HISTORY OF RUBBER AGROFORESTRY SYSTEMS DEVELOPMENT IN INDONESIA AND THAILAND AS ALTERNATIVES FOR SUSTAINABLE AGRICULTURE AND INCOME STABILITY

Eric Penot¹, Bénédicte Chambon², and Gede Wibawa³

¹ CIRAD IMR Innovation, 34398, Montpellier, France, eric.penot@cirad.fr
² CIRAD UR 34, Bangkok. Bénédicte.chambon@cirad.fr
³ Riset Perkebunan Nusantara, Bogor, Indonesia

Abstract

Promoting environmentally friendly and socially responsible rubber cultivation is relatively new in current agricultural policies in Asia (since the 2010’s). However, agroforestry systems based on rubber are very old, based on local know-how. Their interest and recognition is relatively recent since the beginning of the 2000’s. If rubber was introduced in South Asia as a colonial crop, it would have been immediately adopted by local farmers since 1910’s and developed as a very extensive agroforestry system based on unselected rubber seedlings: the jungle rubber, established in Indonesia, Malaysia (North-Borneo) and southern Thailand. Malaysia in the 1950’s and Thailand in the 1960’s developed specific institutions and policies to replace jungle rubber by clonal monoculture and rapidly implemented highly productive new plantations based on clones. Indonesia started rubber clone development programs in the 1970’s. Though there is no more jungle rubber in Thailand and Malaysia (except a little bit in Sabah/Sarawak), there still exists between 2 and 2.5 million hectares of jungle rubber in Indonesia. Meanwhile, local farmers started experimenting agroforestry practices themselves in the 1990’s, with clonal rubber, with fruits trees, wood/timber trees and other plants for additional source of income. Such systems have been reported in the 1990’s in Southern Thailand, West-Kalimantan and south/central Sumatra. The rubber price volatility and its vulnerability to global market fluctuations in the last 30 years (from 0.5 to 5 US $/kg) have compelled many farmers to leave the cultivation. Strategies for income diversification became priority. In a context of land scarcity, agroforestry appeared as the best-bet alternative to combine production and environmental and social issues. Local extension and research institutions have realized that agroforestry is a viable practice to overcome monoculture constraints (relying on one source of income only, rubber prices volatility etc) and provide environmental services. This new opening of local institutions to alternative agroforestry systems lead to more recognition and now promotion of environmental friendly and socially responsible rubber cultivation. Meanwhile, studies in the 2000’s in Indonesia and recently in Thailand in 2015/2016 show that agroforestry systems do limit various types of risks under different socio-economic conditions (erosion, price volatility etc.). The focus of the communication is put on rubber agroforestry systems history, advantages and recent findings in Thailand to overcome rubber price un-stability and maintain farmers’ income and resilience through diversification (fruits, legumes and timber) where innovation platform could be developed on existing knowledge and know-how.

Keywords: rubber agroforestry, Indonesia, Thailand, resilience, price volatility, sustainability, smallholders
INTRODUCTION

The sustainability of agriculture is becoming a major concern in a world of global uncertainty. The main questions concerning "ecological sustainability" are linked to the problem of degraded environment and fragile soils and thus fertility, biodiversity, and protection of watersheds. Several cropping patterns offer potential solutions to these problems: agroforestry practices, conservation agriculture, agro-ecological practices, livestock-agriculture integration, etc. Crop diversification and rapid technical change characterize the evolution of many existing farming systems. Agroforestry are among agro-ecological practices developed in the world especially in Southeast Asia as it concerns more than 5 million hectares (2 million ha for rubber), especially in Indonesia with various systems based on Durian, rubber, fruits and timber (Tembawang) and Damar for instance. The history of these innovation processes are key elements to analyze and understand farmers’ trajectories and thus be in a position to make viable further recommendations for development. Agroforestry systems have been generally locally developed in a particular context by local farmers profiting from existing local opportunities or specific markets (Damar resin, Durian In Indonesia, various fruits and timber/rubber in Indonesia/Thailand/Malaysia, etc) or to overcome local constraints (lack of capital and adaptability to local practices). Most analysis on agroforestry systems have focused on ecological sustainability. The notion of “economic sustainability”, places emphasis on the profitability of specific technical choices (margins analysis, income generation, return to labor and capital as a function of a specific activity, analysis of constraints-opportunities, etc.) from the point of view of farming systems at the regional level. Knowledge about smallholders’ strategies in these different contexts is thus key elements that should also be taken into account.

As sustainable development is becoming the new “priority objective”, the rehabilitation of previously intensively managed agricultural or degraded land also merits consideration. 1 Perennial crops in particular are subject to rapid changes in plantation/re-plantation strategies in pioneer and post-pioneer areas, as for instance the couple rubber/oil palm. These changes characterize farmers’ strategies through phases of investment, capital or patrimonial building, capital conservation, re-investment and eventually intensification or

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1 With respect to the latter, two different types of areas seem to be important: ecologically degraded areas such as Imperata cylindrica grasslands, which cover 25 million ha in SEA, and former mining areas that require rehabilitation in Southeast Asia for instance).
diversification or both. A constant factor that underlies such strategies is innovation: both the process of technical innovation (technical pathways) and of organizational innovation (producers’ organization, access to credit, etc.).

Rubber is in a relatively severe price crisis as it has been the case in 1997/2004. Commodity prices are subject to volatility with large variations in time. Political changes have also resulted in new decentralization policies in most countries (indirectly linked with democratization in some countries) that may introduce new ways of local governance. The major economic trend is towards globalization since the 1980’s accompanied by a general decrease in prices for most agricultural commodities. Concurrently, most Asian farmers enjoyed, willing it or not, direct links to markets over a relatively long period of time (absence of the commodity boards in Asia when it has been often encountered in Africa in the 1980’s and 1990’s), in particular in the case of rubber.

Therefore emphasis should also be placed on the history of innovation processes in the context of the change from pioneer fronts to increasingly stable post-pioneer areas. To ensure the adoption and appropriation of technology by smallholders is efficient, further research is required on innovation processes and technical change in general using socio-economic tools such as farm income modelling. The problems of coherence between social demand (including the process of innovation and technical change), the role of the state (the relationship between the State and farmers, between production and market) need to be investigated. The historical dimension is very significant in this type of analysis even if economic commodity cycles can be very fast. So far, rebuilding the past with a modelling tool and creating new scenarios of evolution through a prospective analysis can be linked in order to improve the efficiency of development oriented research.

Concerning agroforestry issues, what is the role of each stakeholder? What are the main externalities?

Impact of technical change should take into account effect on sustainability on both farmers’ livelihood and environment. Success in diversification strategies requires a certain number of conditions: capital or credit availability, technical options (innovations), information, markets, farmers’ organizations in order to improve marketing etc. While rubber area and production in Malaysia are decreasing, the trend in Thailand and Indonesia is on the rise. Rubber forms a major export
commodity for both countries. Neighboring countries (Myanmar, Vietnam, Laos, Cambodia, and China) in the region are rapidly developing their rubber sectors but mainly under monoculture.

