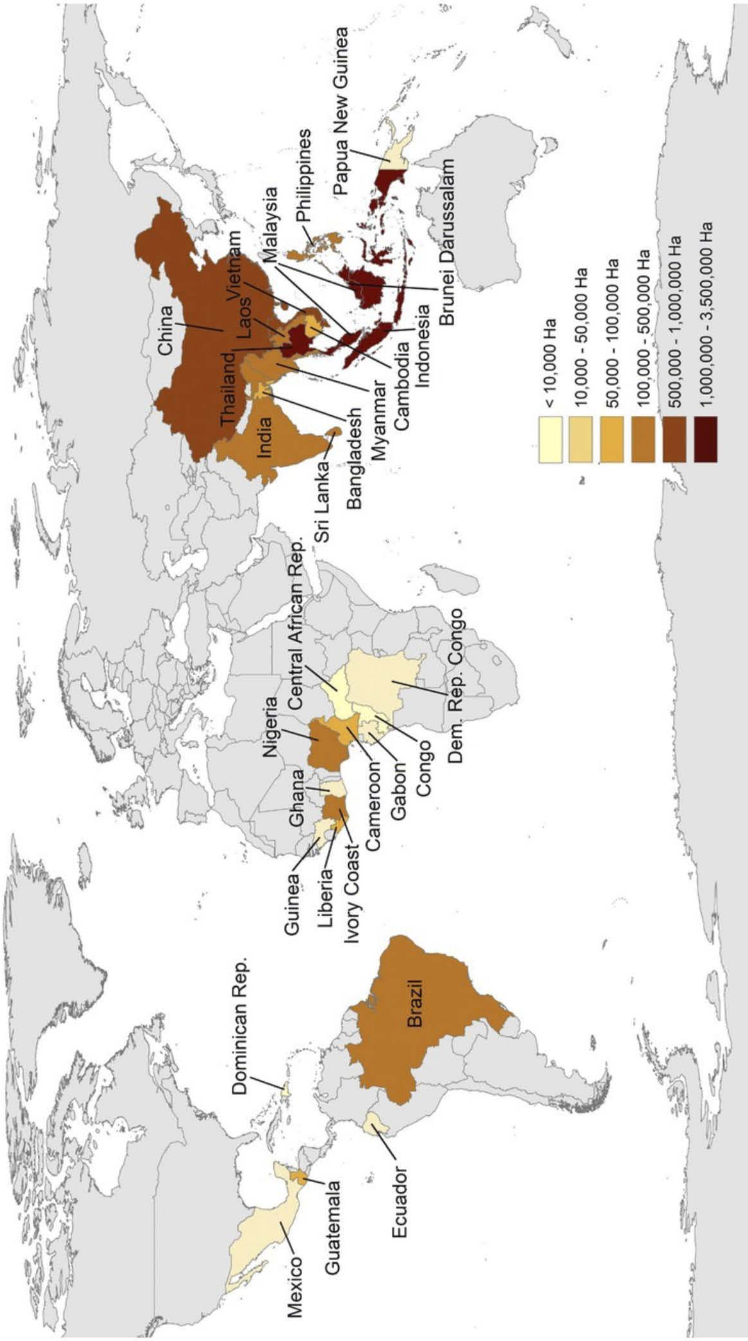

Figure I.1. Surface area of plantations in rubber producing countries (© 2015 The Authors Conservation Letters Published by Wiley Periodicals, Inc.; Warren-Thomas et al., 2015)

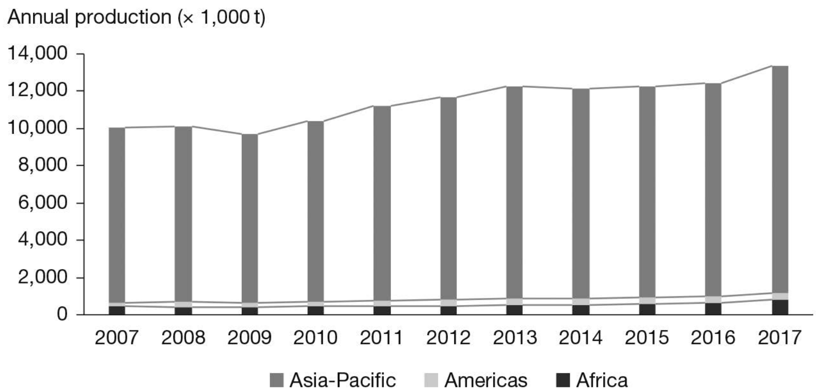

Figure I.2. Annual rubber production per continent between 2007 and 2017 (IRSG, 2018)

