FROM JUNGLE RUBBER TO RUBBER AGROFORESTRY SYSTEMS

History of Rubber Agroforestry Practices in the World

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Chapter 2

Rationale for RAS and impact of agroforestry systems

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As the result of a joint analysis performed by ICRAF, Cirad and GAPKINDO, the three institutes pooled resources in a development-oriented research project (SRAP[38]) which began in April 1994. The goal of the project was to improve rubber agroforestry productivity by optimising labour and by reducing the use of inputs and costs, while conserving the benefits of agroforestry practices and not shifting too far from current practices in order to increase the farmers' rate of adoption of technical innovations. Even though agroforestry systems are very similar to what the farmers were practicing at the time, in our opinion it is important to base innovations and technologies on analyses of the constraints to and opportunities offered by existing farming systems, to be sure farmers' strategies and trends are taken into account, and to incorporate them in an operational classification of farming systems. In this case, irrespective of the innovation concerned, the viewpoint of a farming system is relevant, as it helps ensure that both apparent and hidden farming constraints are incorporated in strategies that result in the adoption of innovations. In 1994, the main innovation was implementing Rubber Agroforestry Systems (RAS) as clonal rubber-based agroforestry alternatives to both the jungle rubber system (low productivity but low cost) and the estate system (high productivity but high cost).

⏩ The need for improved rubber agroforestry systems (RAS)

The objective of this new approach in 1994 was to demonstrate the advantage of conducting trials in real farming conditions using a participatory approach, to show that rubber agroforestry systems (RAS) are an improvement over traditional jungle rubber practices or standard rubber-based monoculture development schemes

38. SRAP: Smallholder Rubber Agroforestry Project, a research project based on farm experimentation using a participatory approach with Cirad, ICRAF (International Centre for Research in Agroforestry) and GAPKINDO (the rubber association of Indonesia).

based on estate technology. The main challenge for research was to test improved clonal planting materials to identify the optimum level of inputs and labour under which the planting materials grow and produce best in these agroforestry systems, and which were most appropriate – and affordable – for smallholders (Penot, 1996a). In other words, it meant trying to optimise the natural trend of endogenous farmers' experimentation with RAS *sendiri* (the farmers' own RAS experiment or "of his own").

An on-farm experimentation network was set up with 120 farmers in three selected provinces: Jambi and West Sumatra in Sumatra and West Kalimantan in Borneo (Table 1.1). All the innovations tested were first discussed with the farmers to improve their adoptability and to match RAS technologies with farmers' resources and requirements. Experimentation was based the maximum possible reduction in inputs and labour while conserving agroforestry practices and their advantages, i.e., income diversification, obtaining an income during the rubber immature stage through intercropping, conservation of a certain level of biodiversity and the use of an environmentally friendly approach. SRAP was based on a participatory approach to on-farm experimentation with three main kinds of RAS. The suitability of each system was tested in local agro-ecological conditions to identify associated labour requirements and costs, and the optimum level of intensification.

Three different RAS types were tested: (i) RAS 1, which involved planting clonal rubber with forest regrowth in the interline (the most extensive system), (ii) RAS 2 in which clonal rubber was associated with fruit and timber trees and intercropping during the immature period (the most intensive system), and (iii) RAS 3, which was the same as RAS 2 but with the addition of fast growing shade trees and of a cover crop (mainly *Flemingia congesta*) to get rid of alang-alang (*Imperata cylindrica*) in invaded plots (Penot, 2001). The main aim was to determine whether the different combinations of trees and crops associated with clonal rubber had a long-term impact on income diversification and on the adoption of agroforestry practices.

In SRDP[39] plots in the village of Sanjan (Penot 1997) where, before 1994, local farmers were already implementing what ultimately became the RAS 2 type of agroforestry, 25% of the SRDP (Smallholder Rubber Development Project) farmers in the village successfully implemented agroforestry associated with fruit production and very limited timber production (Shueller, 1997) and according to Chambon (2001), 46% of SRDP farmers did develop agroforestry in one form or another. The SRDP RAS plots in Sanjan showed that agroforestry practices were possible with no significant decrease in rubber production (the main economic output). The idea, through SRAP, was to test several combinations of trees to provide a wide range of technical solutions adapted to a variety of local situations.

The main problems were the following: (i) making sure that agroforestry really had no negative impact on rubber production and in which conditions, but also no effect on rubber growth during the immature period, to enable the rubber trees to be tapped as soon as possible after planting (generally between 5 to 7 years), and (ii) to identify the best combinations of trees and other plants to achieve the desired results in terms of competition with *Imperata cylindrica*, among others.

39. SRDP: Smallholder Rubber Development Project, developped by the World Bank.

Each trial was replicated in 2 or 3 villages with 7 to 10 replications/farms in each trial using the same planting density, association of trees and practices on the same type of soil and in the same climatic conditions (Tables 2.1 and 2.2). Each trial comprised 6 to 8 sub-plots in which a different treatment was applied (type of clone, type of fast-growing associated trees, type of intercrop, type of cover crop, etc.). All the trials were managed by the farmers using the same agronomic practices, which were defined before planting (Boutin et al., 2001). In all, 60 trial plots/farmers were involved in West Kalimantan, in 2 main zones: (i) on Dayak smallholdings (mainly following the jungle rubber system) in local traditional zones, and (ii) on Malayu

Table 2.1. Characteristics of benchmark sites in West Kalimantan in 1997

Factors	Forest margins with poor soils: traditional jungle rubber	Forest margins with poor soils: jungle rubber + SRDP	West Kalimantan transmigration areas.
Villages	Kopar, Engkayu	Embaong, Sanjan	a) Pariban Baru (Sintang) b) Trimulia c) Sukamulia
Type of farm population	Dayak (Christians)	Dayak (Christians)	a) Dayak (Christians) b) Javanese transmigrant (Muslims)
Population density	Low with plenty of land	Medium: land was becoming scarce	High with limited land (2.5 ha/household)
Ecological environment	Secondary forest, jungle rubber and *tembawang**, poor soils	Secondary forest, jungle rubber and *tembawang*, poor soils	Degraded *Imperata* land, poor soils risk of fire
Farmers' behaviour and strategies	Extensive systems, slash and burn (S&B) for local upland rice only grown for wine rice. Accept a low level of intensification.	Extensive and intensive systems (rubber monoculture), S&B for local upland rice Accept a medium level of intensification.	Intensive on *sawah/ irrigated rice*; extensive on rubber on uplands.
Main constraints	Low productivity of jungle rubber	Low productivity of jungle rubber. Wrong choice of rubber clone in SRDP: leaf disease, limited production.	Very degraded land with *Imperata* on a very limited cropping area (2 ha). Risk of fire. Remoteness.
Opportunities	Land is plentiful. Oil palm and wood pulp. Existing old complex agroforestry practices.	Presence of SRDP/ TCSDP project: rubber monoculture in the 1980s. Oil palm and pulp. Existing old complex agroforestry practices.	*Sawah* off-farm activities.
Type of on-farm trial	RAS I and 2	RAS I and 2	RAS 2 and RAS 3

**Tembawang* are indigenous fruit and timber-based complex agroforestry systems where the main tree species is usually the illipe nut tree.

farms in transmigration[40] areas (where some *Imperata cylindrica* was present) through dedicated programmes or the relocation of people from Java.

The first type (RAS 1)[41] resembles the jungle rubber system, but unselected rubber seedlings are replaced by clones selected for their potential adaptation capacity. These clones must be able to compete with the natural secondary forest growth. Different planting densities (550 and 750 trees/ha) and weeding protocols were tested to identify the minimum management needed for the system to succeed. This is always a key factor for farmers whose main concern is to maintain or increase labour productivity. Biodiversity is presumed to be very similar to that of jungle rubber, which is quite high and resembles that of secondary forest at the same age. This system is probably the closest to the concept of fallow enrichment and suits a vast number of farmers because of its simplicity.

The second type, RAS 2, is a complex agroforestry system in which rubber trees (550/ha) and perennial timber and fruit trees (92 to 270/ha) are planted after slash and burn. It is very intensive, with annual crops intercropped in the first 3 or 4 years, with emphasis on improved upland rice, using different rates of fertilisation as well as dry season cropping with groundnuts, for instance. Several different combinations of crops were tested including food crops and cash-crops such as cinnamon. Several planting densities of selected species were tested according to a pre-established tree typology, in particular with the following species: rambutan, durian, petai and tengkawang. Biodiversity is limited to the planted species (between 5 and 10) and those that regenerate naturally and are consequently preferred by farmers.

The third type, RAS 3, is also a complex agroforestry system with rubber and other trees planted in the same way as in RAS 2, except that this system is used on degraded lands invaded by *Imperata cylindrica,* or in areas where *Imperata* is a major threat. The main constraints are labour or cash to pay for herbicides to control *Imperata*. In RAS 3, annual crops, generally rice, are only grown in the first year, with non-vine cover crops planted immediately after the rice harvest (*Mucuna* spp., *Flemingia congesta*, *Crotalaria* spp., *Setaria* and *Chromolaena odorata*), multi-purpose trees (wingbean, *Gliricidia sepium*), or fast-growing trees for use as pulpwood (*Paraserianthes falcataria, Acacia mangium* and *Gmelina arborea*) can be planted (several combinations were tested). The objective was to eliminate the need for weeding by providing a favourable environment for the rubber and associated trees to grow, while preventing the growth of *Imperata* with limited labour. The aim of associating non-vine cover crops and MPT[42]'s for shade was controlling *Imperata*. Biodiversity was expected to be similar to that of RAS 2.

These RAS types were tested from 1994 to 2007 and surveyed again in 2019 and 2021. The clones tested were PB 260, BPM 1, RRIC 100, and RRIM 600, compared to rubber trees grown from seedlings.

40. Transmigration was a Indonesian government programme to resettle people from Java in less populated areas of Indonesia (known as the "periphery"), mainly Kalimantan, Sumatra, Sulawesi, Maluku and West Papua (Irian Jaya).
41. The description of RAS types has been published in Didier Babin (ed), 2004. *Beyond tropical deforestation. From tropical deforestation to forest cover dynamics and forest development*, UNESCO/Cirad, 488 p.
42. MPT: multi-purpose tree.

Table 2.2. Specific constraints to the adoption of RAS in 1996

Topic	West Kalimantan	Jambi	West Sumatra
Previous and/or current projects Access to information	SRDP/TCSDP	ASB (Alternatives to Slah and Burn Project)	Pro-RLK (Project for land Rehabilitation for rubber)
Indigenous knowledge and agroforestry practices	+++	+++	+/-
Clone availability	+	+/-	-
Availability of Bah Lias Isolated Garden (BLIG) seedlings	-	-	+++
Fertiliser use	+	-	-
Availability of high yielding varieties (HYV) of upland rice	-	---	--
Seed quality	-	-	-
Availability of cover crop seeds	-	-	-
Pests and diseases	-	-- Monkeys, pigs	- Pigs
Weeds	*Imperata*	*Mikaenia*	*Imperata*
Rubber diseases	*Colletotrichum*		possibly *Colletotrichum*
Land constraints	Very low fertility, land scarcity in transmigration areas	Steep slopes in pioneer zones	Very low fertility and steep slopes, altitude: 550 m - close to upper limit for rubber
Upland rice production	Average potential with selected local rice varieties	May succeed in peneplains	Excellent weed control, requires soil and water conservation techniques
Potential for the adoption of RAS			
RAS 1	+++	+++	0
RAS 2.2/rice	++	+	+++
RAS 2.5/cinnamon	0	+++	++
RAS 3	+++	0	+

Main results of RAS

RAS in Indonesia

The performance of clones in RAS 1 environments was encouraging 6 years after planting. Compared to plants originating from seedlings, clones perform better in terms of growth from establishment on. Among the clones tested, BPM 1 grew best up to 40 months, followed by other clones, while trees grown from seedlings grew the most slowly. After 40 months, due to white root disease, the growth of the two clones BPM 1 and RRIM 600 was reduced whereas the growth of the other two clones, RRIC 100 and PB 260, was very good and the trees were ready to be tapped at 5 years of age. However, trees grown from seedlings can also be tapped about 5.5 years after planting. In this trial, the frequency of weeding in the rubber rows was 3-4 times per year.

Farmers know that rubber growth will be affected by competition with other vegetation. In West Kalimantan, farmers did not fully respect the trial protocol, rather, to adapt to local conditions, they slashed the vegetation in intra-rows once a year from the second year on and kept only a few tree species, mostly those of monetary value. This resulted in slightly slower rubber growth than in Jambi. No significant difference in rubber growth was observed due to the level of weeding. The effects of perennial intercrops on rubber growth varied from year to year, but, except for the treatment involving durian, no significant difference due to intercrops was observed at 54 months. The difference in rubber performance was more due to the site and/or to the practices used by the farmers who took part in the trial than to the different intercrops used.

Due to shading by rubber trees, fruit trees cannot produce fruit of the same quality as the fruit of trees planted in open areas. The RAS 2 trials in West Kalimantan were not as intensive as we expected. Annual intercrops (mainly upland rice) were only planted in the first two years. It is also clear that if the rubber tree spacing is 6 m × 3 m, planting perennial plants under rubber is not optimal in terms of fruit production. Under RAS 3, creeping legumes were clearly the top performers in controlling *Imperata*. *Pueraria* was slightly but statistically significantly better than *Mucuna* for rubber growth. Both *Pueraria* and *Mucuna* grew well and managed to prevent regrowth of *Imperata.* However, the creeping legumes had to be regularly removed from the rubber rows as they entangled the rubber trees. Among the erect legumes, *Flemingia* was good for rubber; *Crotalaria* was disappointing. Rubber trees with no cover crops but with *Imperata* or *Chromolaena* had not yet reached tapping size by the end of the trial. This finding is consistent with the results of earlier work done in Sembawa research station where it took more than 10 years for rubber trees to reach tapping size in the absence of proper control of *Imperata* (Mulyoutani et al., 2006).

Farmers very often do not follow all the protocols designed by and proposed to them by researchers. This kind of problem was encountered both in Jambi and in West Kalimantan. Again, establishing a close relationship with farmers and trying to understand why they do not follow a protocol is one of the objectives of participatory on-farm trials. In addition, intensive discussion is important so as to choose the technical options that best match the farmers' needs. Our results showed that the trade-off between inputs (fertilisers, labour, chemicals) and growth or plant diversity interests most farmers. Due to the many constraints that farmers face, especially lack of cash for most Indonesian farmers, they have to choose between spending money and allocating family labour. Maximum rubber growth is not always the objective farmers have in mind when choosing between different forms of RAS. The main challenge for researchers is consequently offering farmers technologies that account for their real constraints and opportunities.

RAS 1

Effects of different levels of weeding on rubber growth under RAS 1

In West Kalimantan, farmers did not fully respect the weeding protocol (Table 2.3). The level of weeding used by farmers was slightly below that specified in the trial protocol. It was thus logical that there was no significant difference in rubber growth between plots classified as "medium", "intensive" or "intensive with legumes cover crops (LCC)" plots because the weeding frequency was the same in all of them from the 1st to the 5th year. Nevertheless, rubber growth in this group of treatments was better than that in plots with "low weeding frequency" (Figure 2.1).

Table 2.3. Frequency of weeding within the row of rubber trees specified in the protocol and the frequency actually implemented by farmers in RAS 1 trials in West Kalimantan

Treatment	Expected frequency per year	Actually, implemented by farmers				
		1st year	2nd year	3rd year	4th year	5th year
Low	4 then 2	2	1	0	0	1
Medium	6 then 4	2	2	1	1	1
Intensive	8 then 6	2	2	2	1	1
Intensive+LCC	8 then 6	2	2	2	1	1

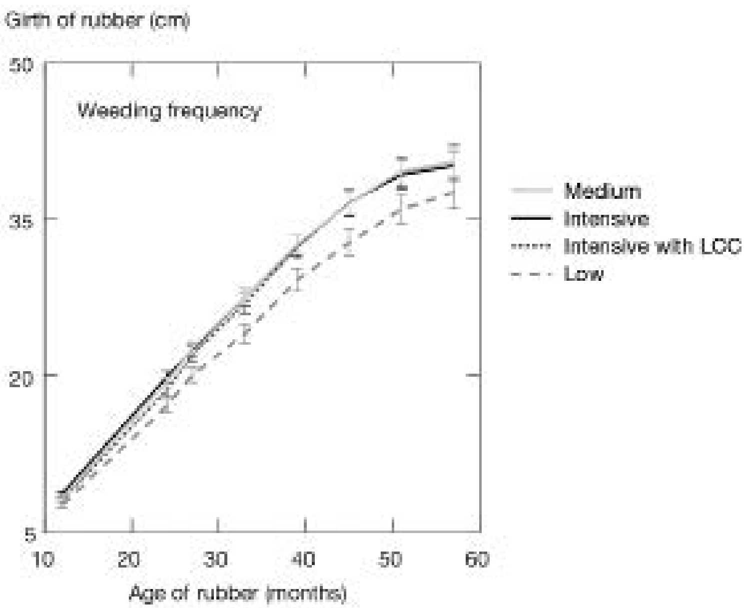

Figure 2.1. Effects of weeding frequency within rubber rows on the girth of rubber trees in West Kalimantan (RAS 1)

LCC: legumes cover crops.

Variation in growth was based more on the location of the plot (farmers) than on weeding frequency (Figure 2.2). The slowest relatively good rubber growth was observed in plots in Loheng and Sidon. In Loheng, particularly after the third year, the rubber rows were not cleared and were consequently infested by *Melasthoma, Chromolaena, and Mikania,* all noxious weeds for rubber. Between the rows, the vegetation was dominated by the same weeds and by a variety of trees that reached more than two metres in height. Many plants died in the second year due to white root disease and continued to die in the third year. The height of the different types of vegetation in the inter-rows can reduce rubber girth, as shown in Figure 2.2. The other four farmers in Sidon controlled weeds (which did not include noxious species and were dominated by grasses) in the rubber rows up to year 3 and the height of the vegetation in the inter-row was less than two metres.

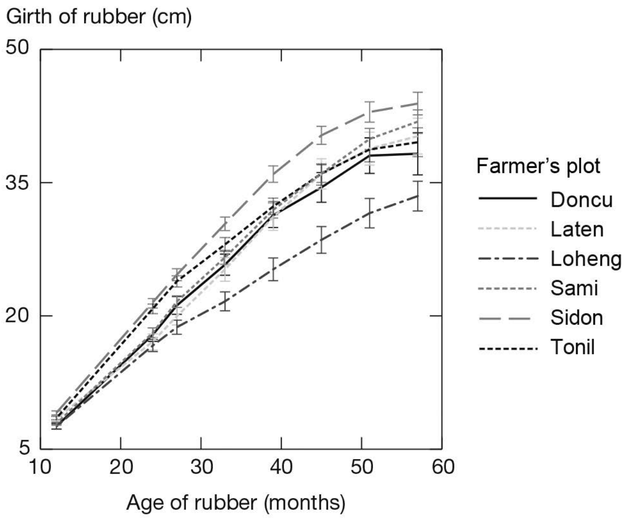

Figure 2.2. Variation in rubber growth in plots belonging to different farmers in West Kalimantan (RAS 1)

Performance of different rubber clones in RAS 1 environments

There is widespread belief among farmers in Sumatra and Kalimantan that, compared to rubber trees originating from seedlings, rubber clones cannot perform well in agroforest environments. A series of trials were carried out in Jambi and West Kalimantan starting in 1996 to test the performance of different rubber clones in agroforest environments (RAS 1 series). Clones PB 260, BPM 1, RRIC 100, and RRIM 600 were compared with rubber trees originating from seedlings. According to the RAS 1 principle, the land was previously jungle rubber or secondary forest, prepared using slash and burn. In the 1st year, a variety of food crops were planted as intercrops. In the rows of rubber trees, weeding was only carried out up to a distance of 1 m on each side of the rubber row, 3-6 times in the first year (considered as low and medium levels of weeding) and 3-4 times in the second year; and only once in the third year. Vegetation growing between the rubber rows was expected to be left in place by the farmer to conserve a certain level of biodiversity.

Results of the trials in Jambi suggested that weeding frequency has a positive influence on rubber growth starting in the early stage of establishment. The trials clearly showed that by limiting weeding to the rubber rows (at a frequency of every two months in the first two years; every six months in the 3rd year, and only one weeding in the 4th year), and letting the vegetation between the rubber rows (in this case *Micania*, *Melasthoma, Chromolaena*) grow to a height of 1.5 m, rubber reached tappable size 5 years after planting. However, when the frequency of weeding was reduced to 3 times a year or once every 4 months, then rubber only reached tappable size between 5 and 7 years after planting.

As mentioned previously, farmers know that rubber tree growth is reduced by competition with other vegetation. Like in RAS 1, the farmers did not fully apply the trial protocol in West Kalimantan. The weeding frequencies they used are listed in Table 2.2. The trial protocol clearly stated that farmers should let vegetation grow in the intra-rows and respect certain weeding frequencies on the rubber line. Most slashed the vegetation in the intra-rows once a year, starting in the second year. Only a few tree species were kept in the plots, especially plants that had monetary value at the time. This resulted in a slightly slower rubber growth than in Jambi.

The performance of clones in RAS 1 environments compared to the performance of trees originating from seedlings was encouraging, clones performed better in terms of growth immediately after establishment (Figure 2.3). Up to 40 months, clone BPM 1 showed the best growth rate. The rubber rows in the plots in this trial were weeded between 3 and 4 times a year, again confirming that rubber seedlings grow more slowly than clones. Using this plot as a demonstration plot for farmers was very effective as the performance of the rubber clones was significantly better than that of seedling rubber. In Jambi, except in the plot affected by white root disease, there was no significant difference in rubber growth linked to farmers' performance.

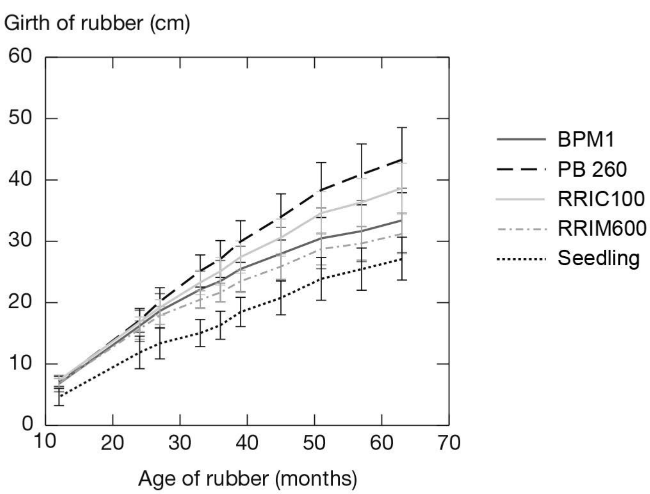

Figure 2.3. Growth performance of different clones in the RAS 1 environment in West Kalimantan

Fertilisation requirements in RAS

In Indonesia, most farmers use no fertilisers in their rubber plantation, or if they do, they apply less than half the recommended doses. Trials to study the effects of fertilisation on rubber growth in monoculture rubber plantations are very well documented in all rubber producing countries worldwide, but many questions concerning the application of fertilisers in RAS remain unanswered. A study was thus undertaken to compare the effects of additional doses of urea, SP36, KCl (see Table 2.1) with the effects of the application of basal fertiliser (200 g urea, 160 g SP36, 100 g KCl per tree in the first year; 100 g urea, 80 g SP36, and 50 g KCl in the second year), on rubber growth. The fertiliser was applied four times a year. The doses tested are listed in Table 2.4.