This communication presents brief results of history of the development of different Rubber Agroforestry Systems (RAS) mainly in Indonesia and Thailand\(^2\) which represents almost 2/3 of rubber world production with existing agroforestry traditional practices\(^3\).

Although rubber is currently enjoying US$ 1.7 at the international market in 2017, at times it has been up to US$ 5 in 2011 and also dipped to nearly US$ 0.5 in 2001 when many farmers in Indonesia stopped tapping and looked for alternative jobs such as illegal logging, gold mining, daily labor and US$ 1 in 2014 leading to lower rubber production in Thailand when some farmers began to stop tapping. The rubber price volatility seems to be a common and unfortunately very frequent uncomfortable situation for smallholders.

**From Jungle Rubber to Improved Rubber Agroforestry Systems (RAS)**

**The Jungle Rubber History**

Rubber has been developed in Indonesia since more than a century and since then Indonesia has had the largest rubber area in the world (3.5 million ha). Rubber plantations are mainly operated by smallholders in Indonesia (80 %) and Thailand (96 %) with less than 8 hectares per family. Most smallholder rubber areas are multi-strata in nature called “Jungle Rubber” and based on seedlings. Rubber is mixed with timber trees (forest re-growth), fruit trees, and different annual crops during immature period. Due to this extensive management adapted to local farmers’ conditions, smallholder rubber areas in Indonesia are mostly under “jungle rubber” pattern: from 3 million ha of jungle rubber in 1990, Indonesia still has between 2 and 2.5 million ha today in 2017. At the turn of the 19th century, the Sumatra and Kalimantan plains at an altitude of lower than 500 meters were sparsely inhabited with a population density of less than 4 persons/km\(^2\). The population relied mainly on shifting cultivation of upland rice. The introduction of rubber by private Dutch

\(^2\) Agroforestry systems are very scarce in Malaysia, Vietnam and China. Some jungle rubber remains in Sarawak/Sabah states in North Borneo in Malaysia.

\(^3\) Jungle rubber mainly (and some clonal rubber agroforestry systems) covers more than 2 million ha in Indonesia. In Thailand it is estimated than 3 to 5 % of total rubber area in under agroforestry management mainly in southern Thailand.
History of rubber agroforestry systems development in Indonesia and Thailand as estates in the 1910’s triggered a radical change in the landscape evolution but not in farming practices, at least in the beginning. Although estates adopted monoculture right from the beginning, trying to maximize rubber production, farmers immediately saw and exploited the possibility of growing rubber in a very extensive way by enriching their fallow (‘belukar’ in Indonesian) with unselected rubber seedlings that were freely available. Planting rubber during, or after, upland rice demanded only marginal extra work, with no risks and, more important, no costs. Rubber was grown as a component of the secondary forest in a complex agroforestry system widely known as ‘jungle rubber’.

The advantages of jungle rubber were clear: no cost; no labor required for maintenance during the immature period; and income diversification with fruits, rattan, timber and other non-timber forest products harvested from the agroforest. Although rubber tapping was delayed compared to rubber monoculture in estates, it still provided an attractive income. Indirect environmental benefits included soil conservation and rehabilitation of degraded lands. Originally, the adoption of this system did not change farmer practices and, in addition to managing their jungle rubber, farmers continued to slash-and-burn new plots every year. At this stage jungle rubber could be considered as a "fallow enriched with rubber" as extensive and low management systems.

An important feature is the labor requirement that shift from a cyclic basis (upland rice) to a permanent basis for rubber (from 6 to 11 a.m. every day when rubber starts producing). There is no concurrence between the two systems as the afternoon is potentially still usable for “ladang” activities (upland farming). Rubber has proved to be adapted to meet the challenge with rice particularly in the rainy season. This is an important feature because labor is the main available factor of production in the lack of any capital when land is still plentiful. So, from the beginning, rubber and ladang rice could merge with flexibility in existing farming systems. Rubber has never been seen as an alternative to rice, however that statement is becoming less and less true with the intensification and the increasing pressure on land in some provinces such as North and South Sumatra.

Historically, farmers move to rubber because it suited local environment and was sustained by a constant increasing market, providing a very good opportunity to easily increase farm income. Average population density in Sumatra is now 40/50 inhabitants/km² and land is becoming scarce in some provinces (North and South Sumatra,
According to Dove (1993), "the comparative ecology and economy of rubber and upland swidden rice result in minimal competition in the use of land and labor, and even in mutual enhancement, between the two systems". Jungle rubber and shifting cultivation are not at all antinomic as the two systems can coexist in local farming systems. The notion of "composite system" has been developed by Dove (1993): "there is little analysis of the relationship between the two systems (rubber as swidden agriculture with rice) and thus little understanding of why this combination historically proved to be so successful".

The cost advantage of “smallholder versus estates” to establish a rubber plantation has been assessed as 13 to 1 during the colonial area (Dove, 1995), 6 to 1 related to estates in 1982 and between 3 to 1 and 11 to 1 related to governmental rubber schemes (Barlow et al, 1982), showing that there were very competitive cost advantages for rubber. Various consequences of this low farm management are identified such as a) slow and heterogeneous rubber growth and long immature period or late reaching tappable size (8 to 12/15 years after rubber planting) and; b) rapid growth of forest re-growth.

Historically, rubber development was at the beginning very similar in Thailand, at least until the 1960’s but very rapidly local jungle rubber have been replaced by clonal monoculture plantations through a very large governmental planting program (ORRAF). Jungle rubber has almost disappeared in 2017 in Thailand.

**Rubber, Fertility, Biomass, and Biodiversity**

With rapid deforestation taking place in Sumatra (since the 1970s), rubber agroforests are becoming the most important forest-like vegetation covering substantially large areas in the lowlands (Joshi et al. 2001). It has become a major reservoir of forest species itself and provides connectivity between forest remnants for animals that need larger ranges than the forest remnants provide. While jungle rubber cannot replace natural forest in terms of conservation value, the question whether such a production system could contribute to the conservation of forest species in a generally impoverished landscape is very relevant. This leads to a diversified tree stand dominated by rubber, similar to a secondary forest in structure (Gouyon et al. 1993). For vegetation, Michon and de Foresta (1995) concluded that overall diversity is reduced to approximately 50 percent in the agroforest and 0.5 percent in plantations (Figure 1); but these estimates are based on plot-level assessments. Similar findings were
reported for plants, birds, mammals, canopy insects and soil fauna by Gillison and Liswanti (2000) who covered a wider range of land use types, from forest to Imperata grassland, in their investigation. Studying terrestrial pteriodphytes, Beukema and van Noordwijk (2004), also found that average plot level species richness was not significantly different amongst forest, jungle rubber and rubber plantations, however at the landscape level the species-area curve for jungle rubber had a significantly higher slope parameter, indicating higher diversity.

Figure 1. Comparisons of plot-level richness of plant species between natural forest, rubber agroforest and rubber plantation for higher plants (de Foresta and Michon 1995)

Bio-mass of a rubber plantation at 33 years old (445 t/ha dry weight) is similar to that of humid tropical evergreen forest in Brazil (473 t/ha, from Jose et al, 1986 cited in Wan Abdul Rahaman Wan Yacoob et al, 1996 or Sivanadayan, 1992) or in Malaysia (475-664 t/ha, from Kato et al, 1978 cited in Wan Abdul Rahaman Wan Yacoob et al, 1996).