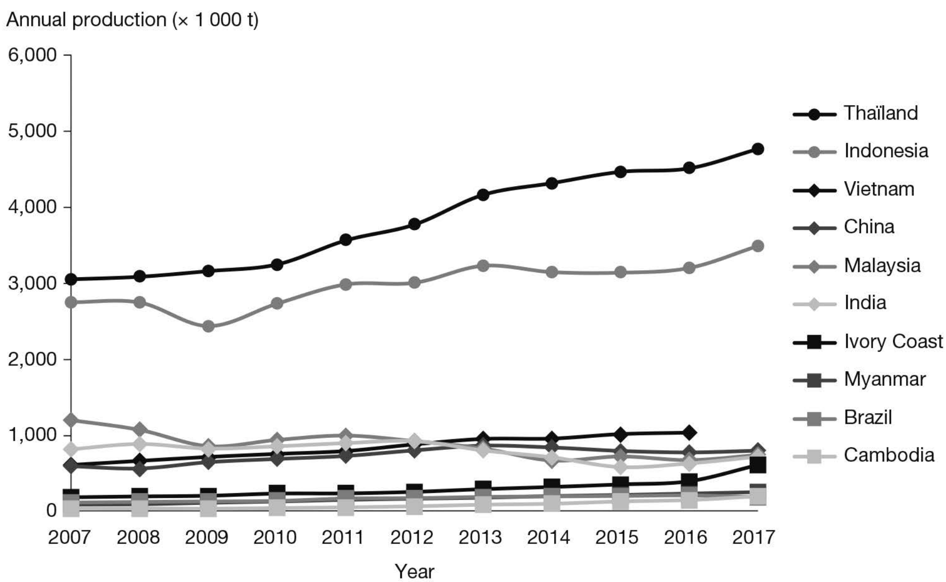

Figure I.3. Annual production of the 10 biggest rubber producing countries (IRSG, 2018)

Table I.1. Countries grouped based on their annual production

Category	Country	Production in 2018 (x 1,000 tons)
Group A	Thailand	4,755.0
3 to 5 million tons	Indonesia	3,499.0
Group B	Vietnam	1,032.0
0.5 to 1 million tons	China	798.0
	Malaysia	741.0
	India	713.0
	Côte d'Ivoire	604.0
Group C	Myanmar	249.0
100 to 250,000 tons	Brazil	184.0
	Cambodia	193.3
	Philippines	1022
	Guatemala	100.2
	Sri Lanka	83.1
	Laos	78.3
Group D	Liberia	63.0
40 to 60,000 tons	Nigeria	53.0
	Cameroon	53.0
	Ghana	37.0
Group E	Gabon	21.2
Less than 20,000 tons	Bangladesh	21.0
	Guinea	17.0
	Mexico	18.1
	Republic of Congo	13.2
	Colombia	12.0
	Americas – Other countries	9.2
	Bolivia	5.7
	Papua New-Guinea	5.7
	Africa – Other countries	4.8

The development of rubber plantations. Booms in China, Côte d'Ivoire, Laos, Cambodia and Vietnam

Two countries account for 61% of world production: Thailand and Indonesia. This is also the case for the last countries to have joined or are in the process of joining the leading group (Myanmar, Cambodia, Côte d'Ivoire, Vietnam and Brazil, a special case), which significantly increases the total area planted (Table I.2).