Table 2.4. Doses of fertilisers (g/tree/year) applied in different treatments based on RAS 1 and RAS 3 in West Kalimantan

Type of RAS	Treatment	First year (g/tree/year)			Second year (g/tree/year)		
		Urea	SP36	KCl	Urea	SP36	KCl
RAS 1	Year 1	300	160	100	100	80	50
	Year 2 to 5	200	160	100	100	80	50
RAS 3	Year 1	300	160	100	100	80	50
	Year 2 to 5	200	160	100	100	80	50

In RAS 1, rubber responded positively to additional urea in the first months after establishment. The additional urea, i.e., increased from 50 g/tree/application to 75 g/tree/application, was needed to increase rubber growth by about 7% in the 30 months after planting. Even the statistical test showed no significant difference in girth resulting from the treatments, but the growth of rubber with additional urea was consistently better than without (see Figure 2.6). These results indicate that additional urea (nitrogen) is needed as additional fertiliser (rather than P and K) to increase rubber growth. Indeed, this result has been put into practice by farmers who have to choose between fertilisers. They choose urea before other fertilisers. In this way, farmers who practice annual intercropping provide additional benefits to their rubber especially when they cultivate horticulture species that require intensive fertilisation (including organic fertilisers). Combining perennials and intensive horticulture species as intercrops creates a positive relationship between rubber and intercrops (Wibawa et al., 2006).

RAS 2

The growth of rubber under different treatments that associate perennial intercrops in RAS 2 conditions showed that variation within a farm was higher than variation within treatments (see Figure 2.7), especially after the second year. The effects of growing perennial intercrops on rubber growth varied from year to year, and except with durian, no significant difference due to intercrops, was observed at 54 months. Differences in rubber performance were more due to the site or to the practices used by the farmers who took part in the trial than to different intercrops (Figure 2.4). Due to shading, fruit trees do not produce as much fruit as fruit trees planted in full sun. The RAS 2 trials held in West Kalimantan were not as intensive as expected. The annual intercrops (mainly upland rice) were only planted in the first two years. With normal spacing of the rubber trees (6 m × 3 m), fruit trees will produce less due to more intensive shading. If farmers want to plant trees, double-row spacing is a better option, in which case rubber will reach tappable size 6 -7 years after planting.

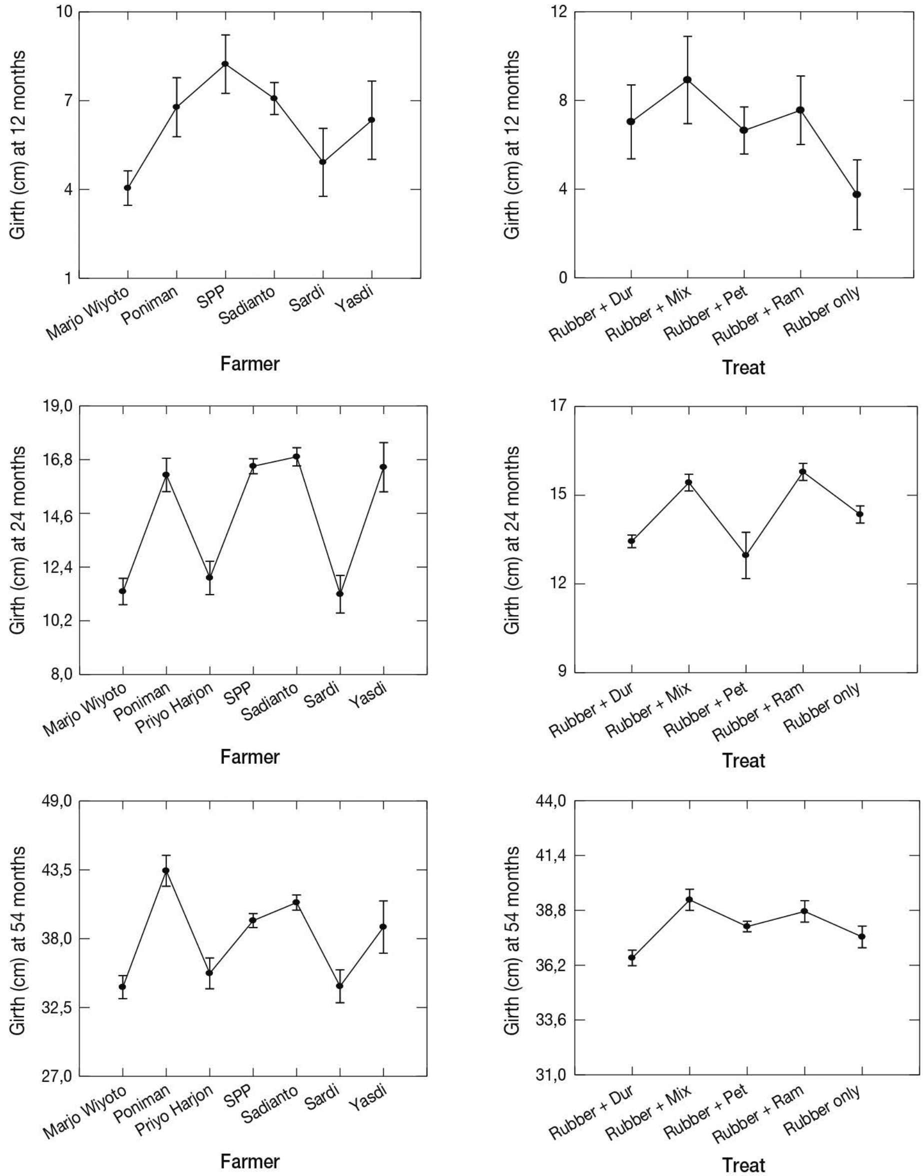

Figure 2.4. Variation in the girth of rubber trees at different ages, sites and treatments in RAS 2 in West Kalimantan

RAS 3 type to kill *Imperata cylindrica*

One idea behind RAS 3 (Mulyoutami et al., 2006; Penot, 2001) was to enable the establishment of rubber agroforests on land previously infested by *Imperata* by using legume cover crops, (*Pueraria javanica*, *Mucuna utilis*), shrubs (*Flemingia congesta*, *Crotalaria anagyroides*) and fast-growing trees (FGT – *Paraserianthes falcataria*, *Gmelina arborea*, *Acacia mangium*) that are capable of shading out *Imperata* regrowth, particularly in the first few years of rubber establishment. Planting cover crops is usually recommended when establishing rubber monoculture. FGT density was kept under 100 stems per ha under the assumption that a higher density seriously affects rubber tree growth. Natural seedling mortality meant that in some plots, only a few individual FGTs remained three years later (Penot, 1997).

The first RAS 3 trials were planted in 1996 in three farmers' fields in Kopar village in West Kalimantan (Boutin et al., 2000). High yielding clonal (PB 260) rubber plants raised in polybags were planted in the field after clearing using slash and burn. *Mucuna, Pueraria, Flemingia* and *Crotalaria* were planted in four rows between the rows of rubber at varying densities depending on the crop. Naturally occurring *Imperata* and *Chromolaena* were also left in place (i.e. not weeded out) for the purpose of comparison. In the village of Trimulya, located in a Javanese transmigration zone, FGT were planted between rows of rubber trees themselves planted at their usual density. All the plots, i.e., both those with cover crops and those with FGT, were weeded (manually or using herbicides) at 3-month intervals, but only in the rubber rows; limited fertilisers (rock phosphate and urea) were applied only in the first two years. Regular measurements of the girth of rubber trees, and the presence and dominance of ground vegetation formed the basis of our analysis.

Cover crops

The combined results of more than 6 years of monitoring the 3 experimental sites in Kopar village indicated that legume cover crops have different potential for the control of *Imperata* and hence for influencing the growth of young rubber trees (Figure 2.5). Creeping legumes were clearly the top performers, with *Pueraria* topping the list, followed by *Mucuna*. Among erect legumes, *Flemingia* was the best, while *Crotalaria* proved disappointing. Plots containing rubber trees with no cover crops that were invaded by *Imperata* or *Chromolaena* had not yet reached tapping size at the end of the 6-year monitoring period. This finding is consistent with the results of earlier work done in Sembawa Research Station where, without proper control of *Imperata*, it took more than 10 years for rubber trees to reach tapping size (Joshi et al., 2001).

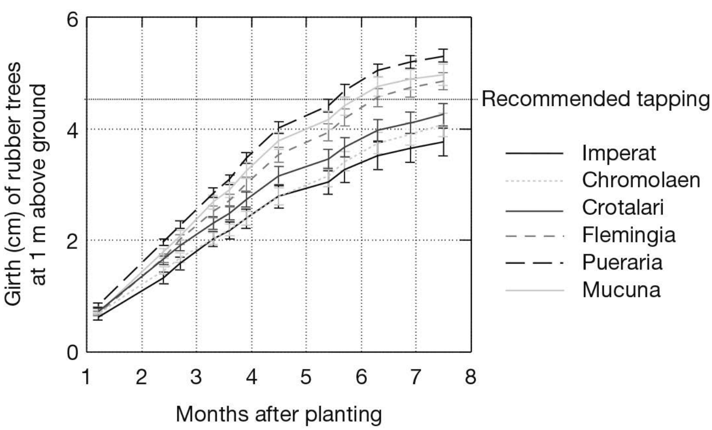

Figure 2.5. Rubber tree growth in the RAS 3 trial plot with cover crops against the weed Imperata

Although *Pueraria* and *Mucuna* grew well and succeeded in preventing regrowth of *Imperata*, they required regular interventions to remove the climbing vines from the trunks of the young rubber trees. Another major problem with *Mucuna* is the need to plant its seeds repeatedly as its life cycle is shorter than six months, which consequently requires more labour than the other species. On the other hand, the seeds produced by the previous *Mucuna* crop can be sown to maintain the cover. *Pueraria* seeds cannot be produced locally and are not easy to obtain on the local market. Likewise, the supply of *Flemingia* seeds was problematic in 1994/1997 (and still is in 2023).

Fast growing trees

The FGT trials in Trimulya village showed that all the FGT were only partially successful in controlling *Imperata* regrowth, i.e., *Imperata* manged to regrow in more than half the plots. There was no significant difference between the FGT species tested, *Acacia*, *Paraserianthes* and *Gmelina*, either in controlling *Imperata* or in their influence on rubber growth. In the early years, the effect of *Acacia* on rubber trees was slightly less positive than that of other species. However, the rubber trees in *Acacia* plots soon caught up when the *Acacia* trees were cut down after three years. The rubber trees in the FGT mixed plots took nearly six years to reach tapping size, i.e., a girth of 45 cm measured 1 m above the ground.

Comparison of rubber data from cover crop trials and FGT trials yielded quite interesting results. While rubber growth in FGT mixed plots was better than in *Imperata* or *Chromolaena* infested plots, growth was far behind that of rubber grown in plots with legume crops. Rubber trees needed more than a year longer to reach tapping size than rubber grown with cover crops (*Pueraria* and *Mucuna* plots; Figure 2.6).

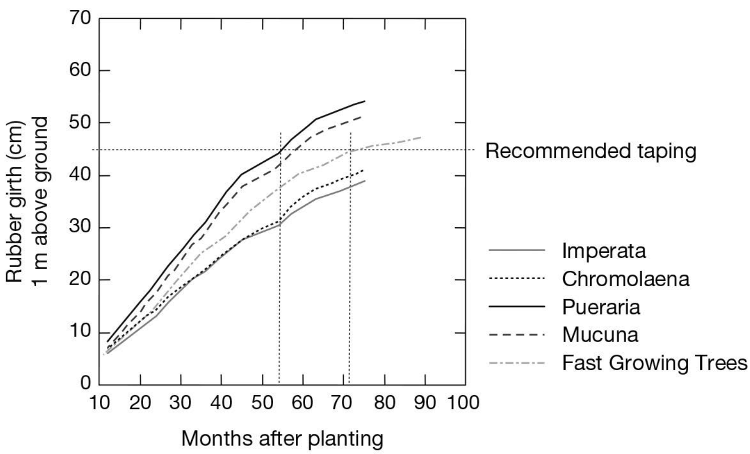

Figure 2.6. Comparison of rubber tree growth with cover crops and fast-growing trees against the weed *Imperata*

While FGT mortality was high, the surviving trees, particularly *Acacia*, grew rapidly and started affecting rubber tree growth in year 2 and year 3. The farmers who obviously preferred rubber were concerned, and, after three years, all remaining FGT had been removed from their fields. The harvested wood was only useful as firewood.

White root disease of rubber is becoming a serious problem in West Kalimantan and is known to be more severe in areas where the previous system was jungle rubber. However, in the RAS 3 trial, there was no evidence for a higher incidence of rubber tree mortality due to white root disease in plots converted from jungle rubber (2-6%) than in plots that were previously *Imperata* grassland (1-7%). The survival rate of planted rubber trees was more than 90%.

The FGT trials in Trimulya village showed that all the FGTs were relatively successful in controlling *Imperata* regrowth, even though *Imperata* was still encountered in nearly half the plots. This is not surprising as in their early stages, trees only have small crowns and are consequently unable to efficiently shade out *Imperata*. There was no significant difference between the FGT species tested – *Acacia*, *Paraserianthes*, and *Gmelina* – either in the control of *Imperata* or in their effect on rubber growth. The negative effect of *Acacia* on rubber trees was apparent from the early years, but, as mentioned above, the rubber trees caught up rapidly after *Acacia* trees were cut down after three years. Analysing the results of on-farm participatory trials is difficult due to uncontrolled factors that could interfere with the main factors described above. An inventory of any factors that could influence rubber tree growth needs to be undertaken very carefully. Participatory trials depend on a close relationship and continuous communication with farmers. Planning, implementing and any modification to the trials need to be preceded by detailed discussion with the farmers. Trust between researchers and farmers has to be built from the very beginning of a project if the objective of the on-farm trial is to be achieved. Once trust was established, the SRAP programme and associated activities were carried out more efficiently.

RAS 3 is a rubber agroforestry system whose "technologies" were tested and promoted only in West Kalimantan (Penot, 1997). The primary aim of the RAS 3 series was to establish productive rubber agroforests in degraded *Imperata* grasslands using legume cover crops or FGTs to shade out *Imperata,* combined with limited labour and limited use of chemical inputs. Legumes improve soil fertility thus benefiting the rubber trees in addition to controlling *Imperata* and *Chromolaena*. The RAS 3 trials confirmed that the cover crops alternative is the best. The proof that rubber trees can be tapped less than five years after planting, require less intensive weeding (generally only half that needed in standard monoculture plantations), and less fertiliser is certainly encouraging for smallholder farmers. The results obtained in these trials are comparable with those obtained in intensive monoculture plantations. However, lack of seeds of these useful legumes and the need to replant *Mucuna* are serious drawbacks that remain to be addressed.

On the other hand, FGTs were planted at the same time as rubber and were expected to control *Imperata* and *Chromolaena* in the early years of establishment. The sale of timber from these trees to the pulp industry in seven or eight years was predicted to provide extra income for farmers. Neither of these expectations was completely fulfilled. While all the FGTs tested proved partially successful in controlling *Imperata*, they also had a negative impact on the rubber trees. The farmers were reluctant to accept any negative impact of these FGT on rubber trees and consequently after 3 to 4 years, they cut down their FGTs, especially *Acacia mangium,* due to very high competition for light, even though *Imperata* was effectively controlled by the shade provided by *A mangium*. An interesting point is that more Javanese and Dayak migrants, who have fewer land resources, consider FGT as a viable source of income than local Dayak people.

One major problem that emerged after establishment of the cover crops was the poor quality of the seeds, a widespread problem in Indonesia in the case of varieties that are not indigenous. Both cover crops and FGT have roles to play, albeit slightly different, in improving the chances of successful and rapid establishment of clonal rubber in a low input system, and modifications to enable the combined use of cover crops and FGT may be a better solution than choosing one or the other. Based on the results obtained so far, it appears possible to control *Imperata* by planting a cover crop (*Mucuna* or *Pueraria* when the seed problem has been solved) within the first two or three years. FGTs can then be planted when rubber is already established. The effect of FGTs on rubber is significantly reduced when the FGTs are planted too late. The selection of FGT and other associated trees (such as fruit and timber species) will require careful thought as the choice depends on the local context and on demand for their product. Both smallholder farmers and rubber agroforests will then be able to profit from optimal use of previously degraded *Imperata* grassland.

Biodiversity observed in RAS

The two main advantages of jungle rubber (and subsequently of clonal RAS) were: (i) biodiversity conservation, as biodiversity is close to that of primary forest or old secondary forest in the case of old mature jungle rubber (de Foresta and Michon, 1992, 1995; Werner, 1997), (ii) environmental benefits in terms of soil conservation (Sethuraj, 1996) and water management due to its forest-like characteristics. The biomass of a 33-year old rubber plantation is very similar to that of a humid tropical evergreen forest.

Previous results on jungle rubber biodiversity that were available to the author (Werner, 1997; de Foresta, 1997) as well as a guidebook on plant uses (Levang and de Forestia, 1991) provided very useful preliminary information for this chapter.

The data presented in this section were collected between August and October 2001 in 4 villages in the West Kalimantan province and included 23 rubber agroforest plots. It has been originally published in 2004[43]. The nature of the previous vegetation, neighbouring vegetation and soil characteristics were recorded in addition to standard data (rubber growth, etc.) collected from the plots used for on-farm trials.

The "transect" method was used to assess existing biodiversity, with a sampling size per transect of 1 m × 0.2 m, and 15 replications of each treatment. The transect method was chosen to cover as wide a range of situations as possible, but the results obtained using this method do not allow direct comparison of biodiversity between RAS and jungle rubber systems because the plots — and hence the transects — are too small. Further research is therefore required but this has never been completed.

Correspondence analysis

Correspondence analysis was chosen because it makes it possible to focus on the different effects that influence plant biodiversity in rubber inter-rows under the different systems. The five first axes were taken into account in each analysis. Data were

43. Diaz-Novellon S, Penot E, Arnaud M, 2004. Characterisation of Biodiversity in Improved Rubber Agroforests in West-Kalimantan, Indonesia: Real and Potential Uses for Spontaneous Plants. *In*: Gerold, G., Fremerey, M., Guhardja, E. (eds), *Land Use, Nature Conservation and the Stability of Rainforest Margins in Southeast Asia*. Springer, Berlin, 426–444.

collected from RAS as well as in selected fallow plots with different densities of existing vegetation. Our analysis included 23 RAS plots, 1, 2, 3, 4 and 5-year-old fallow plots, 6-year-old jungle rubber plots (i.e. the same age as RAS plots), some *tembawang*[44] plots and some secondary forest plots located near the study villages. Complete results are reported in Diaz-Novellon's MSc.Thesis (2001).

Assessment of biodiversity under rubber agroforestry systems: a comparison of jungle rubber and RAS 1 and 3

Species diversity, i.e., the number of species, appeared to be higher in jungle rubber than in improved RAS. However, in RAS 2 and 3 in which fruit and timber trees were planted in the inter-rows, the biodiversity of a number of species per transect was comparable with that of jungle rubber. A similar result was observed with RAS *sendiri*. It thus appears that different methods of cultivation can have a direct influence on the spontaneous diversity of plants in the inter-rows, and in practice, experimental RAS, "RAS *sendiri*" and jungle rubber are managed differently, resulting in a significant "farmer effect".

According to trial protocols discussed with project farmers each year, the inter-rows are weeded more frequently in RAS. In practice, in RAS, weeding is limited to selective cutting of trees and shrubs that grow taller than the young rubber trees, whereas in jungle rubber, no weeding is done in the first few years. Weeding appears to be the main factor that influences plant diversity. When the cutting of spontaneous vegetation of the inter-row is spread out over time, the result is more species. On the other hand, the type of rubber trees (clonal or seedlings) does not influence the type, diversity or the quantity of vegetation. Inter-row biodiversity is therefore more influenced by farming practices and in particular by the frequency of selective cutting or by the number of weeding operations. Species distribution and biodiversity of RAS plots is shown in Table 2.5.

Table 2.5. Distribution of each type of plant across all plots

	Trees	Herbaceous	Ground lianas	Climbing lianas	Bamboo rattan	Shrubs
Number of plants	1,138	2,480	368	128	54	231
Number of species	55	24	7	6	1	3

One important question concerning the comparison between RAS and jungle rubber is whether jungle rubber has a higher specific plant density, i.e., number of plants per unit area, than improved rubber agroforests. Our results show that jungle rubber does indeed have more individual plants in inter-rows than RAS, although the density of plants is very similar to that of "RAS *sendiri*". The different agroforestry practices (and in particular the frequency of selective cutting) explain this difference. Compared to the biodiversity found in secondary forest or *tembawang*, the number of species appears to be similar to the number found in RAS even though the ground-level density of species is considerably lower (see following tables). In other words, the difference is mainly quantitative.

44. *Tembawang* is the name of fruit and timber agroforestry system developed by Dayak people.

What are the most significant factors that explain the variation in biodiversity? Discriminant analyses showed that previous farming practices play a significant role. An area that had been cultivated for at least 3 years hosted higher species biodiversity than an equivalent fallow area. One possible explanation is that areas cultivated as "open systems" have a bigger seed bank and can collect seeds from surrounding forests or agroforests. Environmental factors probably also influence biodiversity. The presence of jungle rubber in the immediate vicinity results in greater biodiversity. One to 5 years of fallow around plots probably also increases biodiversity. As far as agricultural practices are concerned, the number of selective cuttings per year appears to be the main factor that influences plant biodiversity in the inter-row (see Diaz-Novellon's MSc thesis, 2001 for details).

Smallholders' perception of plant biodiversity

It was clear that local populations know the plant species in their fields and their specific uses perfectly well. More than 300 species needed indexing during field surveys and interviews with farmers. The most common uses of spontaneous biodiversity (in forest and agroforests) ranked in decreasing order of importance are health (medicinal plants), food (fruit, vegetables), construction (wood and timber), firewood and others (Table 2.6).

Table 2.6. Existing and potential uses of biodiversity by the Dayak population (1997)

Uses	Number of species
Timber for construction, housing	83
Firewood	40
Timber for sale or furniture making	2
Fruits	112
Vegetables	68
Medicinal plants	179
Animal feed	24
Pulp (for paper making)	1
Cosmetics	1
Colouring properties	2
Use as paper	9
Weed control	14
Insecticide	6
Handicrafts	66
Latex	4
Oil	7
Fertilisation	14
Spices	55
Others	8

However most spontaneous vegetation is not yet used by the local population and is thus available for “potential uses”. Medicinal plants have considerable potential (Table 2.7), they are not widely used because some farmers prefer “modern” drugs, which are thought to be far more effective against malaria, diarrhoea and other illnesses as long as their incomes do enable such expenses.

Table 2.7. Uses of medicinal plants

Health disorders treated with local plants	Number of species identified
Coughs	12
Fever	23
Itching	15
Tiredness	11
Malaria	2
Dysentery	1
Sore throat	13
Toothache	1
Stomach ache Nausea	44
Burns	9
Headaches	11
Others	11

In the case of timber and wood, the most valuable species (Table 2.8) are becoming scarce in local forests in the study area in 1997 and the situation is worse in 2024 leading to a real new demand on such products.

Table 2.8. Timber species that are becoming scarce in remaining forests (1997)

Local names	Latin names	Village
Belian	*Eusideroxylon zwageri*	All villages
Tapang	*Koompassia excelsa*	Embaong, Kopar
Tekam		All villages
Benkirai	*Shorea* sp.	Embaong
Meranti	*Shorea* spp.	Engkayu, Trimulya
Terenak		All villages
Jeluntung	*Dyera costulata*	Trimulya
Kayu Raya	sorea spp.	Kopar
Majau	*Shorea palembanica*	Embaong
Omang	*Hopea dryobalanoides*	Sanjan, Engkayu
Medang	*Litsea elliptica*	Kopar, Engkayu
Tunam	*Shorea lamellata*	Kopar
Nyatuh	*Palaquium* spp.	Engkayu
Owan		Engkayu

Local names	Latin names	Village
Ubah	*Glochidion* sp.	Sanjan, Engkayu
Taba	*Aquilaria malaccensis*	Kopar
Keladan	*Dryobalanops beccarii*	Engkayu
Tengkawang	*Shorea macrophylla*	Kopar

Most farmers are interested in 2024 in including particular timber species (Table 2.9) in their agroforests for both housing (construction) and sale.