A High Level of “Useful” Biodiversity

From all plants abundant in traditional jungle rubber, be it spontaneous ones or managed ones, about one third are used (Table 1). These plants include timber and non-timber uses (timber species and non-timber forest products (NTFPs). ‘Timber’ uses are divided into fuelwood (mainly low-quality timber) as well as for house construction and furniture. In areas where no more natural forest is in the reach of the villages, jungle rubber has become the main source of timber for the local people (De Foresta, 1992). In these areas, timber from rubber gardens is already sold, indicating a prospective source of income that could be expanded by the planting of valuable timber species. Non-timber uses include edible ones (fruits and vegetables (edible shoots and pods). Planted fruit tree species include durian, stinkbean (jengkol), rambutan,
locust bean (*petai*), mango, jackfruit and mangosteen. *Petai* and *jengkol* (Mimosoidae), including pods whose seeds are eaten raw or cooked as a vegetable. Both legumes as well as many other fruits are highly priced in urban markets and probably could be sold if transportation is provided. Some fruit tree species, like longsat and carambola, are only planted in the village area because they do not grow well in shady forest conditions. In Sumatra, as opposed to Kalimantan, mango species (*macang, kwini, mangga golek, mempelam*) were also mainly found within the village area. Other NTFPs are medicinal plants and handicraft materials, especially rattan, pandanus and tree bark, but also timber used to craft special items (e.g., machete sheaths). Latex and resin from rubber agroforestry systems are also sold (e.g., *Hevea*-latex, the latex of some *Sapotaceae* (Nyatoh) and *Apocynaceae* (especially *Dyera costulata*). Besides these, products harvested for cash-generation are few. Worth mentioning, however, is *tengkawang*, or illipe nut, harvested from Dipterocarpaceae and cultivated in West Kalimantan by the local Dayak population. Forest gardens, including *tengkawang*, are named *tembawang*. They are usually mixed with fruit trees and sometimes with rubber (Werner, 1993). Other uses of plants growing in rubber gardens are for ceremonial purposes, as ornamentals, thatching materials for field huts, fruits used as fish feed, or latex used to trap birds and the like.

The data presented in table 1 and 2 prove the strong relationship between rubber garden biodiversity and presence of useful species (at least in the 1990’s). About two-thirds of all species present in rubber agroforestry systems have one or more uses. In the quest for yield increases of rubber gardens, it is therefore important to search for systems providing optimal growing conditions for improved clonal rubber varieties, but still allowing a major part of the biodiversity of traditional gardens to be present (table 2). It has been one of the main objectives of the Smallholder Rubber Agroforestry Project (SRAP) activities CIRAD/ICRAF (1994/2007, funded by USAID and CFC).
Table 2. Useful spontaneous vegetation within rubber gardens not cleared by farmers in West Sumatra and Jambi

<table>
<thead>
<tr>
<th>Fruit tree species</th>
<th>Medicinal plants</th>
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<tbody>
<tr>
<td>Durian</td>
<td>Durio zibethinus</td>
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<tr>
<td></td>
<td>Artocarpus</td>
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<td></td>
<td>heterophyllus</td>
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<td>Nangka</td>
<td>Nephelium</td>
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<td></td>
<td>lappaceum</td>
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<td>Rambutan</td>
<td>Sicerek</td>
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<td></td>
<td>Sidingin</td>
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<tr>
<td>Langsat &amp; Duku</td>
<td>Durian</td>
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<tr>
<td>Macang</td>
<td>Mangifera foetida</td>
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<tr>
<td>Mango</td>
<td>Mangifera indica</td>
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<tr>
<td>Jambu</td>
<td>Eugenia aqua</td>
</tr>
<tr>
<td>Langsat &amp; Duku</td>
<td>Lansium domesticum</td>
</tr>
<tr>
<td>Petai</td>
<td>Parkia speciosa</td>
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<tr>
<td>Mangosteen</td>
<td>Garcinia mangostana</td>
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<tr>
<td>Jengkol</td>
<td>Pithecellobium jiringa</td>
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<tr>
<td>Kabau</td>
<td>Pithecellobium bubalinum</td>
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<tr>
<td>Timber species</td>
<td>Plants with other uses</td>
</tr>
<tr>
<td>Sungkai</td>
<td>Peronema canescens</td>
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<tr>
<td>Meranti</td>
<td>various genera and</td>
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<td></td>
<td>families, but esp.</td>
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<tr>
<td></td>
<td>Shorea spp.</td>
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<tr>
<td>Kulim</td>
<td>Scorodocarpus borneensis</td>
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<td></td>
<td>Ochanostachys amentacea</td>
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<tr>
<td>Petaling</td>
<td>Indet.</td>
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<td>Kumpabok</td>
<td>Elaeocarpus palembanicus</td>
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<td>Maraneh</td>
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<td>Tamalun</td>
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<td>Kawang</td>
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<td>Madang</td>
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<td>Surian</td>
<td>Toona sureni</td>
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<td>Rimbang</td>
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<td>Daun kayu sibuk</td>
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<td>Damar</td>
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<td>Jambu monyet</td>
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<td>Elaeocarpus palembanicus</td>
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<td>Lauraceae</td>
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Table 1. Useful plants of traditional rubber gardens in Jambi, West Sumatra, and West Kalimantan

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<thead>
<tr>
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<th>Jambi</th>
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<td>LM 7</td>
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<td>DB 16</td>
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<td>P 6</td>
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<td>48</td>
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<td>55</td>
<td>73</td>
<td>61</td>
<td>73</td>
<td>69</td>
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</tbody>
</table>

* Plot size 2,500 m² as opposed to 1,000 m² of the other plots. Tembawang, no rubber abundant.
** Less than sum of uses, because some species have more than one utilization.
Modern rubber agroforestry systems have to be able to integrate local wisdom about useful plants because in times of shrinking forest reserves, these systems might soon be the only ones still harboring these species over large areas. Preserving biodiversity, therefore, also means guaranteeing the access of local people to these plant resources for their daily needs (Werner, 1993; Lawrence, 1996). Landscape level diversity of rubber agroforestry systems probably depends on the diversity in management intensity.

**Rubber Monoculture**

The most important government action on the development of the commodity started during the beginning of 1970’s and continued till 1980’s. Various development and rehabilitation projects for smallholder tree crops were established, which were mainly grouped into two schemes: 1) the schemes based on monoculture, providing full support for the immature period, with whole credit package, supposed to be refundable within 15 years: Perusahaan Inti Rakyat/Nucleus Estates of smallholder (PIR/NES) and Project Management Unit (PMU) and 2) partially funded projects providing support for planting and for maintenance during the first year of plantation only. The outcome of these different projects was rather positive. Indeed, they contributed to the dissemination of clones among smallholders, and considerably improved the livelihoods of farmers who benefited from them. However, only a limited number of farmers were involved: in 1999, at a time when most major initiatives benefiting smallholders were coming to an end, only 20% of rubber smallholdings had been involved in a development project and access to planting material was a major constraint for the farmers inside and outside the project to extend clonal plantations (Chambon, 2001). In 2017, 1.37 million ha have been planted with clones with smallholders through the various projects (from a total of 3.65 million ha for a production of 3.2 million tons). The average smallholder production in Indonesia (800 kg/year/ha) is not representative as it mixes production from jungle rubber (500/600 kg/ha/year) and that of clonal rubber production (1200/1600 kg/ha/year).