Table I.2. Increasing production by countries with growing global production dynamics (IRSG, 2018)

Country	Rank	2007 (x 1,000 tons)	2017 (x 1,000 tons)	Increase (x 1,000 tons)	Increase (Percentage)
Thailand	1	3,056	4,775	+ 1,719	+56%
Indonesia	2	2,755	3,499	+ 744	+27%
Vietnam	3	606	1,094	+ 488	+80%
Côte d'Ivoire	7	183	604	+ 421	+230%
Myanmar	8	89	249	+ 160	+ 180%
Brazil	9	116	184	+ 68	+ 59%
Cambodia	10	33	193	+ 160	+ 485%

These countries operate under different models. While production in Thailand and Côte d'Ivoire is mainly based on village plantations (family and family business), Cambodia is developing industrial plantations on private concessions. Private investment is all the more important as land prices are low and the country's policy favour the development of large plantations (Chambon et al., 2018).

It is interesting to note that in Cambodia, the development of large industrial plantations follows more or less the same logic as in this group of countries at the beginning of the last century: attractive selling prices for raw materials and labour, public policies favouring domestic and foreign private investment and the desire to develop an agricultural model based on agribusiness (Byerlee, 2014).

In the case of Brazil, production is growing slightly but suffers from severe constraints. The rubber comes from industrial plantations under the pressure of the phytopathogenic fungus *Microcyclus ulei*, which limits its expansion to so-called "escape" zones. An escape zone corresponds to an area whose agro-ecological conditions limit the development of *Microcyclus ulei*. The rest of the rubber comes from tapping in spontaneous forest areas.

Thailand is currently the world's largest producer with 4.77 million tons in 2017, corresponding to 37.1% of global production. Rubber production has continued to increase at an average rate of 4.3% per year for the last 5 years. Thailand is the only country where rubber cultivation has been developed exclusively by family farms. This is largely due to the fact that the country has never been colonised, the Thai state has strongly supported these family farms (Fox and Castella, 2013), and had no policy to encourage private investment and large-scale industrial plantations. Support for family farms in southern Thailand, the traditional cradle of rubber cultivation in the 1950s and 1960s, was also established for political reasons, mainly to counter the communist rebellion (like in Malaysia) and to esure a good source of income for local farmers. Industrial plantations occupy a very small place in Thailand, 3.5% to 7% of the total rubber production area (Chambon et al., 2018; IRSG, 2018). The world's major industrial groups have acquired land in Thailand, but most of it is fragmented, with an average area of 63 ha for this type of industrial plantations. It should be noted that the model of family business plantations is in full development, particularly in the so-called marginal areas (Chambon et al., 2018; Fox and Castella, 2013). Their average surface area ranges between 10 and 300 ha.

Indonesia[3] has been the world's second largest producer for many years, with 3.4 million tons in 2017, or 25% of the world's natural rubber production. Like in many countries in Southeast Asia, rubber tree cultivation was developed under colonisation in the form of "domains". At the beginning of the 20th century, natural rubber prices were very volatile, which pushed tire manufacturers to internalise the production stage. In Indonesia, this was the case of Goodyear (Barlow, 1978). Small family farms very quickly adopted rubber in the 1920s, which reached 85% of the country's total area (Fox and Castella, 2013; IRSG, 2018). In the 1960s, some of the large plantations were nationalised to form the state-owned company PTP (PT Perkebunan Nusantara III). The State introduced concession policies promoting the development of oil palm in the 1990s, thereby contributing to massive deforestation (Byerlee, 2014; Feintrenie *et al.*, 2010).

Over the last decade, natural rubber production has increased at an average rate of 2.4% per year, with a slight slowdown in growth since 2013. This growth is due to the conversion of land formerly dedicated to cocoa, tea and coffee to rubber, but also to oil palm and *Acacia mangium* (Feintrenie *et al.*, 2010). The slowdown is being caused by the reduction in available land and competition with other types of speculation. Yields in Indonesia are reported to be lower than in other producing countries, mainly due to the use of unproductive tree planting material in jungle rubber systems (ANRPC[4]), the ageing of the trees and competition with oil palm when replanting.