Table 2.9. Timber species preferred by farmers (1997)

Local names	Latin names	Local names	Latin names
Belian	*Eusideroxylon zwageri*	Mentibu	
Keladan	*Dryobalanops beccarii*	Medang	*Litsea elliptica*
Tekam		Nyatuh	*Palaquium* spp.
Ketuat		Oman	*Hopea dryobalanoides*
Meranti	*Shorea* spp.	Owan	
Terindak	*Shorea senimis*	Jonger	*Ploiarium alternifolium*
Tengkawang	*Shorea macrophylla*	Taba	*Aquilaria malaccensis*
Mengkirai	*Trema orientalis*	Tantang	*Buchania sessifolia*

Prices of timber species vary considerably, indicating that this market was already well developed in 1997 (Table 2.10). However production has seriously decreased with the loss of the forest, the deman is still high in 2024 for quality timber.

Table 2.10. Prices for local timber species in 1997 (just given as an example)

Timber species	Latin name	Price in rupiah in 1997
Belian	*Eusideroxylon zwageri*	50,000 Rp/board
Raya		3,500 Rp/board
Jonger	*Ploiarium alternifolium*	4,000 Rp/board
Owan		8,000 Rp/board
Medang	*Litsea elliptica*	8,000 Rp/board
Paku		5,000 Rp/board
Tapang		20,000 Rp/board
Tengkawang	*Shorea macrophylla*	4,000 to 10,000 Rp/board
Tantang	*Buchania sessifolia*	200,000 Rp/m2

Note: Exchange rate in 1997: US$1 = 10,500 Rp. Prices are given to show the difference in price for different types of timber.

Some local species have always been maintained or preserved by replanting or by favouring regeneration from natural regrowth in the different types of agroforests (Table 2.11) and have a range of different uses.

Table 2.11. Spontaneous timber species maintained in local agroforests and their uses (1997)

Local names	Latin names	Uses
Leban	*Vitex pinnata*	Timber, wood, spice, medicinal
Medang	*Litsea elliptica*	Timber, latex
Ramboutan	*Nephelium lappaceum*	Fruits, timber
Jengkol	*Pithecellobium jiringa*	Fruits, vegetable, timber, medicinal
Durian	*Durio zibethinus*	Fruits, timber
Pingam	*Artocarpus* sp.	Fruits, timber, vegetable
Cempedak	*Artocarpus integra*	Fruits, medicinal, vegetable
Lengsat	*Lansium domesticum*	Fruits, medicinal, handicrafts
Pekawai	*Durio* c.f. *dulcis*	Fruits
Mentawa	*Artocarpus* c.f. *anisophyllus*	Fruits
Nyatuh	*Palaquium* spp.	Timber, latex
Owan		Timber, handicrafts
Bungkang	*Polyalthia rumpfii*	Timber, spice
Belian	*Eusideroxylon zwageri*	Timber
Ubah	*Glochidion* sp.	Timber
Kemenyan	*Styrax benzoin*	Timber, latex, animal feed
Tantang	*Buchania sessifolia*	Timber
Bidara	*Nephelium maingayi*	Fruits

Some of these species have been re-introduced in agroforests (Table 2.12), in particular in *tembawang*, or are protected when they emerge in natural regrowth in jungle rubber and RAS.

Table 2.12. Local species reintroduced in agroforest (1997)

Local names	Latin names	Uses
Jengkol	*Pithecellobium jiringa*	Fruits, vegetables, timber, medicinal
Mangga	*Mangifera indica*	Fruits
Ramboutan	*Nephelium lappaceum*	Fruits, timber
Manggis	*Garcinia mangostana*	Fruits
Durian	*Durio zibethinus*	Fruits, timber
Cempedak	*Artocarpus integra*	Fruits, medicinal, vegetables
Coklat		Cocoa
Kopi		Coffee
Petai	*Parkia speciosa*	Fruits, vegetables
Lengsat	*Lansium domesticum*	Fruits, medicinal, handicraft
Kedupai	*Mischocarpus pentapetalus*	Fruits
Sibau	*Xerospermum norotanum*	Fruits

Local names	Latin names	Uses
Mentawa	*Artocarpus anisophyllus*	Fruits
Pekawai	*Durio* c.f. *dulcis*	Fruits
Melinjo	*Gnetum gnemon*	Fruits, vegetables
Nangka	*Artocarpus heterophyllus*	Fruits
Tengkawang	*Shorea macrophylla*	Fruits, oil, timber
Tekam		Timber, handicraft
Ketuat		Fruits, timber
Tempuih	*Baccaurea* sp.	Fruits
Pisang	*Musa* spp.	Fruits, vegetables, medicinal

Other species farmers do not consider suitable in RAS inter-rows were also identified (Table 2.13). These species are in fact still used in that their products are still collected in true forests, but are not specifically selected in agroforests due to the fact that – at least in the farmers' opinions – they might have a negative effect on rubber growth during the immature period. For example, after 20 years of growth, the number of durian trees per ha has to be less than 20 to reduce shading when the durian canopy begins to outgrow that of rubber. Another example is *tengkawang* (Illipe nut tree) which is considered to "dry out" soils and consequently to limit rubber tree growth (but this observation has not been scientifically confirmed).

Table 2.13. List of species not specifically chosen for agroforests and their uses (1997)

Local names	Latin names	Uses
Belangai	*Eurya nitida*	Timber, medicinal, handicraft
Tucet	*Alstonia angustifolia*	Timber
Plaik	*Alstonia scholaris*	Timber, latex, medicinal, handicraft
Bamboo		Housing, handicraft, other uses
Todoh	*Phrynium capitatum*	Wrapping
Ringkan	*Ficus grossularoides*	Fruits, wrapping, timber
Resak	*Melastoma malabathricum*	Timber, fruits, vegetables, medicinal
Pakis		
Semolang	*Euodia aromatica*	Medicinal, timber
Siyet	*Sceria prupurescens*	Medicinal
Entiup	*Artocarpus sericicarpus*	Fruits, oil, handicraft
Leban	*Vitex pinnata*	Timber, spices, medicinal
Jambu america	*Bellucia axinanthera*	Fruits, wrapping, timber
Alang-Alang	*Imperata cylindrica*	Medicinal
Marade		Timber

Certain species (Table 2.14) may be selected to limit invasion of *Imperata cylindrica* in young agroforests.

Table 2.14. Species specifically used to limit *Imperata cylindrica* (*alang alang*) in young agroforests

Local names	**Latin names**	**Type of action**
Semenput		Provide shade
Beringing		
Melastoma	*Melastoma malabathricum*	Cover crop
Coklat		Cover crop
Nenas	*Ananas comosus*	Root competition
Gmelina	*Gmelina arborea*	Shading
Orok-Orok	*Crotolaria mucronate*	Competition with alang[2]
Gamal	*Gliricidia sepium*	Shade (limited)
Akacia	*Acacia mangium*	Shade
Albizia	*Albizia* sp.	Shade

Table 2.15 summarises the different species in agroforests, *tembawang*, jungle rubber, RAS *sendiri*, RAS 1 and RAS 3, as well as in home gardens (*pekarangan)* belonging to the local population and consumed and sold on local markets. It gives an idea of the wide variety of products that have an impact on both the household food supply and on the economy.

Table 2.15. Species and products already sold on local markets (price system of 1997)

Indonesian/local names	**Latin names**	**Sale price**	**Origin**
Pisang/Banana	*Musa* spp.	1,500 Rp/lot	Agroforest
Pakis piding/ferns		500 Rp/lot	Agroforest
Kangkong	*Ipomea aquatica*	500 Rp/lot	
Cangkok manis		500 Rp/lot	Agroforest
Daun kacang/bean leaves		500 Rp/lot	Home garden
Daun ubi/cassava leaves	*Gnetum gnemon*	500 Rp/lot	Agroforest
Bunga pisang/banana flower	*Musa* spp.	1,000 Rp/fleur	Agroforest
Jengkol	*Archidendron pauciflorum*	1,000 Rp/kg	Agroforest
Maram	*Eleiodoxa conferta*	2,000 Rp/kg	Agroforest
Kacang panjang/bean	*Vigna unguiculata*	2,000 Rp/kg	Home garden
Timun/cumcumber	*Cucumis sativus*	2,000 Rp/kg	Home garden
Bunga jagung/maize flower	*Zea* sp.	500 Rp/flower	Pontianak
Bayam	*Amaranthus hybridus*	500 Rp/lot	Home garden
Petai	*Parkia speciosa*	2,500 Rp/kg	Agroforest
Labu air/pumpkin	*Lagenaria siceraria*	2,500 Rp/kg	Home garden
Jahe/gingember	*Zingiber officinale*	2,500 Rp/kg	Home garden
Kelapa/coco nuts	*Cocos nucifera*	1,000 Rp/fruit	Home garden
Peringgi		4,500 Rp/kg	Home garden
Kecambah		1,000 Rp/portion	
Ubi/cassava	*Manihot esculenta*	2,500 Rp/kg	Agroforest

Indonesian/local names	Latin names	Sale price	Origin
Kedondong	*Spondias pinnata*	500 Rp/lot	
Pekawai	*Durio* c.f. *dulcis*	10,000 Rp/lot	Agroforest
Terong	*Solanum melongens*	5,000 Rp/kg	Home garden
Cabe/pepper	*Capsicum annuum*	20,000 Rp/kg	Pontianak
Buncis	*Phaseolus vulgaris*	3,500 Rp/kg	
Gambas	*Luffa acutangula*	2,000 Rp/kg	
Jeruk/lemon	*Citrus* sp.	3,000 Rp/kg	Home garden
Nangka/Jacqj fruit	*Artocarpus heterophyllus*	2,500 Rp/kg	Agroforest
Kencur	*Kaempferia galanga*	10,000 Rp/kg	
Kunyit	*Curcuma longa*	5,000 Rp/kg	Agroforest
Serai	*Cymbopogon nardus*	500 Rp/lot	Agroforest
Keladi	*Colocasia esculenta*	1,000 Rp/lot	Agroforest
Kundur	*Benincasa hispida*	2,500 Rp/kg	
Asam	*Tamarindus indica*	500 Rp/fruit	Agroforest
Labu siam	*Sechium edule*	2,500 Rp/kg	Home garden
Pane	*Momordica charantia*	5,000 Rp/kg	Pontianak
Wartel/carott	*Daucus carota*	9,000 Rp/kg	Pontianak
Jeruk nipis/lemon	*Citrus aurantifolia*	4,000 Rp/kg	Pontianak
Kol/cabbage	*Brassica oleraceae*	5,000 Rp/kg	Pontianak
Kentang/potato	*Solanum tuberosum*	4,500 Rp/kg	Pontianak
Tomat/tomato	*Lycopersicon esculentum*	6,000 Rp/kg	Pontianak
Bawang merah/red onion	*Allium cepa*	7,000 Rp/kg	Pontianak
Bawang putih/white onion	*Allium sativum*	7,000 Rp/kg	Pontianak
Kayu manis/cinnamon	*Cinnamomum burmanii*	2,000 Rp/lot	Agroforest
Nenas/pinepale	*Ananas comosus*	2,000 Rp/fruit	Agroforest
Sawih/cabbage	*Brassica rugosa*	5,000 Rp/kg	Pontianak
Jambu air	*Syzygium aquaeum*	1,500 Rp/kg	Home garden
Pepaya/papaya	*Carica papaya*	2,500 Rp/kg	Home garden
Kenikir	*Cosmos caudatus*	500 Rp/lot	
Lengkuas	*Alpinia galanga*	1,000 Rp/lot	Agroforest
Daun salam/leaves	*Eugenia polyantha*	500 Rp/lot	Agroforest
Daun sop/celery leaves	*Apium graveolens*	1,000 Rp/lot	Home garden
Daun pepaya/ papaya leaves	*Carica pepaya*	500 Rp/lot	Home garden
Mangga	*Mangifera indica*	8,000 Rp/kg	Agroforest
Petai	*Parkia speciosa*	2,000 Rp/lot	Agroforest
Kacang tanah/peanut		3,000 Rp/kg	Home garden
Cempedak hutan	*Artocarpus integra*	500 Rp/fruit	Agroforest
Kumis kucing	*Orthosiphon aristatus*	1,000 Rp/lot	Home garden

NB: The Latin names of the species should be interpreted with caution because of the difficulty in identifying the species and correspondence between vernacular names and scientific names.

Conclusion: Market potential for associated trees in the 1990s and today

Some products were of obvious economic interest in the 1990s (see Table 2.4) and are still of interest in 2023. Smallholders tried to domesticate some of these species in their agroforest inter-rows (RAS and jungle rubber), by replanting or facilitating regeneration from natural regrowth, which has the advantage of being almost cost-free.

Timber species and fruit trees are particularly appreciated when they emerge from forest regrowth because they do not require planting and very little additional labour is needed to maintain them, but they may also be replanted to enrich the vegetation in the inter-rows.

Fruit trees have the most obvious potential market value, in particular durian which is already sold everywhere in Indonesia as well as in other countries in Southeast Asia (e.g. Thailand and Malaysia), rambutan and duku, for which demand is high on the Indonesian market. National markets did not appear to be saturated in the 1990s but in 2023, export would be the best market option for smallholders, particularly in the case of durian. The lack of larger organised marketing channels other than the traditional Sino-Indonesian one is still a serious obstacle to the expansion of fruit markets and exports.

As a result of the high demand for timber and wood products such as plywood in consumer countries (Japan, USA, and Europe), there may well be a shortage of timber in the very near future. Smallholders in West Kalimantan would be well advised to anticipate this trend and include species in their agroforest inter-rows that can be used to supply demand from the plywood industry. Some species (particularly nyatoh/*Palaquium* spp.) have a life span similar to that of rubber (30 to 40 years). The final life cycle of RAS could then be extended with the exploitation of timber trees such as belian (*Eusideroxylon zwageri*, life span 60 years) or meranti (up to 90 years). In this way, old rubber-based agroforests could develop into *tembawang*. Finally, at the end of rubber lifespan, rattan could prove to be a useful crop, as indicated by the strong demand for furniture for export.

One major obstacle is Indonesian legislation on land and tree tenure that needs to be re-examined and adapted to the context of smallholder production, whose future potential could be high. Current regulations concerning timber exploitation practically preclude trade in timber from forests or agroforests by smallholders.

Other forest products with future potential are without doubt medicinal plants. Local sales of these products are already limited, as they have gradually declined due to the effectiveness and availability of pharmaceutical products. However, pharmaceutical firms could be interested in several forest and agroforest species in Borneo and perhaps undertake research projects that could indirectly benefit local populations. Examples of this type have been already observed in other countries in Amazonia, as well as in Côte d'Ivoire where a product to control hypertension was discovered growing under rubber.

Irrespective of the future potential of agroforest products, and even if it is high for fruit, timber, rattan and medicinal plants, most products are under-exploited in 2024, and hence represent a major challenge for the very near future. Several constraints persist in terms of both market organisation and official regulations.

⏩ Farmers in West Kalimantan and RAS

Local Dayaks and Javanese immigrants are the two main ethnic groups in the area whose characteristics differ and who use different farming practices. Local Dayak populations are scattered and occupy more agricultural land. Javanese migrants are concentrated in villages and have limited land, which was often previously invaded by *Imperata* grassland after deforestation and was distributed through the government transmigration programme. Some Dayak families have also migrated to other areas within the region and the country as a whole. Like the Javanese, these Dayak migrants have limited land, but their access to local communal natural resources is not as limited as it is among the Javanese. The two groups have quite dissimilar land holdings, different access to other resources, different constraints and opportunities, which have important implications for the adoption, adaptation or rejection of RAS 3 (and other) technologies for their fields. Table 2.15 summarises the attributes of the three groups (local Dayaks, Dayaks who have migrated, and Javanese transmigrants) directly or indirectly related to rubber agroforestry.

Labour and modelling

Data on the inputs and outputs of major rubber-based systems were collected in West Kalimantan and Jambi with the aim of developing a prospective analysis tool to model fluctuating prices and yields of the different farming systems. The *Olympe* model (developed by Cirad) was used to input the data including detailed information concerning labour. RAS technologies were included in the survey and used as input data to enable comparison of these technologies and other technologies that were already available at the time. Here we only present data from Jambi. The level of maintenance refers to a combined parameter depending on the application of fertiliser and the frequency of vegetation slashing and weeding mainly during the establishment phase, i.e., in the first 6 years. In some areas where the risk of damage caused by pests (deer, boar, and monkeys) is high, considerable labour may be required to build fences; but for the purpose of our comparison reported here, labour needs were excluded as labour is independent of technology.

Much of the labour required prior to planting goes into land preparation and includes cutting down trees, slashing ground vegetation, burning and building fences. The following task is planting rubber. Other regular management tasks include applying fertiliser, manual and/or chemical weeding, tapping latex and harvesting other products.

Low maintenance RAS 1 requires only infrequent manual or chemical weeding, and only between the rows of rubber. Paid outside labour is generally not used but may be needed for land preparation. The RAS 1 high maintenance category requires more weeding and slashing during the establishment stage (Figures 2.7 and 2.8); the use of chemical herbicides is limited to the first two years. Minor weed slashing is carried out during tapping. In the RAS 2 low maintenance category, the use of both external labour and of chemical fertilisers is rare. The RAS 2 high maintenance category involves intense weeding in both the rows of rubber and in the inter-rows.

Table 2.15. Farmers and their characteristic in 1997

Group to which the farmers belong	Ethnicity	Farming system	Ecological characteristics	Constraints	Farming system
Local	Dayak	Extensive and intensive rubber	Upland Poor soil	Frequent rubber damage White root rubber disease	*Ladang* 1 ha – pulut (sticky rice for wine) one crop/ year *Sawah* 0.7 ha, Oil palm 3 ha *Tembawang* 0.7 ha based on illipe nut or durian
Local	Dayak	Intensive	Upland Poor soil	Frequent rubber damage White root rubber disease	*Ladang* – pulut once a year *Sawah* 0.7 ha – paddy one crop per year *Tembawang* 1.3 ha
Local Migrants	Dayak	Extensive	Low land Poor soil Imperata	Plenty of land but limited knowledge/skills Lack of capital to buy clonal stumps and fertiliser	Upland field 0.85 ha – pulut once a year *Sawah* 1 ha _ paddy one crop per year *Tembawang*
Transmigrants	Javanese	Extensive and Intensive	Lowlands Poor soil Imperata	Limited land area (2 ha per household)	*Sawah* 0.7 ha 50% are intensive Upland field 0.5 ha Herbicide used for *sawah* and *ladang*
Transmigrants	Javanese	Intensive	Lowlands Poor soil Imperata	Limited land area (2 ha per household)	*Sawah* 0.2 ha 30% are intensive

Ladang is a upland crop plot. Sawah is an irrigated rice plot.

Conclusion

Observations made in 1993 in Sanjan (in SRDP plots) and in SRAP plots (Smallholder Rubber Agroforestry Project: a research projet from Cirad/ICRAF) dedicated to RAS trials, showed that in specific conditions, clonal rubber can be associated with other trees in complex agroforestry systems, and enable good productivity of both the rubber and the associated trees. Rubber production data concerning these systems are comparable with data on intensive monoculture. RAS 1 technology requires less labour and fewer chemical inputs and allows natural regrowth between the row of rubber including regrowth of timber and fruit species and medicinal plants. RAS 2 combines rubber trees with other high value timber and fruit species. RAS 3 is suitable for rehabilitation of *Imperata* grassland using a mixture of rubber, non-rubber

External influence	Oil palm opportunity	Use of Imperata	Land use before Imperata	Preferred Imperata control	Constraint to reclaiming former Imperata land
PPKR or SRDP SRAP – RAS 1, 2, 3	Oil palm on private land	None	Rubber Ladang	Timber trees Local and clonal rubber Herbicide	Lack of capital
PPKR or SRDP SRAP – RAS 1, 2, 3	Oil palm	None	Rubber Ladang	Timber trees Only clonal rubber Herbicide	Lack of capital
PKRGK rubber project	-	None	Rubber Ladang	Herbicide Roundup Timber trees Clonal rubber	Lack of capital
RAS 2, 3	Oil palm	Thatching Mulching	Ladang Rubber Sawah	Herbicide Clonal rubber Timber trees	High use of herbicide, lack of capital
RAS 2, 3	Oil palm Private oil palm	Thatching Mulching	Ladang Rubber Sawah	Herbicide Timber trees Clonal rubber	High use of herbicide, lack of capital and labour

and cover crops. While in the periods 1993/1996, 2007/2012, the attractive price of rubber encouraged farmers to adopt intensive monoculture, diversification of rubber agroforests was a better option than monoculture for rubber smallholders because it enabled them to diversify the economic basis of rubber agroforests, with value accruing from rubber wood and other timber while fruit trees provided an incentive for maintaining diversity plus ensure the farmers receive tangible benefits.

An improvement strategy investigated in earlier rubber agroforestry research revealed the technical possibility of running rubber plantations with less intensive management. While the financial gains from latex are considered the priority, the profit to be obtained from non-rubber components of the systems should not be ignored. The production of timber from rubber trees and the cultivation of other high value timber species will almost

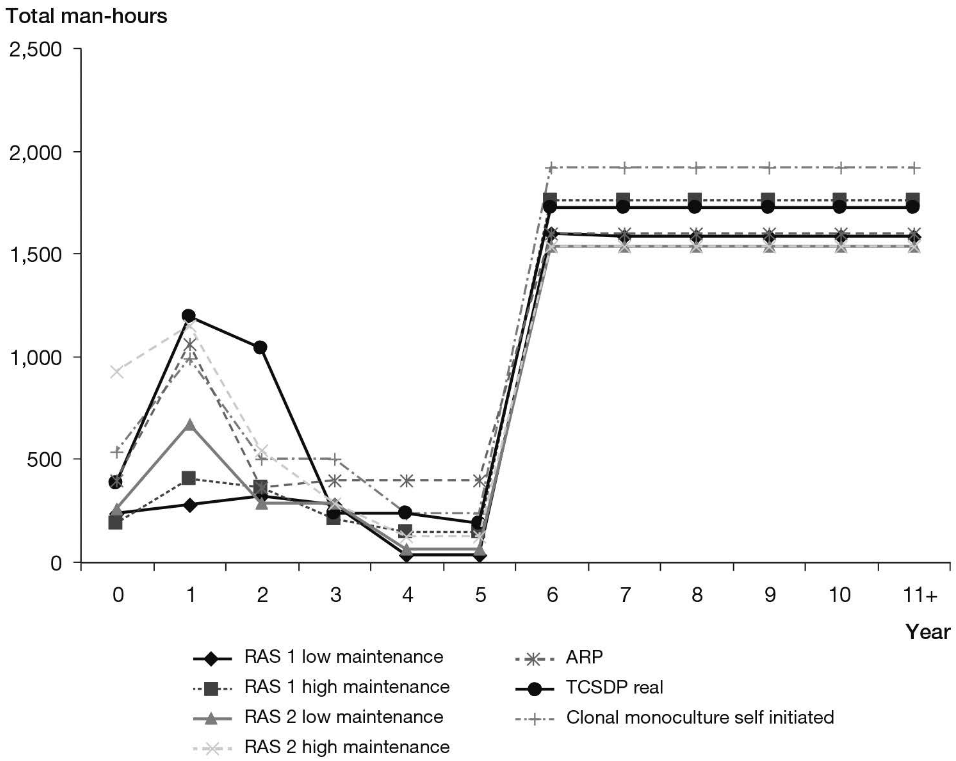

Figure 2.7. Manpower (hours) required by the different rubber systems

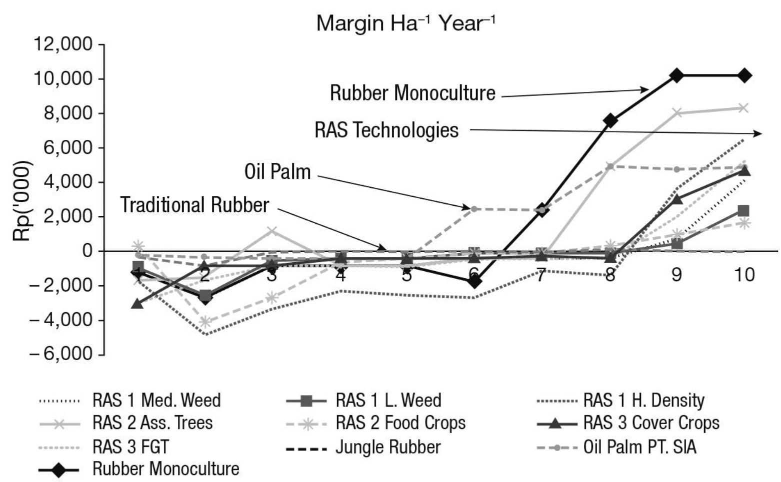

Figure 2.8. Changes in gross margin/ha under different cropping systems

certainly increase: it was true in 1997 and still is in 2024. High value fruits (both local and exotic) for local and export markets have huge potential to increase the farmers' income (as is already the case in southern Thailand). In 2023, it is clear that certain problems concerning double-row spacing have been partially solved, especially optimal spacing in certain RAS. In terms of rubber growth and the possible prolonged use of wider inter-rows for annual intercrops and tree crops, e.g. 6 m × 2 m × 14 m double-row spacing, is a very encouraging model if fast growing rubber clones such as RRIC 100, PB 260 and BPM 1 are the main tree crop. The same process of combining rubber and fruit/timber trees or other permanent crops occurred in Thailand in the 1990s.