In Thailand, ORRAF (now RAOT for Rubber Authority of Thailand) has promoted and funded the development at very large scale of clonal rubber for smallholders since the 1960’s (3.5 million ha for 4.2 million ton or rubber production in 2017).
The Way to RAS (Rubber Agroforestry systems)

The real challenge for smallholders in Indonesia is to move from low yielding seedling based jungle rubber to clonal rubber either in monoculture or in agroforestry. In Thailand however, all smallholders are already relying on clonal rubber and the challenge is to move to a more diversified agroforestry system with various sources of income in order to improve income resilience to overcome rubber price volatility.

In Indonesia, farmers with access to clonal rubber in monoculture also began to develop additional innovations such as inter-cropping during the immature period and planting perennials (or selective protection of those from natural regeneration) such as fruit and timber trees. They thus created an "improved rubber-based complex agroforestry system" where the original aim of improving the fallow disappeared in favor of the desire to establish a more productive cropping system. Such practices were forbidden in rubber development projects until late 1990’s. Population increase, land scarcity in some areas, and introduction of other more remunerative cropping opportunities combined to force farmers to evolve a more productive Rubber Agroforestry System (RAS). In one village, at least, in Sanjan (Sanggau area in West-Kalimantan), SRDP farmers started (at the beginning of the 1990’s) to select timber and fruits trees among the emerging vegetation, first to shade the inter-row and suppress Imperata, and second to expect a production from these new “associated trees” such as meranti (Shorea spp), teak (Tectonia grandis), nyatoh (Ganua spp) (for timber) durian (Durio zibethinus), pegawai (Durio spp), rambutan (Nephelium lappaceum), duku (Lansium domesticum), petai (Parkia speciosa), jengkol (Archidendron pauciflorum), jackfruit (Artocarpus heterophyllus) and cempedak (a wild jackfruit, Artocarpus integer) for fruit trees. The same trend has been observed in the southern tip of North Sumatra province in both SRDP plantations. Farmers always thought that it was possible to grow perennial inter-crop (trees) with rubber, as is the case in jungle rubber and then decide to proceed further on: but they did not know to what extent associated trees could be combined with rubber without severely decreasing rubber production. The density of associated trees was between 94 to 291 trees/ha (average of 167) for 500 rubber trees /ha (Figure 2 and 3) with emphasis on the following species by decreasing order of importance: Pekawai and Durian (Durio spp), Belian

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4 SRDP = Smallholder Rubber Development Scheme, a rubber development project funded by the World Bank.
History of rubber agroforestry systems development in Indonesia and Thailand as (Euxyderoxylon zwageri), Rambutan (Nephelium lappaceum), cacao, assam (Tamarindus indica), cempedak (Artocarpus integer), petai (Parkia speciosa) and Nyatoh (Palaquium spp). Pekawai, Durian and Rambutan were present in all the plots showing farmers’ preference for fruit trees. 64% of the trees were planted, the rest from natural regrowth and selection. In the study area, income diversification and reintroduction of an economically interesting plant diversity in former monoculture were part of Dayaks farmers’ strategies.

Figure 2. Associated fruit and timber trees and rubber in former TCSDP/SRDP plots in Sanjan, in 1997 in West Kalimantan

Figure 3. Different types of associated trees with rubber in former TCSDP/SRDP plots in Sanjan, in 1997 in West Kalimantan
Rubber Clones in RAS

Yield of clonal rubber were between 1400 to 1800 kg/ha/year in estates in Indonesia or with the best farmers in the SRDP\(^5\) rubber scheme (In South-Sumatra, Prabumulih, or Muara Bungo Transmigration area in Jambi, DGE). Another improved rubber planting material was “polyclonal seedlings” (seeds from an isolated garden planted with several selected clones) in favor in the 50’s and 60’s in estates\(^6\), but definitely obsolete in the 1900’s and since that time. All trials and survey have shown that so far, agroforestry practices do not impact rubber production compared to clonal monoculture which makes rubber as one of the most interesting perennial crop for agroforestry systems. Such example of traditional agroforestry practices and extension of agroforestry practices with clones paved the way to develop a research program in the 1990’s to improve and optimize such RAS in both Indonesia and Thailand.

The RAS (Rubber Agroforestry Systems) Developed in Indonesia

The Rationale of Rubber Agroforestry Systems (RAS)

The main challenge for researchers was to search and to test new models for improving smallholder rubber production systems, based on the current farmer practice ones rather than replacing them with estate-like or monoculture, conserving the biodiversity and environmental benefits of agroforestry practices.

Clonal planting material has been historically selected for estate monoculture management and optimized for the highest level of maintenance. Testing clonal rubber in agroforest environment with a certain level of extensive practices means that clone will be selected for other environments where competition is far higher than that of monoculture and based on reduced inputs and labour.

From 1994 to 2007, World Agroforestry Centre (ICRAF) in association with CIRAD-France and Indonesian Rubber Research Institute (Sembawa Research Station) established a network of trials to study rubber agroforestry systems and test different approaches suitable for different conditions under SRAP (Smallholder Rubber Agroforestry

\(^5\) SRDP = Smallholder Rubber Development Project, a World Bank scheme from 1980 to 1990, replaced by TCSDP = Tree Crop Smallholder Development Project (same scheme) from 1990 to 1998.

\(^6\) Mainly the BLIG or Bah Lias Isolated Garden in North Sumatra.
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Project) and SRAS (Smallholder Rubber Agroforestry System) project. The project was funded by various funding agencies such as: USAID, French Embassy, Gapkindo, and CFC (the Common Fund for Commodities) (Penot, 2001, Wibawa et al. 2006).

The network for on-farm-trials were developed from 1994 to 2007. Increase of productivity of jungle rubber in Indonesia may be attained by providing improved planting materials to the farmers and evaluating which were the most appropriate and affordable for smallholders. This research program was based on four major components: a) characterization of selected areas to achieve a “situation typology” covering a wide range of conditions, b) a network of on-farm trials using participatory approach, c) a farmer typology reflecting all strategies and constraints encountered in the rubber growing areas of Kalimantan and Sumatra, and d) in-depth studies on particular relevant agronomic and ecological topics.

| Frame 1: The global methodology used in SRAP/SRAS (1994/200/) by CIRAD/ICRAF team. |
|---------------------------------|--------------------------------------------------|
| It is based on the following implementation framework: |
| - **Diagnosis** |
| ---&gt; a preliminary diagnosis based on the study of all available information (bibliography, data collection, key-persons) and an exploratory survey. |
| - **A farming system characterisation survey**: |
| ---&gt; to understand constraints, opportunities, income and labour productivity of each cropping systems and farm activities. The data analysis should provide an operational farming system typology and later on a “behaviour” typology. Implemented in 1996 (Pasaman/West Sumatra), 1997 (Kalimantan and central Sumatra) with farming system trajectories analysis in 2000 and farming system modelling in 2001, 2003 and 2005. |
| - **On-farm experimentation programme identification** |
--- the identification of a potential on-farm experimentation programme aimed to solve technical constraints (technical innovations) or social constraints (organisational innovations). On Farm trials protocols should be identified according to typology.