Industrial plantations represent 14% of the area planted with rubber trees (Chambon *et al.*, 2018), but are decreasing in favour of village plantations, but also of industrial plantations of *A. mangium* and oil palm. These industrial plantations often belong to the state-owned PTP or are foreign-owned private plantations (owners from China and Singapore). Private plantations can be very large: 35,000 hectares for Michelin and 24,000 hectares for Bridgestone. These plantations mainly follow the hybrid planting model called NES[5], i.e., an industrial plantation feeding a factory, surrounded by family plantations. The possibility to increase the extent of industrial plantations is currently quite limited. Some private plantations may consider taking over concessions that have fallen into the public domain or planting in areas that are still untouched but difficult to access. Access to land is strongly dependent on policies, which are not as favourable to major concessions as in the past. At the moment, the Indonesian government does not wish to open new concessions, but this could change in the future.

GAPKINDO, the association of Indonesian rubber producers, introduced a policy to improve rubber quality in the 1990s. Actions to improve quality are also successfully implemented by private companies themselves (Dao, 2015).

India is the world's sixth largest producer with 713,000 tons produced in 2017, representing 5.3% of global production. Developed under English colonisation, rubber plantations have always been in the hands of smallholders, with production for the domestic market. These are intensive, small-scale family farm systems, resulting in very high land productivity (Viswanathan and Shivakoti, 2008); 89% of Indian production

3. This section has been originally published in: Éric Penot**,** Bénédicte Chambon, Jérôme Sainte Beuve, 2023. An analysis and comparaison of the rubber smallholder sector in 5 countries: Cote d'Ivoire, Thailand, Indonesia, Vietnam and Cambodia. FTA/CIFOR final report, Montpellier France.

4. The Association of Natural Rubber Producing Countries (ANRPC). http://www.anrpc.org/

5. PIR/NES: NES = Nucleus Estate Scheme which has its Indonesian equivalent; PIR = Perkebunan Inti Rakhyat.

is provided by family plantations (Fox and Castella, 2013). India wanted to increase its domestic market for natural rubber, in line with its increasing economic growth. It therefore put in place policies to support plantation renewal, including through its rubber production department at the Indian Rubber Office. However, the policies do not seem to have been sufficient to generate a strong trend towards planting or renewal of rubber plantations. The very significant ageing and fragmentation of the plantations has limited the expected growth. Over the past ten years, production has declined at an average annual rate of 1.2%. Currently, prices are subsidised to maintain or even restart plantations, with the aim of producing for the domestic market. It should be noted that there are also plantations in the seven northeastern states, but yields are lower there (ANRPC).

The dynamics and problems are similar in Sri Lanka with an additional constraint due to the prevalence of heavy rains. Production drops drastically when heavy rains fall every day. This has led farmers to implement rain protection practices such as installing a rainguard to protect the notch and the cup. Agroforestry systems in association with tea were developed in the 1990s.

The years following 2010 saw significant rubber booms in some countries: Côte d'Ivoire, Vietnam, Laos, Cambodia, and China, mainly through the development of rubber monoculture. Rubber agroforestry systems (RAS) remain an interesting alternative in some other countries such as Indonesia, Thailand, Sri Lanka, Columbia and India.

⏩ The concept of agroforestry and agroforestry systems

This section has been published in 1999 as a Cirad working document[6].

The objective of agroforestry can be defined as the reconciliation of two types of land exploitation which have deeply affected the countryside of both tropical and temperate countries in recent centuries: agriculture and forestry. The main feature which characterises agroforestry is the combination, or association, of several annual and perennial plants in the same field.

Agroforestry systems (AFS) are one type of "cropping system", in which the field is homogeneously managed, using a particular technical pathway (or "technological pattern") and a defined plant succession. One may consider AFS as cropping systems, possibly based on one main species. A systemic approach is appropriate to define systems in which labour, inputs, land use and know-how are managed under a particular strategy. Agroforestry strategies can be defined mainly through three features: (i) the minimisation of risk (crop failure), (ii) the optimisation of labour efficiency, different levels of intensification depending on the system, and (iii) the possible use of improved planting material and inputs, according to a strategy that takes land tenure and occupation into account. At the field level, combinations of crops, planted or the result of natural regeneration, lead to interactions between plants: competition and sometimes complementarity.