In 2002, results obtained at the end of the immature stage showed RAS to be very well suited to local constraints and easily adopted by farmers. Rubber tree growth was excellent and most trees were tappable before 6 years of age. In 2024, there is still a considerable demand from surrounding farmers who want to join the project or to develop similar systems on their own (RAS *sendiri*); however there is also strong pressure from local private oil palm estates for local people to plant oil palm. Impact analysis conducted in 2000 (Trouillard, 2001) showed that 60% of SRAP farmers had replanted in the preceding 5 years and that 60% of the farmers concerned replanted using RAS s*endiri* systems. RAS *sendir*i can be considered as a "type of RAS" entirely re-appropriated by farmers, some of which were originally developed by them. Non-SRAP farmers in the area also began to adopt RAS *sendiri* after witnessing the efficiency of RAS (demonstration effect).

Since then, most farmers have planted oil palm, which in 2022, accounted for around 2/3 of tree-crop plantations. In 2023, farmers are all aware that clonal rubber requires more weeding and more inputs than unselected seedlings under jungle rubber, even in an improved agroforestry system such as RAS. They sometimes underrate the minimum requirements tested at different levels in RAS trials. One constraint is farmers' unwillingness to incorporate the minimum amount of inputs and labour in their current practices, which lies between what is currently used in jungle rubber (very low) and that used in the estate model (very high). Research is now underway to discover what level of capital for investment and labour would be acceptable to farmers during the immature stage.

A major challenge in development terms is also to decide which is best: a "complete approach" (as used in current development projects) or a "partial approach" based on the supply of only key components of RAS. Surveys by Chambon (1997-2000, published in Chambon, 2001) showed that a "partial approach" can work well if farmers' awareness has already been raised by previous development projects.

⏩ Diversification of perennial crops to offset market uncertainties in West Kalimantan

This section has been partially published in 2001[45] as a result of a local study.

In less than one century, Dayak farmers in Indonesia first shifted from traditional hunting and gathering of forest products to slash and burn agriculture with progressive

45. This section was co-written with Karine Trouillard, and originally published in 2001 in a working document : Penot E, Trouillard K, De l'intégration à la substitution : histoire sur période longue des stratégies des producteurs hévéicoles en Indonésie : le cas de Ouest Kalimantan.

incorporation of rubber in agroforestry systems called "jungle rubber", then to rubber monoculture in the 1980s based on the use of clonal planting material, and finally to oil palm in the 1990s. The farming systems used by Javanese transmigrants in official transmigration programmes underwent different changes due to the weed *Imperata cylindica,* and to land scarcity. Local farmers progressively integrated export crops and now have access to international markets. The 1997-1999 economic crisis in Indonesia increased the need for development and technical change. A significant degree of coherence was maintained between technical systems and social systems. The example of the Sintang and Sanggau areas in West Kalimantan Province (Borneo) enabled characterisation of the different farming systems, and the identification of a situational framework and of pathways for future change. Here we discuss the different strategies from the perspective of a regional approach to development. Two major challenges characterise the rubber sector: the transformation of existing jungle rubber (2.5 million ha, 85% of smallholders' plantations) into clonal plantations (either in agroforestry or as monoculture) and partial substitution by — or complementary cultivation of — oil palm.

A study conducted in 2000 identified two situations: (i) the planting of new plantations in a parallel process of land acquisition, and (ii) the replanting of old jungle rubber (renewal of productive capital and beginning of intensification). For smallholders, these structural changes implied both technical change and innovation. Here, technical change refers to the adoption of clonal planting material, either in monoculture or in an agroforestry system. At the same time, official and/or spontaneous transmigration as well as the expansion of oil palm estates tended to increase pressure on remaining available land. Dayak communities thus felt the need to secure their land by expanding their plantations. In a context of uncertainty, the use of clones helped reinforce land ownership. It also led to an effort to rehabilitate degraded land. At the end of the 1990s, smallholders profited from a variety of on-farm and off-farm alternatives to diversify their sources of income, e.g., rubber and oil palm monoculture, agroforestry systems, running a nursery, off-farm jobs.

The two ethnic groups have followed distinct courses of action in terms of land use and agricultural practices. The traditional Dayak production system is based on extensive slash and burn rain-fed rice cultivation (*ladang*), with, in the past, the progressive incorporation of jungle rubber in 1997 and in still in 2024 of clonal rubber systems. This system gradually became more intensive (line plantation, maintenance before tapping, etc.). Jungle rubber became economically obsolete. Partially inspired by Javanese transmigrants, the Dayaks also adopted flooded rice. Old fallow, jungle rubber and local *tembawang* (timber and fruit agroforests) are also a valuable reserve of forest products. Originally, Dayak villages did not have to face the problem of limited land[46]. From the beginning of the 1980s, rubber projects gave some villages access to clones and monoculture techniques. At the end of the 1990s, the creation of oil palm estates had the same effect, offering new opportunities based on oil palm, which, at the time, was a new crop for local farmers. After 1997, farmers in villages belonging to the SRAP network also started nurseries and new improved clonal agroforestry plantations. The Javanese who settled as a result of the transmigration programme only had access to a very small area of cultivated land (2.5 ha). They originally focused on intensive

46. The population density is still relatively low with an average of 20 to 30 inhabitants/km^2.

irrigated rice (*sawah*), which allowed them to be self-sufficient – as long as local plots allowed planting of irrigated rice. Initially, the cultivation of fruit, timber and forest species was forbidden as the Javanese were officially supposed to specialise in food crops. Today, in 2023, they are establishing perennial plantations (rambutan, rubber, oil palm, pepper) in addition to food crops[47] (rice, peanuts) on the remaining uplands (dry land or *ladang*). The majority of Javanese planters also own a few cows, which is a good way to accumulate capital. However, most Javanese are obliged to take on off-farm work for 3 or 4 months a year to meet their family's needs (e.g. purchase complementary food, pay off loans). Javanese farmers are very open to agricultural intensification and, whenever possible, will rapidly incorporate perennial crops and seize any other opportunities for income diversification. Their main constraints are lack of land, limited labour, and high pressure from *Imperata cylindrica* in their deforested plots. Rice cultivation remains a strategic and sometimes social crop in both farming systems. It uses up family labour but does not guarantee complete self-sufficiency. The extent of production of clonal planting materiel (nurseries), which represents a relatively new opportunity, varies from village to village, depending on the social, economic and technical status of the farmers.

Thus, different strategic groups with different innovation objectives may co-exist in the same village (Trouillard, 2001). Concerning improved planting material, at the time, we distinguished five behavioural types: (i) rubber smallholders developing nurseries as their main activity, (ii) high status smallholders who invest in monoculture, (iii) smallholders-purchasers who buy clonal planting material, (iv) autonomous smallholders who produce their own clonal planting materiel, and (v) private nurseries (without a plantation). Some villages specialised in one or other of these categories, and were then generally referred to as "nursery villages" (i.e. villages that produce planting material) or "purchasing villages".

The study described here was implemented within the framework of SRAP[48], based on the concept of participatory action research. The project depended on a series of technical and organisational innovations (rubber-based cropping systems, the production of planting material, the organisation of farmers[49] around activities, etc.) that concern pre-established groups of producers. These groups were characterised within a situational framework according to different constraints. Each situation corresponded to a village that was considered representative of a homogeneous situation. A situational framework was established comprising 6 types of villages.

We observed diverse behaviours in the face of similar innovation processes in relatively homogenous zones, and sometimes even within the same village. Farmers may have similar medium- and long-term objectives but different short-term objectives that justify different choices among available opportunities. This led us to use a "constructivist" approach (Chauveau, 1999). In our situational framework, we disregarded geographical and social entities that had previously been defined as operational, such as

47. Up to 80% of transmigrants abandoned their land when they were obliged to only grow food crops, mainly due to lack of control of *Imperata cylindrica*. Those who stayed on all adopted perennial crops.
48. SRAP: Smallhollder Rubber Research Project, implemented by Cirad, ICRAF, GAPKINDO (the Indonesian rubber association) and local NARs (IRRI-Sembawa, Indonesian Rubber Research Institute).
49. Prior to 1998, in Indonesia there were no independant farmers' representatives or organisations, i.e., that were not controlled by the government. Farmers' organisations are still lacking in 2023.

villages, in order to consider smallholders as a "strategic unit". In this way, we were able to emphasise the process from individual decision-making to collective decision-making. However, at the village level, a collective decision may have a significant impact on the farmers' decision-making process with respect to a given problem. Within this framework, we were able to identify behaviours and actions based on similar logic, as well as decisive collective choices or differentiated strategies and were consequently able to identify different groups from those that had been apparent in our first sample of villages.

From a methodological point of view, the qualitative analysis of farmers' strategies led us to use the analytical approach of Yung and Stravinsky (1994), which consists in classifying behaviours according to a "defensive-offensive" gradient of strategies. "Offensive strategies" are defined as behaviours whose objective is economic growth, the accumulation of wealth, and the desire to transform and improve the household's welfare. Defensive strategies are defined as actions aimed at minimising risks, and securing the family's current welfare (for instance, food security as an objective). We then tried to distinguish the strategic groups, the relations that exist between the groups (through a study of the networks and family links) and the innovation processes implemented by the groups.

Identification of the strategic groups

Based on these criteria, behaviour analysis led to the identification of 7 strategic groups according to K. Trouillard (2001):
– *Smallholders who were becoming increasingly specialised in clonal rubber*. These smallholders were gradually replacing their ageing jungle rubber with clonal rubber (38% of those interviewed). Of these smallholders, 35% continued to practice *ladang* but the majority preferred to buy rice rather than to grow it, 70% still tapped their old jungle rubber. *Ladang* was maintained as long as land was available to avoid losing their "right of avail" (usage);
– *Clonal rubber smallholders who specialised in the production of planting material (in a nursery)*. This group was composed of Dayak farmers who originally belonged to the first group. They created nurseries. They replanted clonal rubber under monoculture (50%), in agroforestry systems with fruit trees (25%) or with fodder intercrops (25%). These farmers were formerly leaders, heads of *kelompok* (farmers' groups) and often played the role of knowledge transmitters;
– *Traditional planters in transition*. This group consisted of young Dayaks who worked productive jungle rubber units, and who replanted using clonal rubber as far as their limited means allowed. *Ladang* was still a strategic activity in this group, but had a more social than economic function in maintaining the right of use of land. This strategic group was in transition towards group 1;
– *Young smallholders with off-farm activities*. This group of young Dayaks had access to limited labour resources and to limited areas of productive jungle rubber. They favoured off-farm activity. Some recognized the opportunity offered by nurseries. They lacked the necessary capital to invest in clonal rubber plantations;
– *Traditional "fence-sitters"*. These Dayak farmers continued to rely on jungle rubber and l*adang* and did not replant with clonal rubber. They represented the most conservative group with respect to food security. They did not succeed in using grafting as a means of producing planting material. Lack of capital and technical skills as well as the

absence of appropriate information discouraged them from investing in clonal rubber. If they had access to full credit and a fully identified technological package, they generally changed to oil palm. Most had off-farm employment, mainly as workers on private estates or in local gold mines in order to increase their annual income in the short term;
– *Opportunist owners of private nurseries and people with multiple activities*. These were mainly employees on private estates. At that time, production of planting material was a marginal activity but in a few years, it would replace off-farm jobs. Using their own limited means, they planted clonal rubber in agroforestry systems, as these systems require less labour and less capital investment. They also planted oil palm and viewed any new crop opportunity very favourably. Those who pursued multiple activities were mainly Javanese transmigrants who found themselves in a very precarious position, or people who traded as a way to diversify their income;
– *Javanese transmigrant opportunists*. This group comprised old Javanese farmers who had *sawah* but did not plant clonal rubber because of land scarcity. They pursued commercial activities, particularly cattle rearing and sale. These producers continued traditional practices and favoured short-term accumulation of wealth with the security of an immediate and regular income obtained by working on the estates.

Farmers' strategies and pathways

The strategies we identified are grouped in Table 2.16.

Table 2.16. Type of farmer strategies in 1997

Type of farmers	Strategies	Type of strategies
Rubber smallholders	Planting and replanting	Offensive
	New planting by young farmers	Offensive
	"Fence-sitters", no plans for the medium term	Defensive
People pursuing multi-activities	Diversification	Offensive
	Development of trade or production (entrepreneurs)	Offensive
Workers on estates	Diversification	Offensive
	Fence-sitters who gave priority to the short term	Defensive

The strategy of replanting with clones was slowed down (or blocked), at least initially, when farmers had access to alternatives, e.g. off-farm activities or oil palm. Consequently, there were links between short-term strategies (off-farm) and long-term strategies (new plantations or replanting). Current replanting was funded by salaries (earned off-farm) or income from new oil palm plantations. At the time, we hypothesised that in the medium term, incomes generated by oil palm plantations would fund replanting with clonal rubber.

Smallholders developed diversification strategies while maintaining traditional practices including agroforestry. The persistence of traditional practices is proof of the attachment people have to traditions and social standards, and consequently to cohesion and social structure, at least at the community (village) level. Indeed, the whole process of social organisation is concerned with maintaining these practices, in particular the deployment of labour. Farmers with an off-farm job and/or who were involved in multiple activities changed their social behaviour in the sense that working off the farm implies making concessions with respect to social standards and in particular abandoning the use of *gotong-royong* (collective labour) due to lack of availability. This social rupture, together with the economic cost of such labour, may also explain the progressive abandonment of *ladang*.

Strategic groups as the expression of different pathways/courses of action

Farmers' courses of action over time are particularly influenced by their access to projects (clonal rubber, production of planting material/nurseries, oil palm, even *Acacia mangium* on a smaller scale[50]), which were seen as new crop opportunities and as part of the global innovation process. Farmers integrated these alternatives to varying degrees depending on how appropriate the innovations were for them. We thus observed different courses of action in similar contexts. Three main pathways based on changes in practices emerged from our analysis.

– The first pathway emphasised the shift from jungle rubber to clonal rubber (monoculture or agroforestry). This pathway maintained traditional production systems based on jungle rubber (for Dayaks) and *ladang/sawah (for* transmigrants*)*, with the progressive incorporation of clonal rubber through access to government projects or by their own means (10-20% of farmers accomplished it in this way in the five years preceding the survey)[51]. This pathway was directed towards rubber specialisation and improving productivity and enabled some diversification of activities. Some Javanese farmers chose this pathway which involved changing from traditional off-farm and *ladang/sawah* to plantations (either oil palm or rubber depending on the opportunities available). This strategy aimed to secure income and intensify production. Jungle rubber was expected to progressively decrease and eventually to disappear.

– The second pathway was characterised by a move to off-farm activity and the adoption of oil palm. It involved progressive substitution of similar traditional Dayak or Javanese systems of temporary off-farm activity, which were short-term strategies, by rapid adoption of oil palm, which is a long-term strategy, for the generation of income. In this case, jungle rubber was progressively abandoned. But later on, income from oil palm could be partially invested in new clonal rubber plantations.

– The third pathway was "mixed and opportunist". It combined complementary traditional systems (jungle rubber and *ladang*) with off-farm activities and other crop opportunities, i.e., oil palm (through development projects) and clonal rubber (generally using their own money, particularly for the production of planting material). Emphasis was on intensification and crop diversification to secure an income in the medium and long term.

Conclusion

Agrarian dynamics are characterised by internal conflicts in rural society and in communities as well as by conflicts with other stakeholders (the State, private estates, etc.), by dependence on markets (export crops) and on different projects. Proposed

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50. Forestry plantations with *Acacia mangium* are proposed to some farmers by HTI semi governmental estates (Hutan Tanaman Industri)

51. Results of SRAP surveys in Kalimantan (K Toruillard, 2001) and in Sumatra (Komardiwan/Penot, 2001).

development models are often irreversible but the strategies developed by the farmers in the face of such constraints are extremely varied, and include activities outside the agricultural sector. Innovation through intensification, diversification, and off-farm activities are some of the pathways available to farmers in a global context characterised by market uncertainty and economic crises. In 2024, these pathways represent the baseline of agrarian dynamics. They have been constantly changing since the end of the 1970s, which saw the introduction of development project policies for perennial crops. In the case of rubber, it took 30 to 40 years for clones to technically prevail over jungle rubber (but clonal plantations still only represent 15% of the total area planted to rubber), whereas less than 10 years were sufficient for oil palm to become "the new crop" thanks to the increase in private estates. Both a strong innovation process and market pressure drive agricultural dynamics.

These pathways are the result of changes and advances in farming systems that led us to design prospective scenarios for the future of the West Kalimantan province. The first "only oil palm" scenario would result in the complete abandonment of jungle rubber and *ladang* and their replacement by oil palm. This is a scenario of substitution. The second "diversification" scenario is more balanced with endogenous development of clonal rubber plantations (monoculture or agroforestry) in addition to oil palm, with temporary off-farm employment in the estate sector to guarantee income during the transition stage. This is a scenario of adjustment and complementarity.

Scenario 2 appears to be the most realistic. Indeed, the development of oil palm through private estates will probably continue for the next 10 years until the mid-2030s assuming land availability and the Indonesian economic context. Land and labour are still plentiful in Indonesia compared to in its neighbours, for instance Malaysia, and this leaves scope for smallholder development as well as for export crops. After that, the continuing development of oil palm and rubber plantations on farmers' own initiatives, in the absence of state or other projects, or alternatively, the establishment of more estates, will require an increase in farmers' organisations like *Kelompok Tani* as well as access to micro-credits. Clonal rubber systems have great potential as they are more accessible to local farmers than oil palm and also ensure ecological sustainability thanks to their agroforestry component. The availability of planting material as well as its satisfactory quality are pre-requisites for this type of endogenous development. Scenario 1 might apply in highly saturated zones with severe land scarcity such as transmigration areas or in areas entirely under the control of private estates.

These scenarios need to be discussed in detail with local stakeholders in order to account for their concerns and their vision of the future.

⏩ RAS case studies in southern Thailand

Thailand is currently the world's number one rubber producer with 4.77 million tons in 2017, corresponding to 37.1% of global production. In the last 5 years, rubber production has continued to increase at an average rate of 4.3% per year. It is the only country where rubber has been almost exclusively cultivated by family farmers. This is largely due to the fact that the country has never been colonised, the Thai State has strongly supported family farms, and has never had a policy which encouraged private investment and large-scale industrial plantations (Fox and Castella, 2013; Chambon et al., 2018). Support for family farms in the south, the cradle of rubber cultivation in the 1950s and 1960s, was also provided for political reasons, mainly to counter the communist rebellion (as was the case in Malaysia) and represented an important source of income for local farmers (Besson, 2002). Despite the trend in some neighbouring countries (land concessions to create rubber plantations awarded to foreign investors) during the rubber boom triggered by increasing rubber prices in the late 2000s, industrial plantations in Thailand still only account for 7% of total rubber production (FAOSTAT, 2019).

Thai rubber plantations are characterised by two cropping systems: (i) monoculture, which is now the most widely-used system (85% of rubber), and (ii) agroforestry with various level of intensification (different types of RAS), based on rubber associated with different crops (fruits, vegetables, tubers, shrubs), estimated to account for 15% of the rubber growing area in southern Thailand according to surveys conducted by Chambon (FTA project – Forest, Trees and Agroforests; 2021, published in Penot et al., 2023). Almost all smallholders use rubber clones mostly the RRIM clone either in monoculture or RAS. The average yield of these rubber trees in 2000 was 1,360 kg/ha/year, in 2016, it was around 1,500 kg/ha/year, and in 2020, close to 1,700 kg/ha/year (RAOT, 2021 annual report).

Since 2016, both the institutional and ecological environments have been highly favourable for the development of agroforestry practices based not only on food inter-crops during the immature period but also for the association of fruit/timber and rubber trees in complex agroforestry systems. The vast majority of farmers use the RRIM 600 clone. The original single clone policy is somewhat risky in case of a major disease outbreak, but the policy of using clonal rubber on a large scale through the rubber replanting programme has been successful. Some partial clone diversification at small scale has occurred with RRIT 251 and BMP 24 as well as RRIM 2000/3000 series, introduced illegally from Malaysia (B. Chambon, personal communication).

The main tree species that have been tested by local farmers alongside rubber are the following:

– Timber trees: neem or thiem (*Azadirachta excelsa*), thang (*Litsea grandis*), a timber tree that regenerates naturally in rubber plots, teak (*Tectonia grandis*), mahogany (*Switenia macrophylla*), phayom or white meranti (*Shorea talura*), tumsao (*Fragacs fragans*), *Acacia mangium*, rattan (*Calamus caesius* seems to be the most promising),

– Fruit trees: salak (*Sallaca* spp.), durian (*Durio zibethinus*), longkong (*Lansium domesticum*), sator (*Indonesian petai*), *Parkia speciosa* or Nita tree, jack fruit (*Artocarpus heterophyllus*), cempedak (*Artocarpus integer*), and mangoustan (*Garcinia dulcis*).

– Other species: coffee (*Robusta canephora*), pineapple and banana.

Many studies have been conducted by Thai researchers at PSU (Prince of Songkla University), TSU (Thaksin University) and KKU (Khon Kaen University) since 1990. Here we summarise their main results. Tree diversification was found to be an important step forward by small-scale farmers to remain economically viable (Somboonsuke, 2001b). Tree diversification can also provide timber and environmental services (Joshi et al., 2006); help reduce the risk of the hevea being blown over during storms; and reduce the amount and severity of surface runoff, thereby reducing soil erosion (Kheowvongsri, 1990; Jongrungrot and Kheowvongsri, 2021). Plant diversification favours carbon fixation, and has also been shown to reduce daytime temperatures in summer in rubber-based intercropped plantations compared with mono-cropped hevea (Hughes et al., 2012).

In 1996 in Phangnga province (South Thailand), a rubber-based agroforestry system with old jungle rubber (more than 40 years old) was reported that had also been enriched with bamboo, rattan species, and multi-purpose trees (timber plus trees whose leaves are consumed) such as miang and manboo without Latin names identified (Kheowvongsri, personal communication). Old jungle rubber was still present in Phattalung and Songkhla provinces in the 2010s (authors' personal observations).