- Implementation of On-farm experimentation

--- Implementation of on-farm identification using participatory approach in a on-farm trials network.

Experiments of SRAP have been implemented in 1995-96 and new trials of SRAS in 2002 and 2004-2005.

- Farming systems monitoring

--- implementation of a “farming systems monitoring network of reference” in order to monitor technical change, adoption of innovations and assess its impact as well as its externalities at the farming systems level and at a regional level as well. Implemented in 2006 after farming system modelling in 2005.

- Analysis and re-assessment of the research programme

--- Feedback analysis with farmers, extension and research institutions and re assessment of the on-farm trial in an constant and evolutive process of R-D

Permanent implementation and analysis every year.

The trials, with an average of 3 to 5 farms or replications per trial, covering 100 hectares and involving about 150 farmers were established. Each farmer’s field was considered as a replication with 1 or 2 simple treatments such as: rubber weeding levels, rubber fertilization, rice variety x fertilization, type of associated trees, and types of cover crops (Multi Purpose Trees (MPT)/Fast Growing Trees (FGT)) combination. Labour was one of the main factors considered in assessment of a system’s suitability.

Three rubber agroforestry systems (RAS) were studied:

- **RAS 1** was similar to the current jungle rubber system, in which unselected rubber seedlings were replaced by adapted clones. Vegetation in between rubber rows were kept by farmer in order to
conserved certain level of biodiversity. The main objectives were to determine if clonal rubber germplasm succeeded to grow well under jungle rubber environment, to increase yields significantly, and to assess the minimum required management level of RAS. A secondary objective was to assess the level of biodiversity conservation in the jungle rubber system.

- **RAS 2**, was a complex agroforestry system in which rubber and perennial timber and fruit trees were established after slashing and burning, at a density of 550 rubber trees and a range of 90/250 other perennial trees per hectare. It was intensive, with annual crops being intercropped during the first 2-3 years, with emphasis on improved upland varieties of rice, with various levels of rice fertilization. RAS 2 was aimed to answer the following questions: how was total productivity and income affected by intercrops? what were the dynamics of species interactions? And what were the crop alternatives during rubber immature period? Intercrops are annual (predominantly upland rice or rotation rice/leguminous such as groundnut) or perennial (cinnamon), during the first 3 years of establishment. Previous experimentation showed the positive effect of annual intercropping on growth of rubber (Wibawa, 1996, 1997), in particular due to good weeding.

- **RAS 3**, planted only in West Kalimantan, intended to provide a solution to degraded fields invaded by *alang-alang* grass, *Imperata cylindrica*, (Penot, 1995). It was also a complex agroforestry system with rubber and other trees planted at the same density as that in RAS 2, but with no intercrops except in the first year, followed by a combination of leguminous cover crops, and Fast Growing Trees (FGT) in order to shade the plot and kill *Imperata*. The grass bounds the growth of annual crops so selected cover crops (*Mucuna, Flemingia, Crotalaria*) or MPTs (*Calliandra, Wingbean, Gliricidia*) and FGTs (*G. arborea, P. falcata*, *A. mangium*) were established with various density between 50-110 trees/ha. It was assumed that the FGT could be harvested after 4 to 5 years to provide wood for the existing pulp industry or for fire wood. The objective of RAS 3 was to reduce the weeding requirement by providing a favourable environment for rubber and the associated trees to grow and to cover the soil as soon as possible to bound *Imperata* growth. The clones tested were PB260, BPM1, RRIC100 and RRIM 600 that proved to be adapted. It was a very successful design to get rid of *Imperata* with no costly and polluting herbicide such as the traditional “round-up” traditionally used (at 6/7 liters/ha).
Main Results on RAS

The performance of clones in RAS1 environments was encouraging and showed that rubber growth did not get affected with and adapted limited weeding program in particular in year1. Compared to seedling originated plants, all clones performed better in terms of growth since the beginning of the establishment. Up to 40 months, among clones, BPM 1 had the best growth followed by other clones, and seedling growth was the slowest. After 40 months, due to white root disease attack on BPM 1 and RRIM 600, growth of those two clones was reduced and the growth of the other two clones RRIC 100 and PB 260 was very good and ready for tapping at 5 years. However the seedling originated plant could be tapped at about 5.5 years after planting. The frequencies of weeding (in rubber rows) of the plots in this trial were between 3-4 times per year. It is important to say that no specific clones have been identified specifically for agroforestry purposes and it is in fact not necessary as most clones adapted for smallholder conditions (in term or tapping frequency in particular ) are adapted to agroforestry as well.

Farmer knows that growth of rubber will be reduced due to competition with other vegetation. In West Kalimantan, farmers did not follow entirely the protocol of trials and did adapt to local conditions. They slashed the vegetation in intra-rows since the second year (once a year) with only few tree species kept especially those plants that had monetary value. These resulted in slower rubber growth (compared to Jambi) and no significant difference of rubber growth was observed due to weeding level. The effects of perennial intercrops on rubber growth varied from year to year, except for treatment with Durian, there was no significant difference observed due to intercrops, at 54 months. However difference in performance of rubber was due to more sites/farmers participation in the trial rather than by different intercrops. Due to shading of the trees, those fruit trees could not produce fruit as good as fruit-trees planted in open areas. The RAS 2 trials in West Kalimantan were not as intensive as it was expected. The annual intercropping (upland rice mainly) was only practiced during the first two years. It was also clear that if the spacing of rubber was 6m x 3m, planting perennial plant under rubber was not encouraging in terms of the fruit production.

For RAS 3: The creeping legumes were clearly the top performers in controlling Imperata. Pueraria was slightly better than Mucuna for rubber growth (statistically significant). Both Pueraria and Mucuna grew well and managed to suppress re-growth of Imperata. However, the creeping legumes required to be ‘weeded’ regularly from the rubber rows as they entangled the trees. While among the erect legumes, Flemingia
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was good for rubber; but *Crotalaria* proved disappointing. Rubber trees with no cover crops but with *Imperata* or *Chromolaena* did not reach tapping size before at least 10 years. This finding was consistent with earlier work done in Sembawa Research Station where it took over 10 years for rubber trees without proper *Imperata* control (Wibawa, 2001). All FGT were relatively successful in controlling *Imperata* re-growth.