The traditional definition of ICRAF (International Center for Research in Agroforestry) is the following: "*A collective name for land use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land management unit*".

6. Éric Penot, Bernard Malet, 1999. Agroforestry systems: some definitions and contribution to forests dynamics. Cirad, Montpellier.

Agroforestry is generally practiced with the intention of developing a more sustainable form of land use that can improve farm productivity and the welfare of the rural community (Leakey, 1996).

The general definition provided by Somarriba in 1992 seems to us to be a less "reducing" definition: "*Agroforestry involves diverse technical practices that have in common the following: (i) there are at least 2 different plants in biological interaction, (ii) one of the 2 plants is a perennial and (iii) one of the 2 plants is a forage crop, a food crop or a tree crop*."

The definition was revisited by Leakey in 1996: "*Agroforestry should be considered as a dynamic, ecologically based, natural resource management system that, through the integration of trees in farm and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits*".

Another definition was suggested by the "*Laboratoire de Botanique Tropicale*" in Montpellier, France: "*Agroforestry is a land use system, controlled by the local population in which perennial trees are associated with agriculture and/or stock farming on the same piece of land in such a way that the resulting ecosystem tends to mimic the natural forest ecosystem in terms of aerial and soil biomass, vegetation structure and species richness*".

That definition paves the way for complex agroforestry (CAF). The definition of an "agroforest" was made by de Foresta and Michon: "*Agroforests are a particular kind of agroforestry land use, but the word "agroforest" is sometimes understood as the end-result of all agroforestry systems, whatever their structure and composition. For us*[7] *as for many scientists and laymen, using the word "agroforest" to describe structures that have no forest features, like alley-cropping or trees on contour lines systems, represents a language abuse that only leads to confusion*" (de Foresta and Michon, 1996). This definition is perfect for jungle rubber and complex agroforestry systems.

A typology is therefore necessary to classify agroforestry systems. Many typologies have been defined (King, 1979; Huxley, 1883; Nair, 1985; Macdicken, 1990; Somarriba, 1992; Mary and Besse, 1996; Torquebiau, 1998) and are generally based on their components (crops, trees and livestock) and their combination in space and over time. De Foresta and Michon proposed another classification with two components: simple agroforestry (SAF) systems and complex agroforestry systems (de Foresta and Michon 1965), that perfectly reflect most agroforestry situations: "*Simple agroforestry systems (SAF) refers to associations involving a small number of components arranged in obvious, usually well-ordered patterns: one or a couple of tree species, either as a continuous canopy, in equally distant lines or in edges, and some annual species for ground cover*".

The tree component is generally a crop of major economic importance, coconut, rubber, clove, teak and now oil palm, or plays a qualitative or environmental role, with *Erythrina*, *Leucaena*, *Calliandra* planted for fodder or to improve soil fertility. The annual species are usually important economically as intercrops during the immature period, such as paddy, maize, vegetables, forage crops or banana, pineapple, cassava or sugarcane. These simple agroforestry associations represent the classical

7. This represents the "Montpellier group *Laboratoire de Botanique Tropicale*" with F. Hallé, J.M. Bombard, F. Mary, G. Michon, H. de Foresta, E. Torquebiau, and other Cirad/ICRAF researchers (E. Penot, F. Besse, etc.).

agroforestry model most favoured in the development programmes of most institutions dealing with agroforestry (Steppler and Nair, 1987; Nair, 1989) as they are simple to promote (shading systems with coffee/cocoa, alley-cropping, hedgerows, improved fallows, etc.). The structure and functioning of these SAF do not resemble a “forest structure” and do not provide the same environmental outputs in the humid tropics.