Overview of RAS in Thailand in the 2010s

First, surveys conducted by B Chambon in all rubber producing areas of Thailand in 2016/2018 provide an overview, after which key studies conducted between 2005 and 2020 are reviewed.

The data presented here were collected for projects with specific objectives between 2016 and 2018. The surveys conducted for the different projects were of rubber-based households in the South, Centre-east and Northeast, i.e., the three main rubber-producing areas of Thailand (see Table 2.8). At the time of the survey, all the respondents selected had at least one mature rubber plantation. For some projects focussed on harvesting and post-harvest practices, farmers were also selected based on the type of products they were selling (coagulum or field latex). Although each survey had specific objectives, questions were always included to characterise the rubber cropping systems and particularly agroforestry practices.

The total sample included 771 farms, but the distribution of the sample: 270 farms (35%) in the South, 348 farms (45%) in Northeast and 153 farms (20%) in Centre-east was not representative of the geographical distribution of the rubber farms in Thailand. Consequently, the results are presented here for each region and not for the sample as a whole. This also allows us to highlight possible regional specificities in agroforestry practices.

Diversification is a very common strategy in Thai rubber-based households (Chambon et al., 2021); diversification at the farm level takes the form of non-rubber crops or livestock raising and at the household level, in the form of off-farm activities by members of the household. Here we focus on another level of possible diversification i.e., at the level of rubber plot through agroforestry practices. Most farmers in all three regions had only one or two rubber plots (Table 2.17). However, some farms especially in the Northeast had up to six rubber plots.

Table 2.17. Number of rubber plots per farm in the different regions (% of farms)

Number of plots	Centre-East	Northeast	South
1	61.4	47.7	58.5
2	28.1	31.9	26.7
3	6.5	15.5	13.0
4	2.6	3.2	1.1
5	0.7	0.9	0.7
6	0.7	0.9	0.0

Agroforestry practices during the immature period of the plantations

Whatever the region, intercropping during the immature period of the plantations was common but not systematic. At least 31% of the farmers in the Centre-east and up to 58% in the two other regions had never intercropped during the immature period of their rubber plantations, whether they were immature or mature at the time of the survey (Table 2.18). Intercropping in immature rubber plantations was reported to have long been a common practice among Thai smallholders, and was already mentioned in the early 1970s (Garot, 1970). Intercropping in young rubber plantations was encouraged by the Rubber Authority of Thailand for farmers who received a replanting subsidy (from the Office of Rubber Replanting Aid Fund, ORRAF). The economic interest of the intercrops, i.e., reducing management cost compared with a monocropping system and providing a substantial source of income during the unproductive period of rubber, is well known (Laosuwan, 1988; Polthanee, 2018; Hougni et al., 2018) particularly for poor farmers (Min et al., 2017).

Consequently, we expected intercropping to be adopted by all the farmers; however, in our sample, this was not the case. Indeed, constraints to the adoption of intercrops during the immature period were also well known and could explain why all Thai rubber farmers did not systematically practice intercropping: the condition of the soil, topography, location of the plot, the availability of family labour (which is considered by Langenberger et al. (2017) as being the most important factor in the adoption of intercropping) and marketing opportunities for cash crops (Masae and Cramb, 1995; Somboonsuke et al., 2011). The farmers' perceptions (and the fear that intercropping may be detrimental to the rubber trees) has also been found to limit the adoption of intercropping in some areas (Hougni et al., 2018).

Some authors also mentioned that the level of adoption of intercropping during the immature period of the plantations varies over time depending on the socio-economic situation (Hougni et al., 2018; Jin et al., 2021). In our case for instance, farmers who owned both immature and mature rubber plantations in the very early 2010s may not have needed to intercrop in the immature plots since the income produced by the mature rubber plantations at that time when the price of rubber was very high meant additional income from intercrops was not essential. Supporting the hypothesis concerning intercropping in mature rubber plantations, Romyen et al. (2018) mentioned that the adoption of agroforestry practices was motivated by the need for alternative income, which was provided by the intercrops. This is probably also true for the immature period and could explain the different practices we observed.

Centre-east was the region where intercropping was the most common. The percentage of farmers who planted intercrops in all their rubber plots was much higher than in the two other regions. One of the reasons for this difference could be that in the Centre-east, it was quite common that the owner of a rubber plantation let someone else cultivate the intercrop and in return, this person was responsible for maintaining the rubber trees. This eased the family labour availability constraint. But in these circumstances, the only advantage for the owner of the plantation is avoiding (or reducing) the cost of labour for the maintenance of the rubber plantation as owners do not usually receive any of product or income from the intercrops. Renting out the rubber land in the immature period was also popular in Sri Lanka where this increased the adoption of intercropping practices (Herath and Takeya, 2003) and supports the hypothesis that it may also have facilitated the adoption of intercropping in the Centre-east region of Thailand.

It should be noted that, when a farmer had several rubber plots, the same intercropping practices were not always used in all the plots. Similar observations were also made in China (Min et al., 2017a). In Thailand, the reasons could be linked to the specific characteristics of each plot (type of soil, distance from the homestead to the village, topography/water situation) or to the availability of labour on the farm which could differ for plots established at different periods (different stages in the household life cycle).

Table 2.18. Intercropping practices during the rubber immature period (with number of farms in brackets)

	Center-East	Northeast	South
Yes in all plots	56.2 [86]	27.9 [97]	32.6 [88]
In some plots	12.4 [19]	14.4 [50]	9.6 [26]
No	31.4 [48]	57.8 [201]	57.8 [156]

In about three quarters of the cases, the household planted the same intercrops in all their rubber plots during the immature period out of habit (e.g. a popular crop in the area where the household lived). The remaining farmers who had more than one rubber plot planted different intercrops: this could be linked with the characteristics of the plots, the preference of the person growing the intercrops or market concerns (Tables 2.18 and 2.19).

Table 2.19. Use of the same intercrop(s) in all the plots during the immature period of the plantation (with number of farms in brackets)

	Center-East	Northeast	South
Yes	79.4 [27]	71.7 [43]	76.9 [30]
No	20.6 [7]	28.3 [17]	23.1 [9]

In most cases in the Centre-east and Northeast, only one type of crop was associated with rubber, but in the South, almost half the farmers planted mixed crops in the inter-rows of some or all their rubber plantations in the immature stage (Table 2.20).

Table 2.20. Only one crop associated with rubber during the rubber immature period (with number of farms in brackets)

	Center-East	Northeast	South
Yes in all plots	85.7 [90]	89.1 [131]	57.9 [66]
In some plots	3.8 [4]	2.7 [4]	4.4 [5]
No	10.5 [11]	8.2 [12]	37.7 [43]

The most frequently associated crops during the rubber immature period were (Table 2.21):
– short term crops (rice, corn, peanut, watermelon, melon, vegetables such as cucumber, pumpkin, calabash, long bean, aubergine, rosella, chili), particularly in the Northeast (peanut, rice, corn) and the South (the other short-term crops). Short term crops were less common in the Centre-east;
– tubers (almost only cassava) in the Northeast and to a lesser extent in the Centre-East. In the Northeast, cassava was intercropped in both upland and lowland plantations, whereas rice was only intercropped in lowland plantations (Hougni, 2018). Polthanee et al. (2016) reported that cassava intercropped with immature rubber produced a five times higher net income than banana. Indeed, the market for bananas was not much of an incentive for farmers in the Northeast, where the crop was more considered as an indicator of soil fertility and/or soil moisture content (Hougni, 2018). A market and the farmers' habits were probably important drivers of the choice of cassava as an intercrop in Northeast. Tubers were rare in the South;
– multi annual crops, mainly in the Centre-east (pineapple) and in the South (mainly banana and to a much lesser extent pineapple). Pineapple provides a very high income (380,000 THB/ha/year), much higher than banana (21,500 THB/ha/year; Somboonsuke et al., 2011). We did not find much intercropping with papaya even though it is a potentially interesting intercrop in Southern Thailand (Choengthong et al., 2014). Multi-annual crops were rare in the Northeast for reasons that need to be explored;
– fruit trees and parkia species mainly in the South; in some cases, these long-term crops were planted at the same time as the rubber trees whereas in others, perennial crops were planted before rubber and were continued during the immature period of the rubber trees (e.g. in the case of conversion of another plantation to a rubber-based agroforestry system). The conversion of fruit tree plantations into rubber plantations was also observed in the Centre-east (author's personal observation).

Table 2.21. Percentage of farms in each region where intercrops were observed during the immature period (number of farms in brackets)

	Centre-East	**Northeast**	**South**
Short-term crops	10.5 [11]	38.8 [57]	45.6 [52]
Tubers	34.3 [36]	64.6 [95]	2.6 [3]
Multi-annual crops	57.1 [60]	4.1 [6]	39.5 [45]
Fruit trees and parkia	7.6 [8]	0.7 [1]	20.2 [23]
Timber tree	2.9 [3]	0.0	1.7 [2]
Pak miang	0.0	0.0	6.1 [7]
Other*	2.9 [3]	6.8 [10]	7.0 [8]

* rattan, palm, betel nut, bamboo, lemongrass, galangal, curcuma, napier grass, ruzi grass, jasmine, tobacco, coffee, eucalyptus.

Although they were not present in our sample, some crops including marigold that procure a very high income but only in niche markets have been reported in Northeast Thailand (Hougni, 2018) and could represent opportunities for farmers who have the necessary connections.

Farmers in all the three regions rarely planted cover crops (Table 2.22). This is not specific to Thai rubber farmers, but applies to rubber smallholdings in general (Langenberger et al., 2017). Leguminous cover crops have long been recommended notably to prevent soil erosion (Baulkwill, 1989 cited by Langenberger, 2017) Research was conducted many years ago to identify potential cover crops adapted to Thailand (Sukviboon et al., 1986). In Northeast Thailand, climbing cover crop species that have to be removed from the rubber tree trunks continuously for three years require additional labour which probably limited the adoption of these species (Hougni, 2018). In addition, research conducted in this region showed that using leguminous cover crop in rubber plantations located in dry areas does not necessarily benefit the rubber trees (Clermont-Dauphin et al., 2018), which may have further limited the use of cover crops, particularly in dry areas.

Table 2.22. Use of cover crops during the immature period of the plantations (number of farms in brackets)

	Center-East	Northeast	South
Yes in all plots	0.7 [1]	0.9 [3]	0.7 [2]
In some plots	0	1.1 [4]	0.7 [2]
No	99.3 [152]	98.0 [341]	98.5 [266]

Agroforestry practices during the mature period of the plantations

Intercropping during the mature period of the rubber plantations was rare in the Centre-east (fruit trees and timber trees) and the Northeast (bamboo); and in the South, less than 20% of the farms had intercrops in at least some rubber plots (Table 2.23). The use of agroforestry practices in mature rubber plantations was low compared with in Indonesia (Penot, pers. comm) but quite high compared with previous reports in Thailand. Indeed, according to Charernjiratragul et al. (2014) cited by Romyen et al. (2018), the percentage of farms in which rubber agroforestry practices were used in the two southern provinces they studied was only around 2%, which seems very low compared to the survey by Stroesser and Chambon.

Table 2.23. Intercrops during the mature period of the plantations (number of farms in brackets)

	Centre-east	Northeast	South
Yes	2.6 [4]	0.3 [1]	13.3 [36]
Some	0.7 [1]	0.0	4.1 [11]
No	96.7 [148]	99.7 [347]	82.6 [223]

Even if few publications (at least in English) describe the rubber cropping systems used when rubber was first planted in Thailand, agroforestry systems in the South have a long history. Before 1960 and the implementation of the rubber replanting programme, farmers used a "conventional rubber production system" also called "rubber forestry or rubber community forestry" (Somboonsuke, 2001) which corresponds to Indonesian jungle rubber. It was not the only cropping system at that time, as other authors identified other rubber monocropping systems (e.g. Besson, 2002), suggesting that rubber agroforestry practices are long-standing. With the implementation of the rubber replanting scheme by the Office of Rubber Replanting Aid Fund (ORRAF), jungle rubber has been progressively replaced by rubber monoculture, which was the technical model promoted by the scheme for a long time. Today, very little jungle rubber remains (Penot and Ollivier, 2009; Stroesser et al., 2018), and most clonal plantations are monoculture.

However, rubber agroforestry systems reappeared with the economic crisis in 1997 and started to be more widely used (Somboonsuke, 2001). Since 2008, Thai government policy has changed and a maximum of 15 intercrop tree species can be planted per rai, the equivalent of 94 trees per ha (Romyen et al., 2018) and agroforestry practices were even promoted from 2014 on (Stroesser et al., 2018). These developments encouraged farmers to establish RAS. However, implementation is still limited for two main reasons: 1) the government policy encouraged rubber monoculture through the Office of Rubber Replanting Aid Fund scheme where permanent agroforestry systems were forbidden for decades, and 2) farmers lacked incentives and often the knowledge they needed to adopt RAS (Romyen et al., 2018). Earlier, Somboonsuke and Shiratoki (2001) also identified capital, labour investment, and marketing issues and sometimes water shortage as further constraints to the adoption of RAS. Based on our personal field work and on other surveys of farmers, we could also add that, as long as land pressure is not too high, farmers seem to prefer to separate crops (which is consistent with the on-farm diversification observed we mention in the previous section). This is probably linked to the farmer's lack of knowledge about RAS, i.e., that RAS could improve their margin per ha and their farm's resilience (Stroesser et al., 2018), plus contribute to food security, especially for the poorer farmers, as well as to some extent increase the biodiversity of the rubber plantations (Warren-Thomas et al., 2020). Wider adoption of RAS by farmers will certainly take time, but tools like innovation platforms could help (Theriez, 2017). Labour is undeniably a major constraint (and will probably increase) for the implementation of RAS as most associated crops (except timber trees) require additional labour. Thus the promotion of RAS would need to be combined with other technical innovations to improve labour productivity in rubber plantations such as low intensity tapping systems. Additional research is also needed to strengthen the rubber authority's recommendations to the farmers concerning agroforestry.

In the South, the most common intercrops were *Gnetum* (local name pak liang or pak miang) present in 38% of the farms with intercrops and fruit trees (36%). *Gnetum* is a shade tolerant shrub that provides a regular income all year round; fruit trees generate an annual income but only for a few months per year. These two types of agroforestry systems were found to produce a high gross margin per hectare (Stroesser et al., 2018). Other intercrops were *Parkia* species, timber trees, different species of palms (bamboo, oil palm, betel nut, coconut) and banana (all present on between 8.5% and 13% of the farms).

Farm typology according to agroforestry practices

Based on the farmers' intercropping practices on rubber plantations, we made four groups: 1) farmers who had never planted an intercrop, 2) those who had intercrops in at least some plots but only during the immature period of the rubber trees, 3) those who had intercrops at least on some plots but only during the mature period of the plantation, and 4) those who had intercrops at least on some plots during both the immature and mature period of the plantation.

Table 2.24 shows the very significant difference in the distribution of farms based on their agroforestry practices in the different regions (statistically confirmed). The total absence of intercrops was much more common in the Northeast and the South than in the Centre-east. In the Centre-east, the proportion of farms in the group with intercrops during the immature period was much higher than in the other regions. Farmers in the group with intercrops during both the immature and mature periods were mainly located in the South. This is also the case for farmers who only grew intercrops during the mature period of the plantations, quite a marginal practice.

Table 2.24. Distribution of groups of agroforestry practices according to the region (number of farms in brackets)

	Centre-east	Northeast	South
None	29.4 [45]	57.1 [198]	51.9 [140]
Immature period	67.3 [103]	42.7 [148]	30.7 [83]
Mature period	0.7 [1]	0.0	4.8 [13]
Immature and mature period	2.6 [4]	0.3 [1]	12.6 [34]

Analysis of agroforestry practices in Songkhla area in 2005 when rubber prices were high

In 2005, producers considered the rubber price to be "acceptable". The results of a 2005 study on 20 farms in southern Thailand (Phattalung and Songkhla areas)[52] indicated that it was advisable to diversify and to cultivate another crop in addition to rubber to be able to survive periods of crisis, which then happened in 2012 and continues today (2023). 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 in particular plays an important role in the study area as a way of diversifying farm income; based on a solid value chain and with a very good price. To grow durian at the same time as rubber on the same plot enables farmers to minimise the impact of a decrease in income when rubber prices drop. Durian and rubber are very complementary crops; the market for durian is currently very good and the long-term prospects are very promising (Figures 2.9 to 2.11).

However, the rubber/durian system has a number of drawbacks: it is intensive, requires a lot of both labour and inputs, and the farmers require a good knowledge of the necessary technical itineraries. Diversification, intercropping, and associating timber or fruit trees with rubber for the purpose of income diversification and risk management, seem to be a good alternative to the current trend towards specialisation in rubber. Some farmers cultivate fruit trees as an intercrop, or in agroforestry systems that appear to be a promising way to cope with rubber price volatility as there is a good market for fruit in Thailand, thanks to high urban demand particularly for duku

52. This study was conducted by Aude Simien in 2005 under the supervision of Éric Penot, Cirad and Professor Dr Buncha Somboonsuke and Dr Vichot Jongrungrot from PSU (Prince of Songkla University).

langsat, in the study area. Some trials have been 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 (i.e. double spacing with large inter-rows) in southern Thailand. The study described above was implemented in a period when rubber was profitable due to relatively good prices compared to prices during the 1997-2002 slump. Farmers' behaviour and strategies are closely linked to – and may even depend on – their type of production system as well as on opportunities for diversification (fruit trees, particularly durian). The smaller farms grow either rubber in monoculture or rubber combined with some upland rice plots. Both are relatively efficient as far as intensification is concerned.

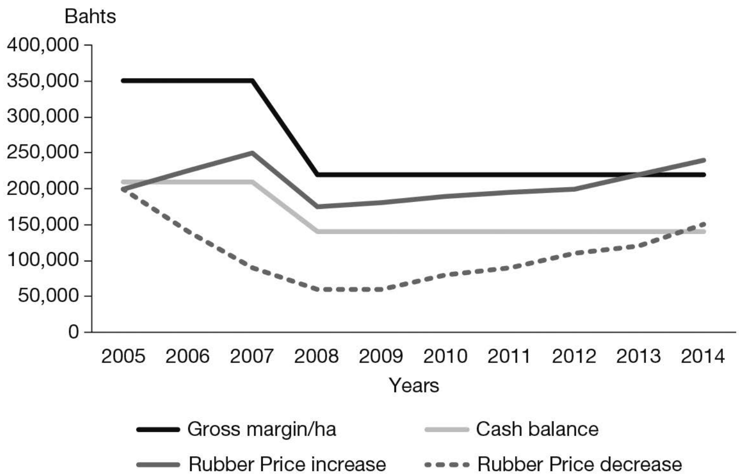

Figure 2.9. Economic results of farming systems based on rubber monoculture in 2005 and future prospects

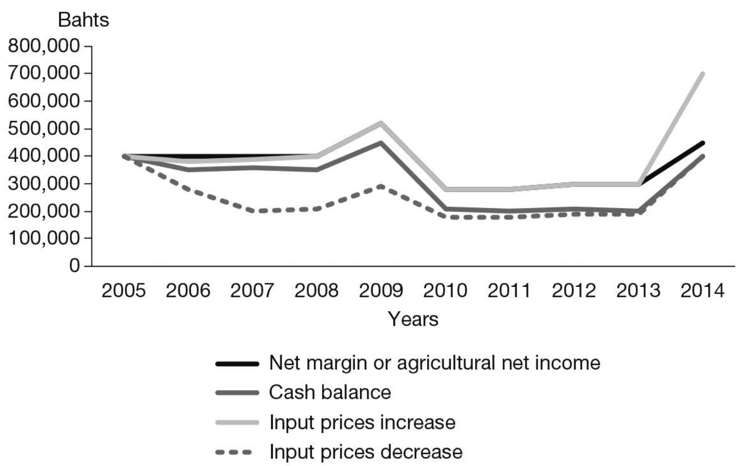

Figure 2.10. Economic results of farming systems based on rubber-durian RAS in 2005 and future prospects

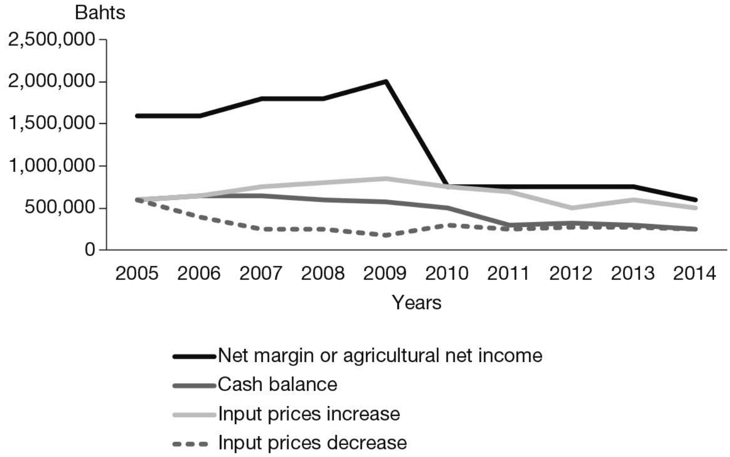

Figure 2.11. Economic results of farming systems including rubber-durian RAS plus mixed activities in 2005 and future prospects

Durian clearly plays the role of economic buffer in the eventuality of a new drop in rubber prices. In other words, for some time now, southern Thailand has been diversifying rubber systems and farming systems in order to strengthen its economy and to be more resilient in the face of possible future crises that affect commodity prices.

Economic analysis in Songkhla and Phattallung in 2012

Jongrungrot et al. (2014a) conducted a study in Songkhla and Phattalung provinces in Southern Thailand. Twelve farmers who practiced rubber-based intercropping were selected based on their social characteristics (the farmer was a member of a group or a network of farmers who practiced and promoted rubber-based intercropping) and the diversity of their agroforestry practices. The 12 farmers had a total of 19 rubber-based intercropped plots that were used to record the socio-economic characteristics of the farms concerned. Eight of the 19 plots were selected for a prospective analysis for the decade 2012-2021.

Selection was based on economic outputs (margin per ha) in 2012; potential to generate a higher income thanks to intercropping; four groups were created based on the age of the rubber trees (< 7 years old, 7-15 years old, 16-25 years old, > 25 years old); and species diversity.

Rubber was associated with different kinds of timber or fruit trees. In all, the sample contained 21 different timber species, 10 kinds of fruit trees, and 9 kinds of other plants. The most popular intercrop species was Ironwood, which was found in seven plots, followed by *Gnetum gnemon* and bamboo, each found in five plots. Next came eaglewood, white meranti, and salacca (fruit palm tree), each found in four plots. Regarding plant diversity, between 2 to 12 species were observed per plot, at densities ranging from 368 to 5,125 trees per ha. This is consistent with the results of several studies conducted by scholars in Thailand and overseas. For example, Joshi et al. (2006) found that rubber-based agroforestry systems could generate income from a variety of species including timber, increase food security, and provide environmental benefits, including biological diversity, carbon dioxide fixation, watershed protection and soil conservation.

The plots were classified in 3 groups based on simulation of the margins of the eight plots for the decade 2012-2021. The price of rubber selected for the simulation was the price in 2012, which was still a very good price compared with the top price recorded in 2011. The gross margins/ha trajectory of the eight most representative RAS for the decade are summarised below (Jongrungrot et al., 2014).
– High margins with a gradual increase and a stepwise increase: Plot 9 (trajectory 4) and plot 13 (trajectory 3).
– Medium margins with a gradual increase and fluctuating development: Plot 19 (trajectory 4), plot 7 (trajectory 4), plot 16 (trajectory 3), and plot 4 (trajectory 3).
– Low margins with a gradual increase: Plot 1 (trajectory 4) and plot 14 (trajectory 1).

