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Part 2, Chapter 2

From shifting agriculture to sustainable rubber agroforestry systems (jungle rubber) in Indonesia: a history of innovations processes.

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ABSTRACT

The plains of Sumatra and Kalimantan were sparsely populated at the turn of the 19th century (less than 4 inhabitants/km²), and the local population relied mainly on shifting cultivation of upland rice. The introduction of rubber by Dutch private Estates in the 1910's triggered a radical change in the landscape but no fundamental change in farming practices, at least at the beginning, with the adoption of a rubber based agroforestry system. As right from the beginning, the Estates adopted monoculture as a way of maximizing rubber production, other farmers became aware of the possibility of growing rubber in a very extensive way by enriching their fallows (belukar) using the unselected rubber seedlings that were available and cost nothing. Planting rubber along with upland rice resulted in only a little additional work, involved almost no risks and, most important, no additional cost. Rubber grew together with the secondary forest in a complex agroforestry system (CAF) called 'jungle rubber'.

Productivity was sufficient to produce a very attractive income, but tapping of jungle rubber only starts after 8-15 years compared with 5-6 years with monoculture. The advantages of jungle rubber are clear: no cost, no labour required for maintenance during the immature stage, income diversification with fruits, rattan, timber and other NTFP (non timber forest products) in the agroforest system. There are also indirect environmental benefits in soil conservation and rehabilitation of degraded lands. Alongside their rubber production, farmers continued to slash and burn new plots every year but less than before.

Estates began organizing their own research programme in the 1920's, which led to the adoption of fertilization, an increase in weeding the use of improved planting material (clones), which had the most significant effect in terms of yield. Meanwhile farmers began to develop their own innovations that can be called "endogenous technical innovations" mainly through the improvement of certain rubber cultivation practices such as planting in lines, minimum weeding (once a year), intercropping during the immature stage. At that point, as the farmers' primary aim was to set up a rubber system that minimized capital and labour requirements, they shifted from an "enriched fallow with rubber" to a real "complex rubber agroforestry system".

As jungle rubber productivity is low (500 kg/ha/year of rubber) compared to that of estates using clones (1500 to 2000 kg/ha/year), and as they had exhausted the possibilities represented by endogenous innovation of production, farmers began to

consider including "external technical innovations" such as clones, fertilization and good tapping systems and the use of a very effective herbicide for Imperata cylindrical (Round-UP) as it decreased the cost of labour for maintenance during the immature stage.

The planting of perennial trees (or their selection among specimens that had regenerated naturally) such as fruit and timber trees was another innovation that began in the 1980's. However, these practices were still forbidden in rubber development projects in 1994. An increase in the density of the population, land scarcity in some areas, and opportunities to plant other more productive crops forced farmers to change to a more productive Rubber Agroforestry System (RAS). Recent agroforestry research has focused on how to integrate indigenous knowledge about jungle rubber with external technical innovations to increase productivity while conserving the benefits of agroforestry practices in terms of environment and biodiversity. The last phase is now underway with improved agroforestry systems available for farmers at low cost and low labour input. This has implications in terms of research and development policies, in particular with the use of the so-called "partial approach" by new farmers.

Key words: shifting agriculture, complex agroforestry systems, jungle rubber, rubber, adoption of innovations.

1. Introduction

The aim of this chapter is to describe changes in the Indonesian jungle rubber system from the angle of the production of innovation by farmers themselves (indigenous knowledge) and the process of integration of external technical innovations in an overall process of creation of innovation. In other words, the integration of indigenous knowledge at different stages of history with rubber has enabled, and continues to enable farmers to rely on the sustainable cropping and farming systems represented by agroforestry systems.

2 The study area

The study area is the central penepains of Sumatra and Kalimantan, upland areas below the altitude of 500 meters (see map 1). These plains are located between a mountainous area (the Barisan mountains in Sumatra) and coastal swampy areas. Soils are leached ferralitic or red-yellow podzolic, very poor soils but nevertheless suitable for tree crops such as rubber, pulp trees and oil palm. Average annual rainfall is between 2000 and 4000 mm/year. Water is not considered as a limiting factor for tree crops. The climate is typically equatorial with a minimum of 100 mm/month, a short dry season and almost no morning rains (except in some areas in Kalimantan) i.e. perfectly suitable for rubber. This land is generally not suitable for the intensive cultivation of sustainable foodcrops due to poor soil fertility and weed pressure (*Imperata cylindrica*). The area was almost entirely covered with primary forest in 1900, but by 2002 most of the forest had made way for rubber, oil palm, pulp tree plantations grown by both smallholders and estates, as well as transmigration (with treecrop or foodcrop programmes). Slashing and burning of old as well as young secondary forest, and even more frequently of old jungle rubber, is still a common practice for rice production. Nowadays, in areas where land is becoming scarce, farmers have shifted to tree plantation and no longer grow rice but buy it.