Implementing participatory trials needed a close relationship and continuous communication with farmers. Planning, implementing and modifying the trials were carried out under close discussion with farmers. Trust building between researchers and farmers was needed since the beginning of the activity, in order to achieve the objective of the on-farm trial. Once the trust was built, then the following programs and activities could be carried out more efficiently. It was very common that farmers did not follow all protocols designed and fixed by researchers previously. This kind of problems was observed both in Jambi and in West Kalimantan. Again, a close relationship with farmers and trying to understand why they did not follow the protocol was one of the tasks of the on-farm participatory trials. Intensive discussion was important to choose better technical options that adapted to farmers’ needs. Results summarised from this paper indicated that the trade-off between inputs (fertilisers, labours, chemicals) and growth or plant diversity was always of interest for most people. Due to many constraints faced by farmers, especially money for most Indonesian farmers, they had to choose between spending money and allocating family labour. The maximum rubber growth was not always the objective of farmers in establishing various RAS when the most critical factor was cost of maintenance during immature period. The critical question was on how to provide technology options to farmers considering their labor constraints and capital opportunities.

**Labor and Modelling**

In order to develop a prospective analysis tool to model price and yield evolution of multiple farming systems, data on input and output for major rubber-based systems were collected from West Kalimantan and Jambi. The OLYMPE model (INRA/CIRAD) was used including detailed labour input. RAS technologies were included in the survey and data entry in order to compare these technologies against other technologies already available. Here we showed only the data from Jambi (Joshi *et al.*, 2006). Level of maintenance referred to a combined serie of parameters depending on fertilizer application and frequency of slashing and weeding mainly during the establishment phase for the first 6 years. In some high
pest (deer, boar, and monkey) risk area labour for fencing could be significant, but for comparative purpose, this has been excluded as it was independent of technology. Much of the labor prior to planting goes into preparing land that includes cutting down trees, slashing ground vegetation, burning and fencing. Other regular management tasks included fertilizer application, weeding (manual and chemical), tapping latex as well as harvesting other products.

Low maintenance of RAS-1 required a low intensity of weeding, either manual or chemical weeding. Weeding was conducted only between rows. External labour was usually not hired (familial labor) but was required for land preparation. RAS-1, high maintenance required more weeding and slashing during the establishment phase (Figures 4 and 5); the use of chemicals was limited to first two years only. Minor weed slashing was carried out during tapping. In case of RAS-2 low maintenance, the use of external labour was rare as chemical fertilizers were used. RAS-2 high maintenance category involved very high weeding, including weeding in rubber rows and inter-row.

Figure 4. Manpower (hours) required in different rubber systems (Wibawa et al., 2006)
In the first ten years, RAS technologies shows much higher margin compared to traditional systems but lower than that of monoculture systems. RAS technologies require lower capital and inputs.

![Figure 5. Net margin/ha/year for different rubber systems (Wibawa et al, 2006)](image)

Conclusion from what has been observed in 1993 in Sanjan and SRAP RAS experimentation plots, it has been proven that clonal rubber could be associated to other trees, in complex agroforestry under specific conditions, with both rubber and associated trees production and no negative impact on rubber growth during immature period. Their rubber production data were comparable to those from intensive monocultures. RAS-1 technology required less labor and chemical input but allowed natural regrowth, including timber and fruit species and medical plants, between rubber rows. RAS-2 combined rubber trees with other high value timber and fruit species. RAS-3 was suitable for rehabilitation of Imperata grassland through mixture of rubber, non-rubber and cover crops. It advocated diversification of rubber agroforests as a better alternative to monocultures for rubber smallholder diversification of the economic basis of rubber agroforests, with value accruing from rubber wood and other timber and fruit trees providing an incentive for maintaining diversity while ensuring tangible benefits to the farmers.

An improvement strategy investigated through rubber agroforestry research under earlier efforts revealed the technical possibility for
establishing rubber plantation under less intensive management. Where the financial gains from latex were seen as the priority, the non-rubber benefits from other components of the systems cannot be ignored. Production of timber from rubber trees as well as other high value timber species will certainly increase in the coming years. High value fruits (both local and exotic) for local and export markets have huge potential to increase farmer income (as in southern Thailand for instance).

It is now clear that certain questions related to the double row spacing is partly answered, especially on the good spacing in certain RAS. In terms of rubber growth and possible longer exploitation of wider inter-rows for annual intercrops and tree crops, the 6mx2mx14m double row spacing as the case in Sri Lanka is very encouraging model, using the fast growing rubber clones such as RRIC 100, PB 260 and BPM1 as the main tree crop and tea. Meanwhile the same process of combining rubber and fruit/timber or other permanent crop happened in the 1990’s in Thailand

The Situation in Thailand

Thailand is the first world producer of natural rubber, ahead of Indonesia and other main producers (China, India, Vietnam). Smallholders mainly use rubber clones (mainly still RRIM 600) in monoculture which represented more than 96% of rubber plantations. The average yield of these rubber trees was 1360 kg/ha/year in 2000 and around 1700 kg/ha/year in 2016 (OAE\textsuperscript{7}, 2016). The environment, both institutional and ecological is very favorable to the development of agroforestry practices based not only on food inter-cropping during immature period but also to fruit/timber/rubber association in complex agroforestry systems. Though single clone policy is relatively risky in case of a major disease strike, the policy of using clonal rubber on a large scale has been successful.

The main trees that have been tried with rubber are the following:

- TIMBER TREES: neem tree or "thiem" or “Thiam” (*Azadirachta excelsa*), "Thang" (*Litsea grandis*), a timber tree that grows naturally from natural regeneration in rubber fields, teak (*Tectonia grandis*), mahogany (*Swietenia macrophylla*), "phayom": or white meranti

\textsuperscript{7} Office of Agricultural Economics website : http://www.oae.go.th
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(Shorea talura), "tumsao" (Fragacs fragans), Acacia mangium, rattan (Calamus caesius) seems to be the most promising),

- FRUIT TREES: mainly "Salak" (Sallaca spp), durian (Durio zibethinus), "longkong" (Lansium domesticum), "mangoustan" (Garcinia dulcis) and as well "petai" (Parkia speciosa or Nita tree), "jack fruit" (Artocarpus heterophyllus), "cempedak" (Artocarpus Integer), banana, coffee (Robusta c),

- Shrubs for leaves used as food; "pak liang" (Gnetum) and Manboo" (no available Latin names cited by Pramoth 1997, personal com.)

2005: a Situation with High Rubber Prices.

In 2005, particularly high price of rubber benefited producers after 6 years of very depleted rubber prices (1997/2004). A study was carried out to review the five main rubber-based production systems in Phatthalung and Songkhla provinces on 20 local farms. Farmers’ behaviour and strategies were closely linked and depended on their type of production system as well as access to diversification opportunities (fruits and in particular Durian). The smaller farms were growing either rubber in monoculture or rubber with some upland rice varieties. They were relatively efficient as far as intensification was concerned.

The results of this study indicated that it is advisable to diversify and to cultivate another crop in addition to rubber to survive in times of crisis. The larger the share of income from the other crop, the better it would help the farmer withstand a decline in the price of rubber. Durian played an important role in the study area as a way to diversify farm income. To grow durian at the same time as rubber enabled the farmer to minimize the impact of a decrease in income if rubber prices decrease. Durian and rubber were complementary crops, and the market for durian is currently very good and long-term prospects are very promising.