Overall comparison of the estimated margins showed that all plots will have a higher margin per ha in 2021 than they had in 2012; and six out of the eight plots will have a higher margin per ha during the period 2013-2021 than they had in 2012. The reasons for these two findings are that rubber and intercropped plants will continue to produce yields with age; after 2013, the rubber trees in four out of the eight plots will be more than 21 years old and their yield will remain unchanged, while the yields of the intercropped trees will increase with age or will start to yield; and the old rubber in one out of the eight plots will be cut down by the farmer and sold as timber. All the RAS plot patterns are described in appendices (Table S1).

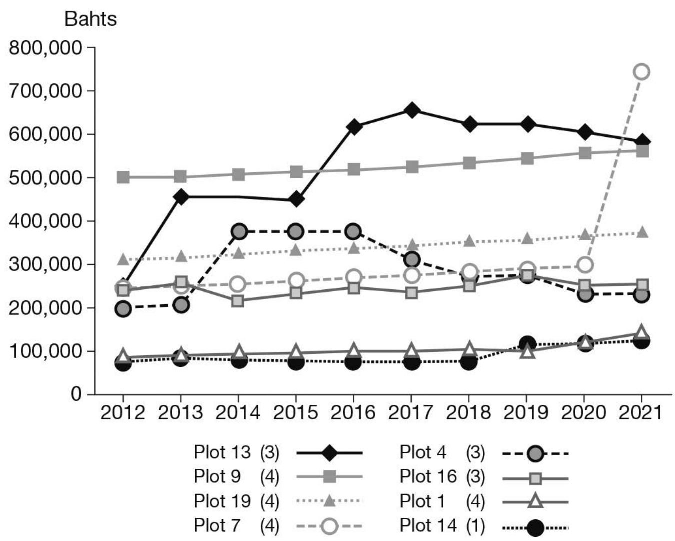

Figure 2.12. The gross margins/ha trajectory of the eight most representative RAS for the decade studied by Jongrungrot et al. (2014)

Comparison of rubber monoculture and 3 types of RAS based on timber and bamboo

Romyen et al. (2018) compared a rubber monoculture system with three rubber agroforestry systems: rubber combined with ironwood and eaglewood (S1), rubber combined with ironwood and champak (S2), rubber combined with bamboo (S3). All three systems used the same rubber density (7 × 3 m) but S1 and S2 added 18 other trees per rai[53] (112 trees per ha) and S3 added 72 bamboos per rai (448 bamboos per ha) in the rubber plantations. Tapping started slightly earlier in the intercropped systems, with the first tapping 6.6 years after planting compared with 7.2 years under rubber monoculture. Based on a rubber lifespan of 28 years in all four systems and an interest rate of 9.25%, they found that rubber combined with bamboo (S3) was the most profitable, followed by S1 and S2 (respectively, 71.5%, 70.4% and 46.3% increase of the net present value (NPV) over rubber monoculture).

Agroforestry patterns in Phattallung province in 2016

This study was conducted in Phatthalung province, Southern Thailand[54], in the framework of the ANR/Heveadapt project. The goal was to analyse how smallholder tree plantations can adapt and survive in the face of profound changes in socio-economic conditions. The study focussed on mature plantations in rubber-base agroforestry systems to understand the extent to which respectively, rubber, associated crops, trees, livestock, and off-farm activities, contributed to income stability and farm resilience. Socio-economic performances were evaluated at both the cropping system and the farming system scale, using farming system modelling with the software *Olympe*. Characterisation of the economic structure of the farms shed light on two main strategies used by farmers to maintain their income despite volatile rubber prices: income diversification through agroforestry and income diversification through off-farm activities. The best agroforestry systems, both in terms of return on land and on labour, was associating rubber trees with fruit and timber trees. Farmers also had off-farm jobs to complement their family income. Finally, prospective modelling showed that most farms were robust to rubber price volatility due to the flexibility of their agroforestry systems. Farmers with no agroforestry system were weakened by over-reliance on rubber trees.

Agronomic description of the different types of agroforestry systems

Associated plant species used in rubber plantations under agroforestry in Phatthalung province (southern Thailand) were of three types: fruit trees, timber trees and perennial vegetables. In the 64 rubber plots comprising the sample[55], fruit trees were present in 39.06%, timber trees in 31.25% and perennial vegetables 29.69% (Table 2.26). This shows that fruit trees dominated, but also revealed significant differences, i.e., fruit trees provide annual food and income, timber only provides a one-off income (when felled) while perennial vegetables provide regular food and regular income (Tongkhaenkhew et al., 2020).

A total of 44 plots belonging to 64 farmers were selected to describe the coexistence of associated plants in rubber agroforestry plots with complex (34%) and simple agroforestry systems (66%). The associated plants grown in rubber plots were divided into

53. 1 rai = 1,600 m².

54. This study was conducted by Laetitia Strosser, under the supervision of Benedicte Chambon, Éric Penot from Cirad and Uraiwan Tongkaemkaew from TSU (Taksin University, Phattallung).

55. This part was written by Uraiwan Tongkaemkaew from TSU (Taksin University, Phattallung), Bénédicte Chambon and Éric Penot from Cirad. Source: Laetitia Stroesser, Éric Penot, Isabelle Michel, Uraiwan Tongkaemkaew and Bénédicte Chambon, 2018. Income diversification for rubber farmers through agroforestry practices. How to overcome rubber price volatility in Phatthalung province, Thailand. Revue Internationale du Développement/Editions de la Sorbonne n°235 (2018-3), https://dialnet.unirioja.es/servlet/articulo?codigo=6537375.

seven groups based on their characteristics: four types of complex agroforest: (i) fruit trees and timber trees and perennial vegetables (26.7%), (ii) fruit trees and timber trees (33.3%), (iii) fruit trees and perennial vegetables (33.3%), (iv) timber trees and perennial vegetables (6.7%); and three types of simple agroforest: only one fruit tree species (37.9%), only one timber tree species (34.5%), only perennial vegetables (27.59%). The different associated crops were planted either using a systematic or an unsystematic system (Table 2.27).

In the agroforestry system, timber trees and fruit trees were planted in both of systematic and unsystematic systems with multiple and simple systems combined with perennial vegetables (Table I.2). After fruits and vegetables, timber trees were the third choice for local farmers as timber trees have significant advantages including low labour requirements for maintenance, but the income is generally only available at the end of the rubber life span. Fruit trees require a large labour force particularly in the harvest season and large quantities of inputs (fertilisers and pesticides) to ensure good yields.

Table 2.26. Associated species used in rubber plantations in Phatthalung province, southern Thailand

Associate species in rubber plots	No. of rubber plots*	%
Fruit trees	25	39.06
Timber trees	20	31.25
Perennial vegetables	19	29.69
Total	64	100.00

*One plot may contain more than one associated plant.

Table 2.27. Rubber agroforestry system in Phatthalung province, southern Thailand

Rubber Agroforestry systems	Systematic system		Unsystematic system		Total	
	N° rbp*	%	N° rbp*	%	N° rbp*	%
Complex agroforestry system	***6***	***40.00***	***9***	***60.00***	***15***	***34.09***
1. Rubber+fruit trees+timber trees +perennial vegetables	1	25.00	3	75.00	4	26.67
2. Rubber+fruit trees+timber trees	1	20.00	4	80.00	5	33.33
3. Rubber+fruit trees +perennial vegetables	3	60.00	2	40.00	5	33.33
4. Rubber+timber trees +perennial vegetables	1	100.00	0	0.00	1	6.67
Simple agroforestry system	***21***	***72.41***	***8***	***27.59***	***29***	***65.91***
5. Rubber+fruit trees	8	72.73	3	27.27	11	37.93
6. Rubber+timber trees	7	70.00	3	30.00	10	34.48
7. Rubber+perennial vegetables	6	75.00	2	25.00	8	27.59
Total	***27***	***61.36***	***17***	***38.64***	***44***	***100.00***

* rbp=rubber plot.

Local perennial vegetables require less labour and few inputs, indeed, they grow well in the shade and can be harvested regularly. RAS in Thailand resembled RAS 2 and RAS 3 in Indonesia (Penot, 2001; Wibawa et al., 2006). RAS technologies in Indonesia were developed between 1994 and 1998 at ICRAF, including some following a visit to Thailand in 1996 to take advantages of existing local agroforestry systems.

Species of associated plants in mature rubber plantations

Twelve families and 20 species of fruit trees were found, mostly local fruit species (Tongkaemkaew et al., 2020): 5 species of the Palmae family: coconut, salak, sala, *areca* nut palm and kelumi. The *Anacardiacea* family came in second with marian plum, plum mango and mango. *Meliaceae*, *Moraceae* and *Sapindaceae* families were represented by two species in each family: longkong and langsat, jack fruit and champedak, rambutan and longan, respectively. *Bombacacaeae, Guttiferae*, *Leguminoae-Minosodeae*, *Minosaceae, Myrtaceae*, *Phyllanthaceae* and *Stilaginacea*e families were each represented by only one species: durian, mangosteen, niang, sator, wa, burmese grape and black currant tree, respectively. However, mangosteen, longkong, langsat and salack were the fruit trees most frequently associated with rubber.

The timber trees were distributed in 8 families and 15 species. The timber tree species were mainly wild varieties that are common in the southern region. Timber trees species in the family *Dipterocarceae* were takian, takina thong, payom and yang na. The *Meliace* family was represented by three species: bay wood, Siamese neem tree and mahogany. The *Malvaceae* family was represented by large and small-leaved hua. The *Labiatae, Lauracea, Leguminosae-Minosoideae, Magnoliaceae, Rubianceae and Barringtoniacea* families were each represented by one species: teak, litsea, brown salwood, champak, tuku and karuk. These timber trees species were found in all the study sites. Rubber agroforestry systems with timber trees can include several species associated simultaneously. Some of them grow naturally and are left in place by the farmers; others are planted by the farmers (Table S2 in appendices).

The species of perennial vegetables depended on the dietary habits of the people in the south (vegetables harvested once and vegetables harvested over a period of more than 3 years) belonged to six families and six species (see Table S2 for Latin names). These were phak nam (local name), phak miang (local name, *Gnetum* sp.), pineapple (used to make local dishes like *"kaengsom, pad peaw hwan"*) bamboo, pandanus palm and rattan palm. The most frequent companion crops in this group were phak maing, phak nam and pineapple, frequently consumed by southern populations. These crops also grow up very well in the shade and require little labour for maintenance (Table S2 in appendices).

The plants grown in association with rubber are popular as little labour is required for their maintenance, they are resistant, grow satisfactorily in the shade and already have good local markets. Through the development of both simple and complex rubber agroforestry systems, farmers have been able to diversify their sources of income with minimal establishment and maintenance costs. The Rubber Authority Of Thailand (RAOT) could promote such systems better and write their recommendations according to RIIT (Rubber Research Institute of Thailand). The role of RAOT is still to provide smallholders with the necessary technical and financial assistance to plant or replant rubber, to which could be added the promotion of rubber agroforestry systems.

Economic analysis

This section has been previously written in 2018 (Stroesser et al., 2018)[56] and revised.

In 2018, the following working hypotheses were formulated: (i) farmers construct RAS through progressive diversification of monoculture systems, (ii) among farms with AFS, agroforestry plots are combined with monoculture plots in different ways, (iii) AFS can effectively withstand the volatility of natural rubber prices and (iv) farmers reserve different shares of their land for AFS, because they have other opportunities to diversify their income. As the majority of studies provide qualitative descriptions of agroforestry, in this section, we provide an economic analysis of the impact of agroforestry on agricultural income.

To compare RAS cropping systems, we used economic indicators such as yield, gross margin (GM/ha) and return to labour as GM/hour of family labour. To compare the different activity systems (farm plus household), we used the following indicators: (i) net farm agricultural Income: the sum of every net margin (NM) of every product, (ii) the origin of on-farm Income: the gross margin (GM) of each product (rubber, fruits and vegetables, livestock products, etc.) divided by the sum of GM, (iii) the calculated net total income (cNTI): the sum of every NM plus off-farm income, before self-consumption, which made it possible to compare the economic efficiency of the farms, (iv) the real net total income (rNTI): the sum of every NM and off-farm income, minus self-consumption, to assess the real income including on- and off-farm incomes and (v) the cash balance: the rNTI minus all family consumption and expenses, self-consumption included (equivalent to cash flow).

By comparing farms and strategies, we provide useful up-to-date economic information for actors of the future innovation platform. Farms were classified in two operational typologies: (i) based on the AFS structure at the cropping system scale, inspired by the work of Somboonsuke (2011), Charernjiratragul (1991) and Jongrungrot (2014a), and (ii) based on the farm structure at the scale of the activity system, based on the household's incomes. The main drivers of farmers' strategic choices, which were briefly broached during surveys, complete this second typology. The main discriminant factor for farm typology was the type of AFS used as a means of diversification.

Using these typologies (cropping systems and activity systems), we modelled each type of rubber farm using *Olympe* software (developed jointly by INRA/Institut national de recherche agronomique, Cirad and IAMM/Institut agronomique mediteranéen de Montpellier; Penot, 2012). The first objective was to run simulation scenarios based on economic risk to analyse farmers' choices and feed a prospective analysis to understand current and future farmers' decisions. Modelling scenarios also enabled us to measure farm resilience.

From the 32 farmers we interviewed, we obtained an inventory of 53 agroforestry plots, of which 64% associated fewer than four different species and 36% associated four or more different species. These AFS are best classified based on the type of species associated with rubber trees: fruit trees, timber trees or vegetables. Vegetables

56. This section was extracted from Stroesser L, Penot E, Michel I, Tongkaemkaew U, Chambon B, 2018. Income diversification for rubber farmers through agroforestry practices. How to overcome rubber price volatility in Phatthalung province, Thailand. *Revue Internationale du Développement/Éditions de la Sorbonne*, 235(3):117–145. https://doi.org/10.3917/ried.235.0117

(*Gnetum gnemon* Linn. in this study) can be sold almost all year round, whereas fruit trees are harvested only a few months a year and timber trees are cut only once. We also identified an average technical management system for each type. The AFS based typology comprises 5 main types (all mature):
– MatAFVg: mature rubber trees only associated with vegetable species (AF for agroforestry, V for vegetable): *Gnetum gnemon* or pak liang/pak miang. The strategy is based on diversification with pak liang.
– MatAFFr: mature rubber trees associated with fruit and sometimes vegetable species: an average of 280 trees/ha: mangosteen (*Garcinia mangostana* L.) [Mangout], stink bean (*Parkia speciosa* Hassk.) [Sator], salacca (Salacca edulis Reinw.) [Sala] and *Gnetum gnemon*. The strategy is based on fruit diversification and access to markets.
– MatAFTb: mature rubber trees only associated with timber species: an average 180 trees/ha: ironwood (*Hopea odorata* Roxb.) [Takian thong], neem tree (*Azadirachta excelsa* (Jack) Jacobs.) [Sadao tiam], tung (*Litsea grandis* L.) [Thung], mangium (*Acacia mangium*) and champaka (*Michelia champaca* Linn.) [Jumpa]. This is typically a long-term strategy where the end product (timber) is sold at the end of the life span of the rubber trees.
– MatAFMx: mature rubber trees associated with fruit, vegetables and/or timber species: with an average 310 trees/ha; mangosteen, longkong (*Lansium domesticum* Corr.) [Longkong], *Gnetum*, ironwood; neem tree, tung and champaka. This is the most diversified strategy with multiple short- and long-term products.
– MatAFLv: rubber trees associated with livestock and other plant species. (only 2 plots): rubber associated with 59 trees/ha: longkong, durian, stink bean, rambutan and 125 trees/ha: neem tree, tiam, ironwood and white meranti (*Shorea roxburghii* G. Don.) [Payom]. The diversification strategy includes livestock products.

Figure 2.13 compares return to family labour, i.e., the gross margin per hour of family labour (GM/h), for each type of AFS and for a mature rubber monoculture (family labour is not a cost). In the case of sharecropping, a worker receives 40% to 50% of the yield. The AFS types with the best return to land (AFLvA, AFLvB and AFVg) have the worst family return to labour. Taking care of the herd and harvesting *Gnetum* are very time consuming. Fruit is only harvested 2 months a year, which explains the better results obtained by AFS types AFMx and AFFr. Two categories are included in type AFMx, depending on fruit yield and the use (or not) of a tapper. In general, farmers with AFS type AFMxA have better fruit yields and hire tappers. Type AFTb provides a GM/h close to that of rubber monoculture.

Figures 2.13 and 2.14 show the wide diversity of RAS which explains why the RAS is the main discriminant factor in the following farm typology.

The list below gives the most representative features of each type linked to the discriminating criteria, and the sample distribution:
– type AR: Rubber producers who earn less than the minimum wage (6/32 farmers): with 3.9 ha of mature rubber plantations, 24% in agroforestry mainly with AFFr (0.4 ha) and AFVg (0.3 ha). Their incomes are one third lower than the minimum wage.
– type AO: Diversified producers who earn less than the minimum wage (3/32 farmers): with 1.2 ha of mature rubber plantations, 31% in agroforestry mainly with AFMx (0.2 ha) and AFFr (0.2 ha) + 1.1 ha of non-rubber crops/trees. Their incomes are half the minimum wage.

– type B: Farmers who depend on another income, earn less than the minimum wage (6/32 farmers): with 1.4 ha of mature rubber plantations, 38% in agroforestry mainly with AFTb (0.2 ha) and AFLv (0.2 ha) + financial support from family. Incomes are one third lower than the minimum wage.
– type CR: Rubber producers who earn more than the minimum wage (3/32 farmers): with 3.6 ha of mature rubber plantations, 21% in agroforestry mainly with AFMx (0.6 ha) and AFFr (0.2 ha). Their incomes are 50% higher than the minimum wage.
– type CO: Diversified producers who earn more than the minimum wage (5/32 farmers): with 1.9 ha of mature rubber plantations, 50% in agroforestry mainly with AFFr (0.7 ha) + 1.2 ha of non-rubber crops/trees. Their incomes are 50% higher than the minimum wage.
– type D: Farmers who earn more than the minimum wage thanks to their off-farm activities (1/32 farmers): with 2.1 ha of mature rubber plantations, 42% in agroforestry mainly with AFFr (1 ha) + 1.2 ha of non-rubber crops/trees + several other activities. Their income is 20% higher than the minimum wage

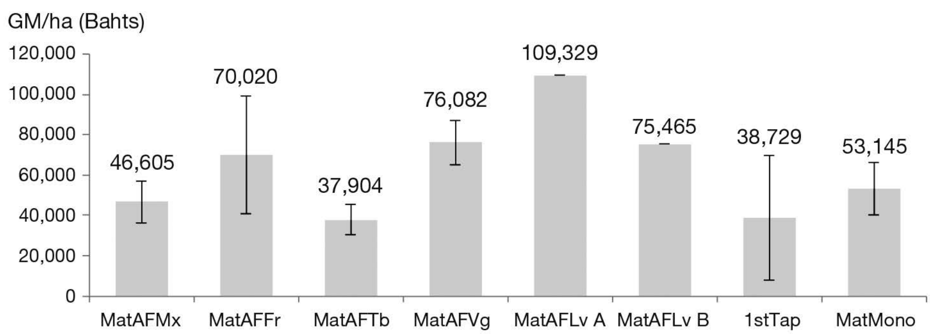

Figure 2.13. Gross margin/ha for the different types of AFS and rubber monoculture

Note all system acronyms are explained in the 5 preceding bullet points. MatAFVg = rubber + *Gnetum gnemon/*Pak liang, MatAFFr = rubber + fruits and vegetables with 280 trees/ha, MatAFTb = rubber + timber species/180 trees/ha, MatAFMx = rubber + fruits + vegetables +timber species (310 trees/ha,) MatAFLv = rubber + livestock + other plant species.

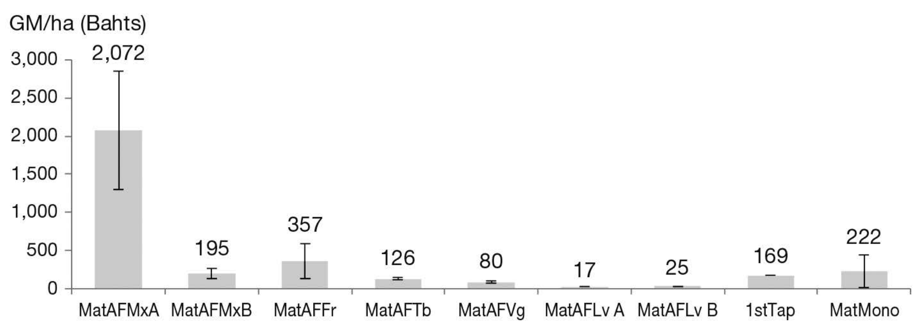

Figure 2.14. Family return to labour for each type of AFS and for a rubber monoculture (GM/h for family)

MatAFVg = rubber + *Gnetum gnemon/*Pak liang, MatAFFr = rubber + fruits and vegetables with 280 trees/ha, MatAFTb = rubber + timber species/180 trees/ha, MatAFMx = rubber + fruits + vegetables +timber species (310 trees/ha,) MatAFLv = rubber + livestock + other plant species.

– type E: Farmers who earn far more than the minimum wage thanks to their on-farm activities (4/32 farmers): with 10.5 ha of mature rubber plantations, 73% in agroforestry mainly with AFTb (5.4 ha) and AFMx (1.6 ha) + 1.7 ha of non-rubber crops/trees. Their incomes are between 2 and 28 times higher than the minimum wage.
– type F: Farmers who earn far more than the minimum wage thanks to their off-farm activities (4/32 farmers): with 2.9 ha of mature rubber plantations, 75% in agroforestry mainly with AFMx (1.6 ha) plus other off-farm activities Their income is four times higher than the minimum wage.

We observed that all three strategies (relative rubber specialisation, on-farm diversification and off-farm diversification) are applied in all the classes.

Prospective modelling of RAS

Among several scenario options, we selected variant agroforestry patterns.

First, seven variants were created for each type of farm to show the impact on economic results of a process in which the choice of agroforestry on economic results was not yet definitive (Figure 2.15). The sub-variants are based on a lower rubber price.
– Variant: Combination of AFS and monoculture plots (Comb) = farms in the current situation with land under rubber-based agroforestry that ranges from 23% (T-AR) and 65% (T-F).
– Variant: specialisation Agroforestry (AF). This refers to the previous variant taken to the extreme. Within each type, we replaced monoculture plots by their agroforestry equivalent and split the areas as a proportion of the distribution of the existing AFS.
– Variant: specialisation Monoculture (Mono). This refers to the other end of the spectrum of farmers' possible strategies. It was constructed in a similar way to the previous variant: we replaced agroforestry plots by their monoculture equivalent, while respecting the type of labour force used for tapping. Other plots were left unchanged.

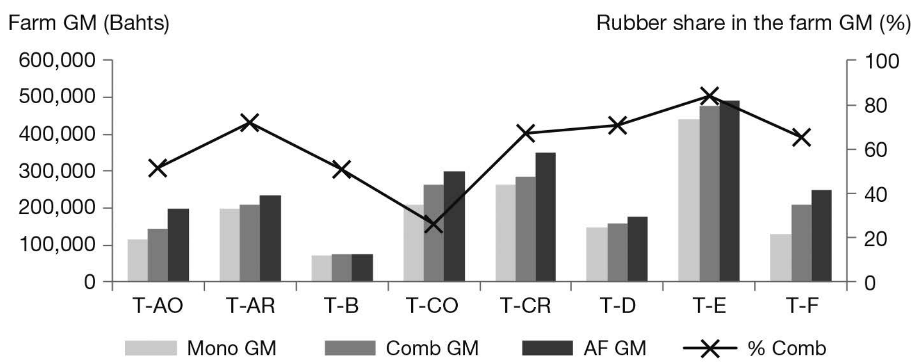

Figure 2.15. Comparison of variants Mono, Comb and agroforestry for the 8 farm types, in the context of a low rubber price (RubL)

Indicator: Farm Gross Margin = Gross Agricultural Income. Type T-AR = Rubber producers who earn below the minimum wage, Type T-AO = Diversified producers earning below the minimum wage, Type T-B = Farmers who depend on another income earning below the minimum wage, Type T-CR = Rubber producers who earn above the minimum wage, Type T-CO = diversified producers who earn above the minimum wage, Type T-D = Farmers who earn above the minimum wage + off-farm activities, Type T-E = Farmers who earn far more than the minimum wage+ diversification on-farm activities, Type T-F = Farmers who earn far more the minimum wage + off-farm activities.