3 The introduction of rubber at the turn of the 20th century triggered the move from shifting cultivation to improved fallow.

3.1 The rubber boom

Rubber (*Hevea brasiliensis*) was introduced in Indonesia from Malaysia by the Dutch at the turn of the 20th century in North Sumatra and was originally cropped in private estates in the form of monoculture in "the Estate belt", following the trend observed among English estates in the western part of Malaysia. At that time the market for natural rubber was booming due to a constant increase in demand and is today still sustained by a permanent demand for around 6 millions tons per year (world consumption in 1997). In the 1910's and 1920's, Sumatra and Kalimantan were sparsely populated, with 1-4 inhabitants /km². Shifting cultivation was the common practice involving slash and burn of primary forest or old secondary forest¹, 1 or 2 years of upland rice cropping followed by a long fallow (up to 30/40 years depending on land availability). Land was plentiful and there was no particular pressure to force farmers to change to another system. The system was sustainable as long as the population remained relatively stable, which was not the case in Java. In Sumatra in the 1910's, rubber seeds were collected from estates in the north and then distributed or sold by Chinese traders and missionaries in the south (Riau, Jambi and South Sumatra provinces) creating a tremendous demand for rubber in pioneer zones. In Borneo, the first seedlings were introduced in 1882 (Treemer, 1864, cited in Dove, 1995). Seeds were distributed to the indigenous population in 1908 by the Sarawak government. In Kalimantan, rubber seeds were introduced in 1909 (Uljee 1925 cited in King, 1988) and were spread by Chinese merchants and Catholic missionaries in the Kapuas river basin.

¹At the turn of the 20th century, the penepains were still largely covered by primary forest.

Farmers immediately saw rubber as an opportunity to create a new source of income, and in addition it was easy to integrate in their existing agricultural practices. They began to collect seeds from surrounding estates or existing plantations and plant their own rubber plantations. Rubber was cultivated in a very intensive way on the estates using fertilizers and continuous weeding that required a high investment in labour and capital. Local farmers, along with spontaneous migrants some of whom came from the estate sector, adopted their own system, according to their limited cash and labour resources. They planted rubber trees with rice after traditional slash and burn (*ladang*). Rubber trees then grew among the secondary forest. No weeding or inputs were required. This system is called jungle rubber (« *hutan karet* »). A higher planting density than that of estates is used in order to compensate loss of trees due to competition and depredation (between 800 to 2000 seedlings/ha). Eventually, after a longer immature period (8-15 years for jungle rubber compared to 5-7 years in the Estates), there are a comparable number of tappable trees (between 350 and 500/ha). From the point of view of the estates, whose objective was monoculture, unselected rubber proved to be perfectly suited to this "new environment" (agroforestry), whereas in its original habitat in the forests of South-America monoculture is not possible².

3.2 The Jungle rubber system

The jungle rubber system has been well described (A Gouyon, 1995, Penot, 2001) and is defined from a botanical point of view as a "complex agroforestry system" (H de Foresta, G Michon, 1992). Originally this system implied fallow enriched with rubber trees. The lifespan of rubber (35 years) is the same as the traditional fallow period necessary to restore soil fertility and get rid of weeds. The "kantus" dayaks considered jungle rubber (or rubber gardens) as "managed swidden fallows" (Cromb 1988). "*Swidden cultivators use simple land and labour resources within the swidden system to cultivate rubber*" as explained by Dove (1993). The suitability of rubber seedlings for agroforestry, with no inputs required, only marginal labour requirements at planting, and very limited risks are the factors that triggered the rubber boom. Labour requirements shifted from cyclic (a period of 4 months a year for upland rice) to permanent for rubber (from 6:00 to 11:00 a.m. every day) although with no competition between the two systems. The afternoons are still available for *ladang* activities (rain fed upland crops such as rice or groundnuts). Rubber proved to be the perfect crop to grow with rice. Beside land, labour is the main available factor of production. The main limiting factors are capital and technical information, but these were not necessary in the initial stages of setting up jungle rubber plantations. Thus in the original farming system, rubber and *ladang* rice could be grown together satisfactorily. Rubber was never seen as an alternative to rice, although this is becoming less and less true due to intensification and the increasing pressure on land in some provinces as is true in North and South Sumatra in 2002. Nowadays, rubber, and in particular clonal rubber, provides income and return on labour far above that of upland rice (return on labour is 4 times that of rice).