Complex agroforestry systems are tree-based systems with a forest-like configuration that associate a large number of components, including trees as well as tree-lets, lianas, herbs, crops, and medicinal plants. Agroforests mimic the structure of natural forests, with a complex multi-strata structure and a closed canopy dominated by a few tree species (definition in van Noordwijk et al., 1997). The word “complex agroforestry systems” (CAF) is far more appropriate for agroforestry systems that match this definition such as jungle rubber, RAS (Rubber agroforestry systems, etc.). According to these authors, the CAF concept implies relative continuity in space and over time. Forest biodiversity in agroforests is usually quite high, as most farmers do not systematically eliminate “unused species”, thereby allowing the regeneration of numerous forest species. CAF functioning is close to that of natural ecosystems. Complex systems are encountered almost exclusively in agriculture in the humid tropics. Except for home-garden systems, a particular form of CAF association that is relatively well documented worldwide, complex systems are now better recognised after having been ignored for decades. The functional reference to a natural forest ecosystem is one of the main features that distinguish “complex” from “simple” agroforestry systems. CAF are far more relevant for the analysis of forest dynamics as their ecological structure and physiological functioning in the mature period is very similar to that of a forest. However, as perennial cropping systems, CAF are also closer to plantations than to forests in terms of investment, management, economic strategies and outputs.

The dimension of the concepts of simple and complex agroforestry systems goes far beyond this physiognomic description or its intrinsic implications for the respective qualities of both systems. SAF and CAF relate to two different, though potentially complementary, conceptions of land development. One refers to field management: SAF address the integration of trees in agricultural lands. The other refers to resource management: CAF address the integration between forests and agriculture. This difference does not only involve important ecological aspects but has also essential socio-political implications, especially concerning the global role and interest of smallholder farmers in the management of forest lands and resources (de Foresta and Michon, 1995).

In the case of rubber, some AFS with rubber include only one tree, which could be one fruit tree (Thailand) or only one associated species (coffee or cocoa). Historically, jungle rubber was the most developed and famous CAF in southeast Asia and, in particular, in Indonesia. Modern RAS such as CAF also exist with several fruit tree and timber species all mixed together.

Chapter 1

Definition and history of RAS

Éric Penot, Bénédicte Chambon, Pascal Montoro, Wilfried Shueller

⏩ Rubber in Southeast Asia from 1900 to 2023

The rubber boom and the development of jungle rubber

This section has been originally published in 2004[8].

Rubber *(Hevea brasiliensis)* was introduced in Indonesia from Malaysia by the Dutch at the turn of the 20th century in North Sumatra and was originally cropped in private estates in the form of monoculture in the "estate belt", following the trend observed among English estates in the western part of Malaysia. At that time, the market for natural rubber was booming due to a constant increase in demand and is still sustained in 2024 by a permanent demand for around 14 million tons per year (world consumption in 2022). In the 1910s and 1920s, Sumatra and Kalimantan were sparsely populated, with 1-4 inhabitants per km^2. Shifting cultivation was the usual practice involving slash and burn of primary forest or old secondary forest[9], one or two years of upland rice cropping followed by a long fallow lasting up to 30/40 years depending on land availability. Land was plentiful and there was no particular pressure to force farmers to change to another system. The system was sustainable as long as the population remained relatively stable, which was not the case in Java. In Sumatra in the 1910s, rubber seeds were collected from estates in the north and then distributed or sold by Chinese traders and missionaries in the south (Riau, Jambi and South Sumatra provinces) creating a tremendous demand for rubber in pioneer zones. In Borneo, the first seedlings were introduced in 1882 (Treemer, 1864, cited in Dove, 1995). Seeds were distributed to the indigenous population in 1908 by the Sarawak government. In Kalimantan, rubber seeds were introduced in 1909 (Uljee, 1925, cited in King et al., 1988) and were spread by Chinese merchants and Catholic missionaries in the Kapuas river basin.

Farmers immediately saw rubber as a new source of income, and in addition, it was easy to integrate in their existing agricultural practices. They began to collect seeds from surrounding estates or existing plantations and started their own rubber plantations. Rubber was cultivated in a very intensive way on the estates using fertilisers and

8. Didier Babin (ed), 2004. *Beyond tropical deforestation. From tropical deforestation to forest cover dynamics and forest development,* UNESCO/Cirad, 488 p.
9. At the turn of the 20th century, the peneplains in Sumatra and Kalimantan were still largely covered by primary forest.