– Variants in the volatility of the price of natural rubber. For each variant in the proportion of agroforestry, we created three variants based on variations in the price of rubber. The price was fixed for each 10-year simulation period.
– Sub-variant: Low rubber price (RubL). This refers to the average price cited by farmers for 2014-2015 and was used to represent the current situation: 50.0 THB/kg dry (US$1.4/kg dry). The price of rubber had dropped far lower in the past (20.5 THB/kg dry in 2001 = US$0.57/kg dry), but as some surveyed farmers had already stopped tapping, the current price was already considered low.
– Sub-variant: High rubber price (RubH). This refers to a high average price calculated based on 2010-2012 (TRA 2015): 105.4 THB/kg dry (US$2.9/kg dry).
– Sub-variant: Rubber price judged “acceptable” (RubA). This refers to the most frequently observed “average” price between 2007 and 2014. Farmers consider this to be the “normal” or “average” price: 81.0 THB/kg dry (US$2.3/kg dry).

Conclusion

The goal of the study was to understand the extent to which rubber, associated crops, trees, livestock, and off-farm activities, significantly improve household income and resilience. Diversification of on-farm activities was high: 50% of the farmers (16/32) raised small livestock, sold other farm products (tree seedlings, food, wood, etc.), collected and sold rubber as a collector. Fruits and vegetables were the second source of on-farm income for the majority of farmers. Many farmers completed their on-farm income with off-farm activities (56% of our sample). AFS were usually created by planting trees in existing monoculture rubber plantations.

Several authors mentioned that in addition to the association of different species, planting density and the timing of planting associated species are also important factors (Tongkaemkaew et al., 2020; Jongrungrot, 2014a and 2014b). Most associated plants can be planted at the same time as rubber as long as shade is provided for species that require it, for instance banana shading for timber trees. On the other hand, some plants might be planted 2/3 years after rubber to profit from the shade provided by rubber, e.g. certain timber species (*Dipterocapacees*) that are only planted three years after the rubber trees to enable cultivation of annual intercrops.

In the beginning (1980s and 1990s), farmers did not adopt AFS with a market-oriented objective, but to fulfil food (fruit) and social functions, which are very important in Southern Thailand. This social role was more important than obtaining a monetary income. However, the increasing volatility of natural rubber quickly made farmers aware of the economic advantages of these systems. The advantage of diversifying on-farm income was confirmed by the sensitivity study on the threshold rubber price required to obtain the same income without agroforestry practices: the lower the price of rubber, the greater the capacity of agroforestry (combined with fruits and/or vegetables) to maintain on-farm income while compensating for volatile rubber prices. Farms are more economically resilient in the face of fluctuating prices, but also face the price volatility of other products (mostly fruits and vegetables, such as mangosteen). Farmers are interested and motivated by RAS as members of agroforestry groups or networks that are a source of information and experience for other farmers. This sample could thus be the basis of a structured network on AFS, for instance in the framework of an innovation platform.

RAS groups and networks as a way towards an innovation platform

The study was conducted in Phatthalung province in southern Thailand in 1916[57]. The aim was to show that smallholder rubber plantations can adapt and remain sustainable despite variable climatic conditions and profound socio-economic changes. Agroforestry practices were identified as promising among the various types of cropping systems. RAS are economically more productive than rubber monocrop plantations and give smallholders more flexibility, particularly when rubber prices are low, which has been the case since 2013. However, adoption of AFS during the mature period of plantations in Thailand has been very limited. The policy to boost rubber agroforestry practices by all local stakeholders thus still requires improvement.

The objectives of the study were to identify the potential and capacity to use current AFS dynamic networks as a basis to set up a rubber agroforestry innovation platform. To this end, the research team studied: (i) farmers' collective organisations, groups or networks with full or partial RAS and (ii) the social dynamics that enable the sharing of knowledge and know-how. An individual producer's grid was created that identified original farmers or farmers with good knowledge and the ability to share. The role of local institutions involved in the promotion of RAS was also analysed.

The results enabled the design of an innovation platform and of activities suited to the socio-economic context of Phatthalung province. The main aims of the platform are to promote cooperation among innovative producers and the transmission of knowledge and know-how about RAS among them. An innovation platform is an efficient tool that Thai rubber institutions could set up to encourage the adoption of RAS by farmers.

Even if agroforestry during the first three or four years of the immature phase is rather common, i.e., is practiced on 65% of plantations spread across 10 provinces in Thailand (Delarue and Chambon, 2012), growing food crops between the rows of tree can provide an income in the period before the new plantation becomes productive. In the 1980/1990s, some farmers continued to cultivate AFS by choice despite the ORRAF ban. Located in the south, these farmers associated clonal rubber trees with on average, 2 or 3 other perennial species (fruit trees such as durian, mangosteen and longan, and timber trees such as teak and mahogany). A few rare "jungle rubber" systems still exist in Phatthalung province (first author's personal observations, 2017), as well as in Phang Nga province (Penot and Ollivier, 2009). Those farmers are usually members of associations or informal networks in order to share their knowledge and experiments and to promote their systems (Jongrungrot, 2014a). ORRAF officially lifted its ban in 1992, while maintaining interest in and funding replanting in the case of rubber monoculture. In 2001, some AFS trials were set up by ORRAF and AFS was officially promoted by the rubber act. In practice, AFS were really only promoted to

57. This study was conducted by Marion Theriez under the supervision of Bénédicte Chambon and Éric Penot from Cirad and Uraiwan Tongkaemkaew from TSU. It was published by Marion Thériez in 2017. Rubber production in Phattalung province, Thailand: potential of a regional innovation platform emergence to co-design innovative agroforestry systems, IRC SupAgro, Montpellier, France. The study is part of "Heveadapt," a Franco-Thai research project. Sources are Éric Penot, Marion Thériez, Isabelle Michel, Uraiwan Tongkaemkaew, Bénédicte Chambon. 2022.Agroforestry rubber networks and farmers groups in Phatthalung area in Southern Thailand and potential for an innovation platform. *Forest and society*, 6 (2), November Issue Published May 14, 2022.

deal with low rubber prices after 2015. There is an old tradition of agroforestry under specific conditions, but AFS are currently a marginal practice.

In 2015, the Rubber Authority of Thailand (RAOT) changed its policy and began to promote AFS practices in an attempt to overcome the strong negative impact of rubber price volatility on farmers' incomes. Some AFS farmers promoted a different approach to rural development, through His Majesty the King's "New Theory of Agriculture", which later became the "sufficient economy philosophy", which is socially very important for these farming communities. The downward trend of rubber prices after 2012 certainly also influenced farmers' attitudes. RAS certainly fits the scope of this new approach.

Phatthalung province in southern Thailand, the historical rubber production area, was chosen as the study site. We first present the conceptual approach and then describe the sample and surveys we conducted, after discussions with local key informants in a preliminary village information meeting. Due to dissemination of potential AFS farmers, a representative sampling method was not feasible, leading to selective sampling. The selection criteria were based on RAS representativeness and group recognition, and resulted in the selection of 54 producers who were subsequently the subject of individual interviews: 8 producers representing the Banna agroforestry community (Sri Nakarindra), 5 from the Lung Toon network (Tamod), 9 from the Lung Boonchu network (Pa Phayom) and 29 individual producers who did not belong to any group or networks and were considered as individuals independent of any structure. The idea behind the selection of groups, networks and satellite farmers was to be relatively representative of RAS in the province in order to set up a future innovation platform rapidly at the regional level. (Table 2.29).

Innovation platform

An innovation platform is an interactive tool to explore opportunities and solutions (Nyikahadzoi et al., 2012), to exchange knowledge and practices through experiments, observations, evaluation, and discussion. Such platforms enable multi-directional exchange of know-how and knowledge among stakeholders (Tittonell et al., 2012) in addition to being a social tool that stimulates collective action and discussion and increases people's ability to innovate (Tenywa et al., 2011). An innovation platform constantly evolves, along with its environment and its members.

An innovation platform has different stakeholders; in our case farmers, researchers, institutions, technicians, companies, carriers, etc. with different profiles and different objectives, but who can find a common solution to problems through discussion. Each individual defines his/her opportunities and weaknesses and his/her part in the work to be accomplished. Each individual can act on one or more points of the chain. Partners need serious collaboration to solve problems and develop innovations: they make decisions together. An innovation platform can be implemented at different scales: local, regional, or national depending on the scale of the stakeholders and their different levels of involvement (Nyikahadzoi et al., 2012). The present study aimed at creating a regional platform with a focus on RAS.

Farmers' knowledge and know-how are widely recognised in a regional innovation platform (IP). But in political terms, an institutional framework and the participation of local leadership are also essential. The challenge is to strengthen the capacity for innovation of the group by creating strong relations in the IP, and by improving everyone's understanding. Group skills evolve over time. Every stakeholder should feel concerned about and involved in the platform and its topics. At the beginning, researchers can be facilitators, defining the potential, characteristics and responsibilities of every stakeholder in order to boost farmers' participation and encourage sharing. The IP can design a stakeholder's diagram (Tenywa et al., 2011). The IP is the forum for knowledge sharing. In concrete terms, in a regional IP, sharing working days on the farm with several farmers can be implemented through sessions with a farmer-to-farmer approach, training courses, specific agroforestry events, regular meetings, etc. In the present study, we focus on what seems to be best suited to the Phatthalung area.

Main results

Table 2.29 lists the groups and networks selected in this study, as well as satellite individual farmers.

Table 2.29. Formalisation of organisations studied in Phatthalung

Name	Banna agroforestry community	Lung Boonchu network	Lung Toon network	Satellite farmers
District	Sri Nakarindra	Pa Phayom	Tamod	9 districts
Focus	Agroforestry	Diversification	Agroforestry	Diverse
Type of structure	Group	Network		Farmers who practice innovative agroforestry
Characteristics	- Established list of members - Regular meetings - Share financial expenses - Share an identity, a history and values	- Not all members know each other - No regular meetings - No delimitation		- Farmers who talk about agroforestry with neighbours, family, friends, groups but are not specialised in AF - Producers located throughout the territory who are not affiliated with any group or network

All the groups have their own network (Table 2.30) or belong to an interaction network between neighbours (only at the village level) with whom they have been able to share government support for a local project. Ultimately, they all interact with a social network, albeit often limited to the village level. Satellite producers may also have access to a DOAE (Department of Agricultural Extension) learning centre on specific practices on their farm. Finally, every producer has at least one within-village network and is not isolated. Table 2.30 describes the three local groups/networks we surveyed and considered to be representative of the different communities in the area.

The "pioneer farmers" began intensive agroforestry as early as in the 1990s. The number of network members was not originally fixed, but was tending to stabilise in 2014. The difference between networks and groups is the perception of a group of people with reciprocal interactions, in a network, new people can be easily integrated. In contrast, in a group, the framework is less flexible: there is a fixed list of members and participation in events or meetings is often a prerequisite for organisation. Finally, these groups and/or networks include several villages, but rarely extend beyond neighbouring sub-districts. Only the Lung Toon network, which is located on the border of Tamod sub-district, extends over two sub-districts. The objectives of each group/network are listed in Table 2.31.

Table 2.30. Identity card of the groups surveyed

Name	**Banna agroforestry community**	**Lung Toon network**	**Lung Boonchu network**
Leader	Lung Jay	Lung Toon	Lung Boonchu
Leader's age	67	69	64
Date of birth of the collective	1995	1993	2004
Subdistrict	Banna	Tamod and Kong Yai	Pa Phayom
Villages	Moo 2, Moo 5, Moo 8	Tamod: Moo 4, Moo 9 Kong Yai : Moo 2	Moo 5, Moo 6, Moo 7
Longest distance between two members	6.3 km	3.3 km	4.5 km
N° of members	8 members	> 10 members	> 10 members
Main objective	To preserve local species	Increase forest area by preserving local species and natural resources	Access agricultural knowledge in order to increase farmers' incomes

Table 2.31 Objectives and activities organised by the groups/communities

Name	**Objectives**	**Tools and activities**
Banna agroforestry community	- Develop new markets for producers - Increase producer income - Share knowledge - Use good environmental practices	- Take part in government activities - Use the group's combined production to negotiate prices - Visit farms - Lead projects to obtain funding
Lung Boonchu initial group	- Reduce dependency on inputs - Crop diversification - Find innovative species to mix with rubber trees - Develop knowledge networks	- Training organised by the government - Create local markets - Visit farms - Make organic compost - Group production to obtain good prices and new consumers - Make joint applications for funding
Lung Toon initial group	- Plant as many trees as possible - Cultivate organically - Convince as many people as possible to plant trees and use organic farming practices	- Help each other with hard tasks - Allow everyone to obtain free seedlings from the forestry department - Write a book about agroforestry - Organise crop diversification activities

These three groups are representative of groups in Southern Thailand. AFS are linked with other development activities such as poultry, fish pond, beekeeping, fruit production, planting timber trees, protecting remaining forests and diversifying crops and income. AFS differs from "integrated farming" but is very similar in terms of strategy. AFS combines cultivation of several products on the same plot, also because land is becoming scarce due to transmission of patrimony from generation to generation within a family. Among possible alternative ways to diversify sources of income, AFS appears to be a key strategy.

DOAE organises inter-village and even inter-district training in learning centres, where producers can discuss their farming practices. These activities are mostly limited to village DOAE leaders, but sometimes allow some producers with a learning centre and/or who are on a DOAE list to expand their network and even get to know members of other groups. Major interactions between networks already take place in Phatthalung. Even though we only found one formal agroforestry group, two dense networks of within-village farmers have developed in parallel. The long history of agroforestry practices is detailed in Kheowvongsri PhD thesis (1996). Originally, Lung Toon and Lung Boonchu were leaders of groups and not of networks. Lung Toon is a leader of a centre for learning on Buddhist agroforestry, and Lung Boonchu, who is the leader of the eponymous network, heads a centre for learning on self-sufficiency and subsistence farming within the framework of the King of Thailand's theory of economy. The general objectives are set out in cognitive and environmental terms. In each group, the initial goal was defined by the leader, who then tried to gather around him farmers who were thinking along the same lines. The communities aim to respond to economic and environmental concerns and to help local farmers obtain government support, but also to participate in field activities.

The leaders of the three groups are quite well known in Phatthalung province. They run small networks to organise activities, obtain funding or set up new development projects. Collectives are open to the outside through dynamic, autonomous and proactive leaders. They create rich interaction networks. Table 2.32 lists the pros and cons cited by each group of being part of an innovation platform.

Sharing knowledge on AFS is a feature shared by all these groups and is an important social dimension for the members of the groups along with an important social feeling of being "knowledge bearers" in a different way than farmers who focus on monoculture.

Six diversification categories were identified that correspond to different benefit and constraint frameworks:

- The association of forest species (20 species), not specifically for sale, and/or fruit/timber species,
- The association of local fruit species (21) and/or fruit for export,
- Combination of vegetable (11) and/or ornamental (7) species,
- Association with cash crops (coffee, palm oil or pepper),
- Livestock or fish,
- Forest wood/timber for fuel wood and valuable timber (minimum of 10 native species).

Producers use one or more diversification pathways on their plots and generally practice more than one type of AFS. Each AFS defines a framework of specific advantages and constraints for each farmer, which have to be identified and considered before planting, according to each farmer's expectations. The main reasons for choosing agroforestry mentioned in our surveys were (i) lack of land and the need to grow intercrops (21/142), (ii) the desire to experiment with new practices and develop sustainable cropping (35/142).

Table 2.32. Pros and cons for each network/group of being part of an innovation platform

Banna Agroforestry community	Lung Toon Network	Lung Boonchu Netwrok
No longer very active Sri Nakarindra Model project Nursery with native rare plants	This network is expanding The network includes learning centre facilities Tree Bank project	This was the 1st learning centre facility A success story for smallholders
High willingness to share knowledge Innovative and dynamic farmers Demonstration plots Ability to organise training in marketing, plant association, crop management techniques, and native medicinal plants	Desire to preserve natural resources Involves strong minded, convincing and innovative farmers Demonstration plots Capable of organising training in organic farming, timber production and fruit tree management	Aims to follow the king's theory of sufficiency Agroforestry systems Demonstration plots Experimental plots Capable of organising training in livestock raising, fish farming and organic farming.

Proposal for a regional innovation platform for rubber agroforestry systems as a tool to better promote AFS among monoculture smallholders

We acknowledge that the existing groups and network we have described in this study are clearly not sufficient to ensure a boom in AFS adoption. Although it is true that all the preconditions for such an AFS boom are present: (i) existing groups and farmers with AFS plots that can be used as demonstration plots for other farmers, (ii) the farmers have real knowledge and master basic AFS practices and have a real desire to share their knowledge, and (iii) there is an economic need for most rubber farmers to increase their gross margin/ha through diversification given the long period of low rubber prices, what is lacking is a regional organisation capable of transforming local opportunities into real challenges for larger communities. Political capacity does exist through the very large and active local administration (e.g. RAOT and the Ministry of Agriculture and Forests). A regional innovation platform could take up the challenge. What is needed is the political will to support it and funds to get the process underway.

The platform presented in figure 2.16 would involve many stakeholders. The main stakeholders would be farmers, donors and the government agencies (RAOT and DOAE), supported by researchers from local universities (PSU and TSU) who provide knowledge, and the local institutions and their technicians who advise farmers and the private sector (in processing and sales). The key to success is regular meetings with all the stakeholders to discuss future actions, to plan and organise actions and share the results with other stakeholders. An innovation platform is a place to share, decide and implement AFS activities, to develop value chains of products and to discuss AFS policies.

A digital centre could be created (Meta — previously called Facebook — page, website with access to documents, etc.) to pool and share reports and activities, to keep people informed about activities and training courses, with e-learning, published articles, demonstration videos about their agroforestry plots, etc. A forum could also be created in the website.

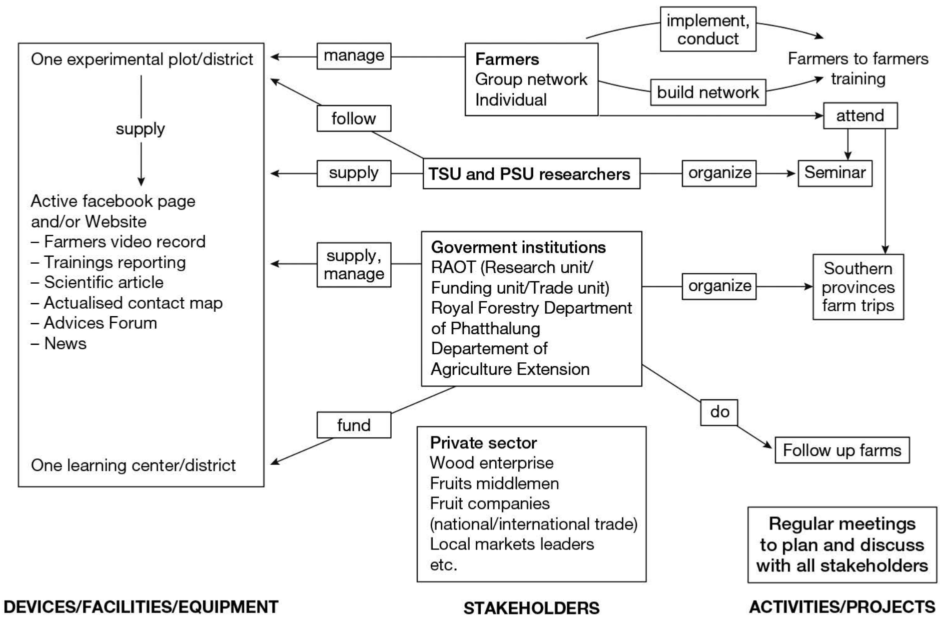

Figure 2.16. Proposed design for an innovation platform (Theriez et al., 2017)

The main axis of the proposed innovation platform is farmer-to-farmer training courses in agroforestry practices. Existing AFS plantations can be selected as “demonstration plots” for training purposes. New plantations could be monitored by researchers like farm trials for the purpose of comparison (two farmers already lead experimental plots), in particular to test double spacing systems which prioritize associating crops and rubber, with fruits that already sell well such as mangosteen and durian. The wide variety of fruits that can be associated with rubber (as well as timber) requires looking for local markets for each product, but at the same time, the variety of products also diversifies the market, which obviously reduces the risk of over production. This study showed that there is real potential for the emergence of an innovation platform for RAS in the Phatthalung area as well as a real demand from local RAOT offices, whose staff are relatively close to farmers via replanting programmes. It is thus possible to offer a range of training courses on the transfer of RAS technology from existing RAS farmers and groups to other farmers. However, the creation of an innovation platform in Southern Thailand requires a concrete political decision by top institutions like RAOT, while forestry institutions also seem to be very keen to contribute.

An innovation platform is a social tool designed to implement new ideas, promote new systems in a rubber-growing world where monoculture still dominates and to innovate rapidly. In Phatthalung, the aim would be to co-design RAS with producers, researchers, development and funding agencies (RAOT, Ministry of Forestry, agricultural extension/DOAE, local banks) and the private sector (fruit sector). Producers' groups organised around neighbourhood networks have existed for more than 20 years and are ready to train other farmers and to innovate agroforestry practices. This study has shown that an important inter-producer interaction network already exists; what is needed now is a detailed analysis of ongoing dialogue between producers in networks which still lack AFS advisers, the frequency of meetings between peers, and the geographical distances at which people interact. In other words, a complete overview of the social and geographical dynamics of the flow of information, knowledge and techniques in agroforestry in Phatthalung is needed.

For farmers, joining a group is a way to join a big network, share knowledge and access government support. The group makes it possible for farmers to participate in many local activities and to share knowledge. The group could be monitored by government agencies including RAOT, DOAE, the natural resources department, the health care department, the livestock department, among others. All local stakeholders already lead actions and organise events to help farmers promote their systems and sell products. Some also provide specific funding. Universities, in particular PSU and TSU, contribute to the dynamics of the sector. Teachers/researchers visit farmers and conduct farm trials. In association with government agencies, they exchange with other groups during official government activities, which concern more than 300 groups in 11 districts in Phatthalung. RAOT should play a central role in the organisation of meetings and the transfer of knowledge and know-how between farmers' groups in a future innovation platform. Meetings, farm visits and training are the most important activities to be promoted by the platform, but access to knowledge via the Internet would also be efficient.

A study of the attendance rate and the type of audience of the "Ko-so-no" (alternative education centre) where computers are accessible free of charge would make it possible to determine whether this infrastructure can offset farmers' current lack of equipment. A strong interactive network of identifiable reference farmers is essential to enable a regional innovation platform involving the main rubber development institutions, such as RAOT, researchers, rubber collectors and buyers, timber, vegetable and fruit collectors, to become immediately operational.

There is a need for further studies of local fruit value chains and for an analysis of the fruit and timber markets, in particular to judge the potential for expansion of the legal timber trade since the market has evolved in the last 10 years. Concerning the fruit sector, it is indispensable to know the saturation levels of the current market and its potential expansion if AFS expands. In 2016, how the timber industry functions is still not known due to illegal trade on the national and global timber markets. The whole sector needs to be reorganised, including the establishment of sawmills and of local timber industries. Finally, the pre-existence of such AFS networks, the sum of immediately exploitable knowledge and know-how and the goodwill of local AFS producers, research and regional institutions have created a climate that is particularly favourable for the establishment of a rubber agroforestry innovation platform.