However, both systems have some drawbacks. They are intensive, very demanding in both labor and inputs, and farmers require a good knowledge of the necessary technical itineraries. Diversification, intercropping and tree-rubber association (timber of fruits) for income diversification and risk management strategy, however more intensive, seem to be a good alternative to the current trend of rubber monoculture. Some farmers cultivated fruit trees as an intercrop, or in agroforestry systems that appeared to be promising to overcome rubber price volatility.
when fruits market was well developed in Thailand, sustained by an important urban demand (in particular Duku/Langsat in the study area). Some trials were carried out but few results have been obtained so far, and a complete analysis (including a long-term economic analysis) has not yet been undertaken. More research is needed on large-inter-row intercropping and double tree line systems in southern Thailand (double spacing with large inter-rows). Durian clearly plays the role of economic buffer in the eventuality of a new drop in rubber prices. In other words, after having specialized in rubber production, southern Thailand may probably have to diversify in order to strengthen its economy.

![Economical results of the rubber monoculture farming system](image1)

**Figure 6.** Economical results for rubber monoculture (Simien, Penot, 2011)

![Economical results of rubber-durian based farming system](image2)

**Figure 7.** Economical results for rubber durian cropping system (Simien, Penot, 2011)

**2015 a Situation with Low Rubber Prices After the 2010 Boom**

Another study was conducted in the frame of the ANR/Heve adapt
History of rubber agroforestry systems development in Indonesia and Thailand as a project in collaboration with TSU (Taksin University), in southern Thailand in Phatthalung province, to analyse how smallholders’ tree plantations could adapt and remain sustainable while facing deep changes in their socio-economic context. The study focused on rubber-based agroforestry systems developed in mature plantations in order to understand the extent to which rubber, associated crops, trees, livestock, and off-farm activities, respectively contributed to income stability and farm resilience. The characterization of farm economic structure showed that two main strategies were used by farmers to sustain their income while facing rubber price volatility from US$5 in 2010 to US$ 1 in 2015: agroforestry through income diversification and development of off farm activities.

The best agro-forestry system, both in terms of land valorization and labor valorization, found to be associating rubber trees with some selected fruit trees (Salak, Mangosteen and Longkong), leaf/shrub such as Gnetum and timber trees (Mahogany, Neem-trees and Teak). Prospective modeling showed that most farms were more robust to rubber price volatility (see rubber price evolution in figure 8), due to the flexibility of their agro-forestry systems. Farmers, who did not have agro-forestry systems, were weakened by over-reliance on rubber trees. These conclusions only relate to a targeted sample of 32 farms having mature rubber-based AFS.

In the beginning, AFS were not market-oriented, but were originally developed to fulfill fruit food and social needs, which are very important in farmers’ societies in southern Thailand. This choice of agro-forestry was also strongly influenced by the “New Theory of Agriculture”, promoted by His Majesty the King, who is highly listened to and respected by the people. However, the increasing volatility of natural

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Figure 8. Evolution of natural rubber prices (SMR20, Kuala Lumpur)
rubber quickly made farmers aware of the economic interest of these systems. Some even specialized in fruit production, while keeping a few rubber plots. The advantage of on-farm income diversification was confirmed by the sensitivity study on the threshold rubber price required to reach the same income without agro-forestry practices. When rubber prices were low, the agro-forestry (with fruits and/or vegetables) showed a capacity to sustain on-farm income. Farms became more resilient to face rubber price fluctuations. But they were also subjected to the volatility of other prices (mostly fruits and vegetables). Planting many different species limited impact of price fluctuations on the farm. Thus, these examples of RAS farmers and existing local AFS groups could be the basis to build a network on AFS, in the frame of future local “innovation platform”.

With 32 surveyed farmers, we obtained an inventory of 53 agro-forestry plots, of which 64% associated with less than 4 different species and 36 per cent 4 and more different species (Laetitia Stroesser et al, 2015). Those AFS could be classified according to the type of species associated to rubber trees into 5 types (Figure 9):

- Type MatAFVeg: mature rubber trees only associated with vegetable species (Gnetum mainly; pak liang and pak miang),
- Type MatAFFr: mature rubber trees associated with fruit (mainly mangosteen, Longkon and salak) and sometimes vegetable species,
- Type MatAFTb: mature rubber trees only associated with timber species (teak, Neem-tree, Mahogany, Iron wood, tung…)
- Type MatAFMx: mature rubber trees associated with fruit, vegetable and/or timber species,
- Type MatAFLv: mature rubber trees associated with livestock and other plant species.
AFS types MatAFlvA and MatAFlvB had highest GM/ha among the considered systems, because associating goats to rubber trees resulted in removing two significant cost items: rubber trees fertilization and goats food. The type MatAFLvA made a higher GM/ha, due to its fruit sales. For the type MatAFLvB, wood from timber trees represented a long-term investment, which would be paid back when rubber trees were cut. The type MatAFVg was in second position, because of the high GM generated by *Gnetum*. This shrub required little care, and grew by itself well under the shade of rubber trees. Moreover, it currently took advantage of high prices, due to strong demand. MatAFFr showed a GM/ha slightly lower: farmers used more inputs for this system, but did not harvest certain fruit trees (as too tiresome, time consuming, and low prices). The low performance of type MatAFMx was due to lesser number of productive fruit trees. However, the timber trees would give an appreciable income in the long term. Compared to rubber monoculture slightly lower rubber yield per tree was obtained, because the trees in this type were in the end of the increasing yield phase at younger age (14 years) as against 18 years for rubber in monoculture. In type MatAFTb, none of the surveyed farmers were cutting and selling wood on a regular basis. The current GM/ha was the same as monoculture. The production per tree was low, which could be explained by the tree age (15 years on an average for this type).

Figure 10 shows a comparison of family labor valorization, i.e. the gross margin per hour of family labor (GM/h farm), for every type of AFS and for a mature rubber monoculture. It is worth noticing that only
family labor was considered, because paid labor was already counted in the GM. It is mainly in the form of sharecropping, to tap rubber trees and to harvest fruit trees and farm worker receives 40 to 50% of the production as payment for his labor. Therefore, the results presented below does not prove better valorization of family labor with one system or another, because it also depends on family involvement in the management of cropping systems. The AFS types with the best land valorization have the worst family return to labor (MatAFLvA, MatAFLvB and MatAFVg). Taking care of the herd and harvesting *Gnetum* were very time-consuming activities. These are the only activities requiring an almost daily work all year long and family members usually take care of it. Fruit harvest only occurs 2 months per year on average, which explains the better results for AFS types MatAFMx and MatAFFr.

We can identify two categories within the type MatAFMx, according to fruit yield and the use (or not) of a tapper. In general, farmers with AFS type MatAFMxA have better fruit yields and hire tappers. The type MatAFTb provides a GM/h fam close to that of rubber monoculture. The variability of the latter can be explained by differences in practices (weeding and fertilization frequency) and variable tappers’ skills.