Some institutions, including the Rubber Authority of Thailand (RAOT), the forestry department under the supervision of the Ministry of Environment and Natural Resources, and agricultural extension departments (DOAE) are aware of the need to support agroforestry. These stakeholders have converging interests, are positively engaged in the promotion of AFS, and are therefore potential partners for the emergence of an innovation platform for rubber agroforestry innovation. A complementary sociological survey at regional level is needed in countries where AFS groups and networks are poorly known.

Conclusions on Thailand

Although long recommended by Thai rubber authorities, intercropping during the immature period of the plantation has not been systematically adopted either by all farmers or in all the plots belonging to one farmer. In addition, intercropping during the immature period has not automatically involved maintaining RAS during the mature period of the plantations.

Despite their advantages, permanent RAS are still rarely adopted by Thai rubber farmers. Although there was formerly a tradition of agroforestry in Southern Thailand, it was almost totally replaced by rubber monoculture with the implementation of the rubber replanting scheme. Nevertheless, changes in the farmers' environment (government measures, rubber prices, research interest) in the last 20 years have created a more favourable context for the development of RAS. Farmers' initiatives have opened the way for changes to the rubber cropping system which need to be supported by research and extension services. There is also a global trend to promote RAS with strong involvement of environmental NGOs (for instance, see Penot et al., 2024) notably in the framework of the Global Platform for Natural Sustainable Rubber (GPSNR).

⏩ Rubber versus other alternatives: what role for RAS?

The need for a specific economic analysis

This section has been originally published in Torquebiau and Penot (2006)[58].

We argue that there is an economic rationale behind the importance of agroforests worldwide, but that this rationale is complex to identify and measure. In the first instance, direct sales of agroforestry products (timber, fruits, vegetables, resin, nuts, rattan, medicinal products, etc.) and self-consumption, which enables significant savings in daily household expenses, are complementary. Beyond this aspect, it has been shown that long-term patrimonial strategies are of utmost importance to the farmers who do practice agroforestry. However, conventional economic analyses based on discounting rates are not ideal for these perennial, multi-component and multi-cycle systems, where future discounted values of tree products are difficult to predict and as such, are seldom taken into account by farmers in their planting choices (Torquebiau et al., 2002), unless the harvested products are easily marketable and generate a net margin which covers replanting costs (e.g. clonal rubber). Finally, farmers also plant and tend agroforests because of their social functions (land tenure, social status, living environment). So, while scientists have continually argued that agroforests are environmentally sound, this is probably not a major incentive for farmers. In Indonesia, the high biodiversity provided by jungle rubber is threatened by oil palm plantations. If a comprehensive economic analysis of agroforests is to be undertaken, it is legitimate that their environmental attributes be taken into account.

58. Chapter "Ecology vs Economics in Tropical Agroforests".

Thus, the objective here is to try to show that the reason behind the "enigma of tropical home gardens" (Kumar and Nair, 2004) lies in elements of positive externalities that are not accounted for in standard economic analyses, yet matter to farmers and perhaps also to other stakeholders (e.g. timber for sawmills). If agroforestry scientists want to convince farmers and policy makers that agroforests are worth considering as land-use options, and not only as relics of the past, appropriate economic analyses of agroforests need to be conducted that include ecological services (e.g. watershed protection, nutrient cycling, functioning as a carbon sink, as a bio-habitat, conserving biodiversity) as well as social, cultural, and aesthetic values.

Following Coase (in Cooter, 1982) and his analysis of social costs, we distinguish between "giving a value to a service" (potentially but not automatically tradable) and "paying for a service" (which leads to "who is going to pay?"). Taking into account (giving a value to a service) or internalising positive externalities (paying for a service) relates to resources or services that cannot be included in private accounting because they are public goods (e.g. landscape beauty, pollinating insects) or because they are preserved for future generations (e.g. biodiversity, soil resources). We argue that such global goods, considered as services to the community, should not only be taken into account in international negotiations on climate change or biodiversity, but also in agricultural policies, incentives and, as a result, in farmers' day-to-day decisions.

One of the services that was likely to be taken into account in the 2000s was the carbon sink function of the Clean Development Mechanism (CDM), which should have been applied in 2012 as scheduled in the Rio and Kyoto rounds. In fact, this mechanism never really worked and was removed in 2016 and replaced by another carbon programme. As rubber was (at the time) the only tree crop FAO considered eligible for CDM (beside timber trees), rubber based (and timber based) agroforests were theoretically eligible. If this is the case, their carbon sink service can be valued and considered in the trade or exchange of pollution rights (Cacho and Hean, 2001). In the 2020s, this mechanism might take first place in a context of climate change and of a "zero deforestation" policy.

Farming system level approach

A first pragmatic approach would be to conduct a household level analysis of the cost saved by products provided by agroforests that consequently do not need to be purchased (e.g. building and fencing materials, food, medicines, raw materials for handicrafts). Next, accounting for environmental benefits could also take place at household level if the surveys are sufficiently detailed and use data compiled over at least a year. Modelling farming systems (e.g. with software like *Olympe*), is a useful way to process data on production, value, cost of production and labour, to be able to compare return to labour and the gross margin of each cropping system at the farm level.

Several case studies have been conducted in Indonesia using *Olympe*, which was specifically designed to obtain an easy, dynamic yet detailed view of the main economic features of a farm, such as margin/activity or crop(/ha/year), return to labour, as well as all sources of income from on-farm and off-farm activities. The simulation is based on a 10-year period. Scenarios can be built according to hypotheses on price volatility (inputs or outputs), yield, or the impact of climatic events. The software provides a dynamic view of the farm trajectory and changes to it resulting from the decisions taken by the farmer, as well as external factors such as prices, risks, or yield (see Penot, 2007).

Economic analysis: a social-ecological perspective

While a farming system approach can enable a better understanding of the different roles of agroforests, there is also a need for a new approach to agroforest analysis to deal with higher levels of complexity and translate their social-ecological[59] performance into economic performance. One apparently irrational behaviour that has been observed in Indonesia is maintaining old rubber agroforests rather than planting economically highly profitable oil palm. One hypothesis was that agroforests would gradually pave the way for oil palm plantations: the social value of agroforests (control over land), the possibility to improve agroforest (with clonal rubber) and diversification strategies that would eventually lead to new self-development of improved rubber agroforests that are within the financial capacity of local farmers who have no access to credit or insufficient capital building capability. In the meantime, despite the enormous gain in return to labour and net margin provided by oil palm, agroforests have never completely disappeared, proof of the value of such systems when they are analysed in a farming system framework and from a social perspective. As a "reserve land factor" or a "long-term land control factor", agroforests may not represent a direct value but they do have an indirect value as a capital reproduction factor or as a potential expanding factor.

Patrimonial analysis, i.e., of changes in ways of building capital and transmitting assets, could be used, as agroforests are considered as land reserves that can be traded, and because trees represent a strategy for building capital for future investment. Long-term multi-cycle analyses should provide a frame to understand farmers' behaviour and long-term trends in farmers' strategies. Economic analysis of mixtures of plants with different length life cycles is also possible through farming system modelling. Smoothing long-term and patrimonial strategies (Torquebiau and Penot, 2006) may help account for the time factor and the historical perspective (e.g. accumulating capital, capacity building).

Subsistence versus cash

The merits of agroforests in providing subsistence food for families, enabling flexible crop production or reducing the need for external inputs also need to be taken into account. The comparison of farms with and without agroforests could reveal the real savings and their impact on household income. However, not all agroforests are based on food crops. Some agroforests are completely cash-oriented e.g. rubber (jungle rubber), resin (Damar agroforest), spices and timber (e.g. cinnamon-durian-timber based agroforest). Home gardens can be labour intensive, and require considerable quantities of inputs.

In 2023, markets are the main driving factor of RAS and most products are sold rather than self-consumed.

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59. The term "social-ecological" implies an interactive system with social and ecological components of equal importance, while the conventional meaning of "socio-ecological" is simply an ecological system with some social aspects (Sayer and Campbell, 2004).

Landscape amenity and social conviviality

The potential of agroforests for the provision of values such as landscape beauty or conviviality for rural societies also needs to be incorporated in their assessment. It seems clear that in many situations, agroforests, and in particular agroforests managed by local communities, and hence considered as a public good with limited but shared access to local resources (fruit, timber), play an important social role. The *Tembawang* of the Dayak people in Kalimantan (Indonesia) is a typical example. In addition to being a reserve of forest products through "extractivism" when original forests have disappeared, these agroforests have important social dimensions as graveyards for Dayak populations in Kalimantan, or may play a role in village protection through the maintenance of a green belt around the village, or by forming concentric layers around the village. Even if there is no economic value (even as a service), its social value will generally prevent its destruction.

Economics in the context of agroforests: rehabilitating the micro-economic approach

Clearly, many particular features of agroforests cannot only be valued as goods. Social value, or the long-term strategic value of a piece of land, are relevant justifications for the existence of agroforests. Risk buffering may be one of the most powerful incentives to maintain or expand agroforests. Modelling farming systems and a prospective approach make it possible to assess the effect of such buffering on risks. Prospective analysis using scenarios will enable the identification of economic thresholds and boundaries and the definition of a domain of economic feasibility.

If the benefits to be had from agroforests (e.g. providing free fuelwood, meeting some nutrient needs, spreading income, contributing to nutritional security, to integrated pest management, to crop pollination, reducing crop failure, acting as a carbon sink) are appropriate for market value analysis, then neo-classical environmental economics can be used and externalities can be included (or re-internalized) in the process of income generation. The cost of pollution and delayed growth can be accounted for as negative externalities or as constraints to further development. Environmental services can be valued according to a "system of values" that is recognised locally as being relevant at a higher level (community or provincial level). The upper level could be the CDM (see, e.g. Cacho et al., 2002 or Albrecht and Kandji, 2003), for an analysis of accounting for carbon sequestration in agroforests in Indonesia (see Hamel and Eschbach, 2001, for the potential impact of CDM on natural rubber).

The real problem is therefore to see if farmers really do — or possibly could — benefit from externalities or from the advantages of agroforestry. In some cases, the answer is yes in terms of savings on the cost of building a home, food in the case of self-consumption, medical treatment thanks to the use of medicinal plants. The answer is less clear, or at least there is no direct profit to be obtained from long-term externalities such as the "sustainability" of land (and hence of production), but which is obviously taken into account by farmers in their decision on whether to invest in perennial crops or tree-based agroforestry systems. Patrimonial transmission as a result of capital building is also an indirect advantage as it provides the next generation with a sustainable and valuable production system. Some benefits, such as social benefits, are traditionally not adequately accounted for in the analysis simply because they are so difficult to assess. Lastly, some benefits are potential: in 2024, biodiversity could be a source of income tomorrow, biodiversity conservation may be considered as a "global service" in which case farmers would be entitled to payment by the international community for its provision, as suggested by the ICRAF/RUPES project (Shared Investment in Pro-poor Environmental Services). It was expected that the carbon sink value would lead to indirect profit through project implementation after 2012 according to Kyoto protocol (for rubber and timber trees in particular, see Hamel and Eschbach, 2001). In reality, the carbon market was not successful.

Only a detailed economic analysis of farming systems will enable correct identification of both direct and indirect benefits when considered in terms of farmers' risk prevention strategies, long-term investments and production sustainability. Research on rubber agroforestry systems is currently underway in Indonesia to identify the potential and real benefits of agroforestry practices compared to monoculture or other alternatives (Penot, 1996b, 1997, 2001, 2002, 2006, 2021-2024; Werner, 1997; Joshi et al., 2000; Lawrence, 1996; Rubis project, Dwi Sninta Agustina, 2022, personal communication).

The context of most developing countries means there are huge income gaps due to strong social stratification, information asymmetry, high transaction costs and institutional failures that have major implications for local economies — particularly when the time factor is important — in identifying and understanding farmers' strategies. Micro economics makes it possible to account for environmental assets, complexity, uncertainty, and implies stakeholder participation. When dealing with agroforests, benefits linked to public goods or goods that cannot be given a market value because they are intended for future generations (e.g. biodiversity, landscape amenity, carbon sink, cultural and aesthetic values) need to be apprehended from a different perspective. We have seen that a multi-functional approach, inspired by that developed by the Common Agricultural Policy (CAP) for European farmers, can be a source of ideas on how to take these externalities into account (but not necessarily the accompanying subsidies policy!). New mechanisms such as those developed for the CDM could be explored, in particular for global issues such as biodiversity conservation.

Agroforest attributes should also be accounted for in national accounting. Policy makers should acknowledge the fact that, if resource depletion was taken into account in an environmental economics approach, agroforests would rank very high amongst land-use options because they generate an "agroforest rent"[60] (Ruf, 1995; Ruf et al., 1999) which is much higher than the rent (i.e. income) obtained from conventional agriculture or other forms of resource exploitation (e.g. logging, mining, depleting the soil through excessive harvests). Agroforestry rent is similar to Ruf's theory of forest rent but generated by an agroforest (less disease, better soil, better productivity, less need for fertilizer, etc.).

Farmers who contribute to this resource rent could receive direct payment or, even better, indirect incentives (e.g. tax exemption) to stimulate land-use options that contribute to such public goods or to the provision of such goods for future generations.

60. The term "agroforest rent" is used here according to the definition of "forest rent" provided by F. Ruf in "Booms et crises du cacao", Karthala, Paris, 1995.

To achieve this status, agroforests need to be recommended along with other land-use options, they require a reference framework that accounts for these alternative economic analyses. Otherwise, they will always be rejected or marginalised as not fitting conventional economics and hence not matching development objectives. Whether for commercially oriented agroforests or subsistence-oriented home gardens, a long-term perspective must be part of a farmer's strategy when dealing with multi-strata agroforestry. However, there is obviously a biased debate between short term (economics) and long term (ecology). In both cases, farmers have developed long-term farming practices as a result of a long innovation process that ultimately accounts for long-term economics through the risk buffering capacity of agroforests. In most cases, social organisation is tightly linked with the technical constraints involved in the production and reliance on food reliance, securing income and potentially, control over land. There is a strong link between technical systems (technical pathways) and social systems (Penot, 2004a). Customary laws take this important point into account and are generally able to adapt to changes. There is an economic strategy behind maintaining agroforestry practices that have proved to be able to secure production and maintain control over land. In other words, long-term economics is fully associated with ecology in terms of sustainability as already well documented for traditional agroforestry systems in, for instance, West Sumatra (Michon and de Foresta, 1991). An appropriate economic analysis should fully account for the long term. A major challenge for the very near future is resolving the dilemma between the internalisation of externalities, by giving a value to "services" through a multifunctional approach, and by giving ecological criteria a real value added.

Conclusion

Rubber farmers have developed a series of innovations to adapt rubber to their extensive agroforestry practices (jungle rubber) or the estate model (SRDP in Indonesia) by associating rubber with perennial or annual crops. However, they have now reached a stage where options for further innovations are limited and productivity cannot be increased without using rubber clones, which require different management. SRAP wishes to respond to this demand. RAS based on clones are the best alternatives for farmers. Technical change is driven by economic necessity, in particular since the Indonesian crisis. RAS are the expression of the recombination of indigenous knowledge (agroforestry practices) and external knowledge based on intensification (clones and chemical inputs). Such technical change leads to more affordable rubber cropping systems that are better suited to the range of different local situations. In parallel, the positive externalities of RAS including biodiversity conservation and environmental sustainability are appealing for future large-scale developments.

Smallholders need reliable information, access to credit, good quality planting material, and recognition of the relevance of complex agroforestry systems by all actors, including by civil servants involved in agricultural development.

Alongside strategies aimed at diversification through the adoption of oil palm, rubber has still an important role to play for local farmers who do not wish to rely on one export crop alone.

⏩ Changes in RAS patterns in West Kalimantan from 1994 to 2019

The focus of RAS/SRAP trials in 1994 was to move on from jungle rubber to clonal based rubber systems in agroforestry. In 1995, more than 80% of rubber was produced in jungle rubber systems. Agroforestry was one the technical options to increase the rubber gross margin per hectare. Most farmers wanted to change to clonal rubber to improve rubber productivity (from 500 kg/ha/yea in jungle rubber to 1,400/1,800 kg/ha/year using clones). However, at the same time, oil palm was undergoing colossal expansion in private estates and associated smallholder development schemes. From representing a good potential opportunity to diversify farmers' income, oil palm became a major competitor for rubber because of its better economic performance, and, in the meantime, the situation has changed, the objective for most local rubber farmers was no longer to replace jungle rubber by clonal rubber but to replace jungle rubber with oil palm. The three most important changes in the period 1995-2023 were (i) oil palm has become the most frequently planted crop and now accounts for 50-75% of the land formerly under jungle rubber in Sumatra and Kalimantan, (ii) most jungle rubber has completely disappeared. From the original 3 million ha in 1995, only 500,000 to 1 million ha of old jungle rubber probably remains in 2023, and this land is considered by local farmers as reserved for the future, irrespective of which crop, but generally oil palm, and (iii) part of the area under old jungle rubber has been replanted with clonal rubber, so that in 2023, most of the rubber produced comes from clonal rubber.

Given this trend, interest in agroforestry has evaporated because most farmers have already integrated both clonal rubber and oil palm in their farming systems. In this context, this is the perfect time to review the results of the 1994/1997 RAS/SRAP trial up to 2019.

The situation of RAS in 2019

In surveys conducted in 1997, RAS 1 was found to perform best in terms of maintaining soil fertility, preventing erosion and low cost of establishment during the immature period, and a survey conducted in 2007 showed that, in the long run, more than 80% of farmers had continued to maintain their RAS plots. This was the case of most smallholders who were reluctant to invest US$2,000 per ha to create a new clonal rubber plantation using their own savings (in contrast to planting oil palm by local oil palm estates with a dedicated credit). In 1997, the cost of establishment and maintenance during the first 3 years were estimated to be US$700 per ha (Boutin et al., 2000).

RAS 2 was the most widely adopted system, thanks to the associated trees (fruit trees and more recently, timber species) despite the fact that poor markets for fruits and timber are real constraints for further development.

RAS 3 "did the job" in areas infested by alang-alang (*Imperata cylindrica*), as control of the weed was very good thanks to the shade provided by associated trees and a cover crop (*Flemingia congesta*). Excellent results were obtained without the use of the herbicide Roundup in transmigration areas and in some villages like Pana (Boutin et al., 2000).

The changes observed in different trial plots were the following:
– conversion to oil palm in 20% of SRAP plots, or to clonal rubber monoculture in 20% of SRAP plots, mainly those located in Trimulia, with RAS 1 or 2 agroforestry systems in 50% of the SRAP plots and *tembawang* in 10% of the SRAP plots;
– specifically in Trimulia village (transmigration area): 100% of rubber plots were under monoculture due to poor sandy soils, lack of water for associated trees and the priority given to rubber trees;
– in Kopar: 80% of rubber plots were under RAS 1, where continuing access to forest products is still important for the local population;
– in Engkayu: 60% of rubber plots were under RAS 2, where total productivity through fruit production is important to ensure a stable agricultural income;
– in Embaong: 30% of rubber plots were under RAS 2, the rest was a mix of RAS 1 and monoculture;
– in Pana: 90% of rubber plots were under RAS 2;
– in Sanjan (former SRDP where no SRAP trials were performed): 50% of the area was still under clonal rubber and 25% of the rubber plantations under agroforestry;
– less than 10% of the plots changed to *tembawang,* a local fruit/timber-based agroforest.

Most trials took place between 1994 and 1996 in the villages of Kopar, Engkayu, Embaong, Trimulia, Pana (Sangau area) and Pariban baru (Sintang area). Another set of trial plots in the village of Pana were established between 2000 and 2005. The trial plots were visited regularly between 1994 and 2007. The photos show the situation in 1994/1997, then in 2005/2007, and most recently, in 2019. Today, all forests and most jungle rubber has been replaced by oil palm in roughly 2/3 of the area and of clonal rubber, either in monoculture or agroforestry in1/3 of the area.

The biggest change in land use and in farmers' strategies in our study area has clearly been the expansion of oil palm which rapidly became the number one priority for local smallholders. At the same time, local estates took over most of available land for their own oil palm plantations while the low rubber price killed any interest in cultivating rubber. Nevertheless, smallholders did not want to completely and permanently abandon rubber. In 2023, rubber continues to be planted, as it makes better use of available family labour, complementary to that used for oil palm production and as a way of diversifying income (mainly monoculture and RAS 2).

Lessons learned from changes in RAS

In 2023, farmers are in the same situation and face the same problems as in 1994: poor access to clonal planting material, no training in tapping frequency or practices, but they do have some knowledge about clones and agroforestry. Rubber agroforestry cultivation techniques no longer appear to be passed on by farmers to their sons or to other young farmers, but the two biggest differences are that (i) oil palm accounts for 2/3 of the land and is now the main source of income, and (ii) jungle rubber disappeared rapidly and all farmers now have plantations comprised of clonal rubber that produce yields, while old jungle rubber is considered as land reserved for future plantations.

All the trial plantations have now reached the end of their life span, which was reduced to 20-25 years due to diseases and poor tapping practices. Agroforestry was considered by most farmers to be very useful (i) during the immature period of rubber trees, because it enabled a better return to land with intercropping, or because of the reduced establishment costs depending on the type of RAS, and (ii) thanks to income diversification (through different kinds of fruit and timber species, either for self-consumption or for sale), improved farm resilience in the face of commodity price volatility.

The lessons learned are the following (i) rubber agroforestry trials were conducted at the right time (in 1994), when there was a strong demand from farmers for systems with low establishment costs that ensured income diversification: at the right time and in the right place, but… (ii) oil palm arrived in 1997 and its adoption was encouraged by very strong pressure from private companies (thanks to the concessions policy) and was a lucrative alternative to rubber cultivation with full credit (but loss of land) and better return to labour, (iii) in 2024, interest in agroforestry practices remains high among old men but evidence for interest in agroforestry among members of the younger generation is lacking, (iv) now is the time to replant rubber because the trees are old, but the same problems persist: access to planting material is difficult, (v) there is still no way for farmers to learn good tapping practices (e.g. through specific training, access to technical information on panel management, upward tapping, etc.), which are essential to prolong the life span of the rubber trees to 35 years, (vi) the severe impact of white root and other root diseases in areas previously under forest or old jungle rubber, and finally (vii) low rubber prices especially compared to palm oil, all of which discourage farmers from cultivating rubber.

As mentioned above, due to the impact of diseases and poor tapping practices, most trial plots are now at the end of their life span. It is thus the ideal time to conduct an in-depth socio-economic survey of all SRAP farmers to assess the current situation in terms of farmers' income (from oil palm/rubber and all other sources), their current and planned long-term strategies, and to explore the reasons for their continued interest in clonal rubber and agroforestry systems. A historical and prospective analysis could assess the impact of oil palm and rubber price volatility. The survey could be implemented in the following villages: Kopar, Engkayu, Embaong and Pana in Dayak area, Trimulia and Pariban Baru in transmigration areas, as well as in Sanjan for former SRDP farmers and include up to 80 farmers.

Three major questions are obviously part of the research agenda:

– Under agroforestry systems, what is the impact of fruit production on food security and on the quality of the diet of local families?
– What is the impact of timber production, both for household use and for sale?
– To what extent can agroforestry systems provide better climatic resilience for both rubber and intercropped varieties?

Future research should include (i) a perception analysis of agroforestry practices as a way to reduce the cost of rubber establishment and provide more income diversification at farm level (for improved resilience to price volatility), and (ii) a study on existing markets (Durian, Gaharu, Duku, etc.) and newly emerging markets for associated trees in RAS (Pekawai, Petai, Jengkol, timber trees).