![Figure 10. Family return to labor for the AFS types and for a rubber monoculture (GM/h farm) (Stroesser et al, 2016)](image)

The farm gate price of fruits and vegetables was also volatile. It was almost double in one year and then dropped 30% in the next (figure 11). There was also strong variability within a year, which depended mainly on climatic conditions. As fruits mature from the North to the South, prices dropped and increased again, following the law of supply and demand (Stroesser, 2015).
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![Price evolution of the main fruits and vegetables](image.png)

Figure 11. Price evolution of the main fruits and vegetables (from OAE, 2014 and Jongrungrot, personal communication, 2015)

**CONCLUSION**

Rubber farmers have developed a series of innovations in order to adapt rubber into their extensive agroforestry practices (jungle rubber) and later in the “estate” monoculture model (SRDP development scheme), through associating rubber with perennial or annual crops. However they have reached a stage where innovations are limited and productivity increase cannot be reached without including rubber clones and some other external innovations that require a different management. After an intermediate stage between shifting cultivation and improved fallow, and then from improved fallow to a complex agroforestry system, they now face the challenge to improve the productivity of AF system. "Complex agroforestry systems can no longer compete with other agricultural systems which may be more risky but are more profitable in the short term" (Levang, 1996). Improved rubber based agroforestry systems can meet the challenge with reduced risks and environmental benefits.

Agroforestry practices are also considered as labour saving agricultural practices and, in some cases, as, for instance, the best anti *Imperata cylindrica* strategy. In an environment of decreasing land availability for local agricultural expansion, improved RAS also reduce the amount of land required per family, by supplying a variety of marketable as well as subsistence crops within a single system. RAS offer income diversification and household needs which otherwise would have to be sought elsewhere, thereby contributing to local economic sustainability.
Another important role is the generation of a “forest rent” as defined by Ruf (1987), i.e., the reduction of costs and risks of perennial plantation establishment – thanks to the forest’s positive externalities such as on soil quality, weed and pest control. This concept has been extended to agroforests by Penot (2001), who showed that agroforests did maintain (sometimes improve) the forest rent while conventional monoculture plantation crops (such as cocoa: *Theobroma cacao*, coffee: *Coffea* spp., and oil palm: *Elaeis guineensis*), generally consumed (part of) it.

Agroforests have some constraints too, however. Since crop mixtures are the rule, some crops are favored while others are not and agroforests may provide small quantities of a given crop that are not always saleable, except locally. For instance, rice, corn and cassava will be preferred when the canopy is not developed in the first 2 years for instance. When canopy is developing an increasing level of shade, banana, pineapple would be favored. Rattan is favored at the end of rubber lifespan rather than during full peak production as harvest destroy canopies. When shade provided by rubber is too high for intercropping cocoa and coffee with severe impact on yields, it remains possible with coconut in particular in ageing coconut plantations.

High reliance on hand labor and limited markets for specific products are other significant features in this respect. Delayed production (from large-sized trees) also delays return on investment. Most farmers use non-improved plants and the quality can be variable, a potential problem for export of fruits, although there can also be a niche market for “organically grown” local varieties. However, some agroforests (e.g., rubber agroforestry systems) also rely on fertilizers and improved planting materials (rubber clones and grafted fruit trees).

The sustainability advantages of agroforests come from a trade-off between ecological and socioeconomic attributes. Conventional economic approaches may be inadequate for integrating these two sets of attributes in a comprehensive manner because (1) farmers manage agroforests with a variety of objectives in mind, (2) ecological benefits are not internalized in existing analyses, and (3) some ecological attributes have no present market value. The analysis will exclude a series of agroforests’ outputs, which are not traded in the market or insufficiently taken into account in farm economics. Indonesia’s jungle rubber provides an example. While it has been a major opportunity for poor farmers at the agricultural frontier for years, it is now becoming obsolete compared to clonal rubber monoculture, in terms of yields and labor productivity (Penot 2001).
However, it is difficult to measure or assign economic values to intangible services and positive externalities. For instance, C sinks values of tree crops and forests are currently available but no one can choose among various prices suggested by various experts as long as the market is not open for them. Risk-buffering potential of agroforests, as in situations of climatic variations and commodity price volatility, also deserves to be measured. The overall key question behind this is: how to make a measurement of the agricultural sustainability of agroforests? Perhaps farm-system models used in farming system research could be a useful tool for such comparative measurements.

**From Farming System Level Approach to Innovation Platform**

A multi-criteria analysis at both farm and community level is far more powerful than simple conventional cost-benefit analysis at cropping system level. Again, linking crucial social aspects (and their consequences in term of use of production factors) with the economic analysis may provide a reliable framework than can take into account all cultural and non-merchantable aspects. Unfortunately, since methods for valuation of non-tangible social and cultural benefits of agroforestry are practically nonexistent (Kumar and Nair, 2004), it is difficult to substantiate the above on published results. Rather, it is a plea for research on these issues which has to be made.

The flexibility in crop and tree production in agroforests relates to the different phases with mature and immature periods of trees or crops. Therefore, it is essential to take into account the life cycle of plants to implement an economic analysis in the long run. Specific discounting rates may be necessary as cycles may extend up to 40 or 50 years. Different scenarios are necessary, as this may introduce bias in valuing products according to the discounting rates chosen. For instance, in tree crop-based agroforests, rubber or resin is produced for more than 30 years when annual and bi-annual crops are generally produced only in the first 3 to 6 years. Timber can be harvested only at the end of the agroforest’s life-span. Therefore, if detailed data are available to obtain a reliable assessment of real income (including self-consumption), system comparison will be more valuable than absolute data (Penot 2001).

If agroforests’ benefits can be analyzed through market values of their products and services, then neo-classical environmental economics can be used and externalities can be included (or re-internalized) into the process of income generation. Growth or pollution cost and delay may be
taken into account as negative externalities or constraints to further development. Environmental services (for example, carbon sequestration potential: Albrecht and Kandji, 2003; Montagnini and Nair, 2004) can be valued according to a “system of values” recognized locally as relevant at a higher, community or provincial level. The real problem is, therefore, to see whether farmers can potentially or do really take benefit of externalities and positive advantages of agroforestry.

Be it for commercially oriented agroforests or subsistence oriented homegardens, a long-term perspective must be part of farmers’ strategy. However, there is obviously a biased debate between short-term (economics) vs. long-term (ecology). In both cases, farmers have developed long-term farming practices through a long haul innovation process that eventually takes into account economics through the risk buffering capacity of agroforests. In most cases, social organization is deeply linked with technical constraints in production, food reliance, income securing and, eventually, land control.

There is a strong coherence between technical systems (technical pathways) and social systems (Penot 2003). Economic analysis methods using farming system modelling which integrate the outputs of mixtures of plants with different cycles and allow for the smoothening of long-term and patrimonial strategies are required to explain with accuracy what farmers do and why they do so. Agroforests, despite their positive externalities and advantages are not a “panacea” but seem to be an ideal compromise between sustainability and risk spreading.

With thousands of current rubber agroforestry farmers since at least 30 years, there is existing and robust knowledge and know-how on agroforestry practices that could be used trough local innovation platforms (Tenyia and all, 2011, Titonell and al, 2012)) were knowledge could be easily transferred with existing plantation used as real demo-plots. There is a real important scope to move progressively to agroforestry systems for farmers very susceptible to rubber price volatility for a better global resilience. If agroforestry system is not “the” solution for all, it is obviously a very interesting alternative for some of them. Promoting RAS based on existing situation could easily accelerate transfer of technology. Thailand and Indonesia seems to be ready for such policy.
REFERENCES