From a historical point of view, farmers changed to rubber not because they were obliged to (as were many farmers during the "forced crop" period from 1830 to 1870 under the Dutch) or were under pressure to change to another more intensive system (as were Javanese farmers during the green revolution) but because it suited the local environment and was sustained by a constant market. It proved to be a safe and easy way to increase farm income without fundamentally disturbing local farming systems, at least in the beginning. Rubber enabled local farmers to improve their standard of living and welfare. At the same time it enabled increasing numbers of migrants to settle down in these areas either on a spontaneous basis or through transmigration programmes. These changes in both autochthon and allochton populations triggered a change in population density and eventually led to an increase in

² The rubber tree is a forest species whose original habitat is the Amazon Basin in Brazil. In this respect, farmers in Indonesia gave rubber a second chance to grow in its original environment: the forest. This was possible because there is no Leaf Blight in Southeast Asian forests enabling wide dispersion of rubber throughout the sub-continent. In Amazonia, rubber trees only survive if they are isolated in forests and cannot be grown in pure plantations.

pressure on available resources. The average population density in Sumatra is now 35 inhabitants/km² (25/30 in West Kalimantan), and land is becoming scarce in some provinces (North and South Sumatra, Lampung).

According to Dove (1993), "the comparative ecology and economy of rubber and upland swidden rice result in minimal competition in the use of land and labour, and even in mutual enhancement, between the two systems". The average area of jungle rubber per family is between 2.7 and 4 ha (Barlow, 1982, Gouyon, 1995). Rubber generates 55 % (Barlow, 1982) to 80 % (Gouyon, 1995, Penot, 2001) of the total farm income. Jungle rubber and shifting cultivation are not at all antinomic, as both systems can co-exist in local farming systems. The notion of "composite system" was developed by Dove (1993): *"there is little analysis of the relationship between the 2 systems (rubber as swidden agriculture with rice) and thus little understanding of why this combination historically proved to be so successful"*.

Farmers profit from a no input/no labour rubber cropping system -during the immature stage, planting jungle rubber requires 4 days of additional work - (Levang et al, 1997) that implies a certain amount of income diversification as jungle rubber also produces fruits, nuts, timber for housing as well as other products such as rattan and NTFP³. The cost advantage of smallholders versus estates in setting up a rubber plantation has been assessed at 13 to 1 during the colonial era (Dove, 1995), at 6 to 1 versus estates in 1982, and between 3 to 1 and 11 to 1 versus government rubber schemes (Barlow et al, 1982), showing that farmers always had a very competitive cost advantages for rubber.

The fact that production per ha of unselected rubber seedlings is very similar in both systems (monoculture or agroforestry) shows that unselected rubber can compete and maintain its yield in association with a relatively large number of other trees (200 to 300/ha). However this fact remains to be verified with improved agroforestry systems using clonal rubber. In the case of jungle rubber, the advantages are quite clear: no setting-up costs (the use of unselected seeds with no value, and no fertilizers), low labour investment (only a few additional days for rubber planting as the land has been already cleared for upland rice) and no maintenance during the immature stage. These three components explain the success of jungle rubber, which became the biggest source of income for most smallholders in inland Sumatra and West Kalimantan. The disadvantages of jungle rubber in comparison with clonal plantations are the delay in production due to the longer immature stage and relatively low productivity

So why has jungle rubber done so well up to now and what is the future of this system?

Jungle rubber was in fact very well suited to the situation farmers faced in 1900. Five conditions triggered the replacement of shifting cultivation by a sustainable rubber cropping system that had been adopted by more than 1.2 million farmers in Indonesia in 2000:

- . land was plentiful and unspoiled (primary forest; in this respect farmers profited from the "forest rent" according to the "F. Ruf theory") and jungle rubber conserves soil fertility and biodiversity, enabling the renewal of the system every 30 or 40 years. Land opportunity cost was low, and remains low in remote or pioneer areas on the outskirts of traditional rubber areas.

- . the particularly satisfactory adaptation of unselected rubber to the forest environment in complex agroforestry systems.

- . a labour pool was available in Java that enabled land colonization by both local dayak or malayu farmers as well as Javanese transmigrants, who originally came as tappers for estates or sharecroppers for local farmers.

³NTFP = Non Timber Forest Products: such as medicinal plants, gaharu, resins, local vegetables....

. a sustained demand for rubber and a pricing policy was almost always positive for farmers with continuous incentives for the further extension of land and an increase in production. In this respect, Indonesia is still very well placed on the world market with a low cost of labour and the capability of significantly increasing its production if more farmers change to clonal rubber. The demand is still sustained and will be maintained for the next 20 years as there is no possible substitution with synthetic rubber for at least 25 % of the total rubber demand (natural rubber contributed 35 % of the total demand in 1997, however 25 % of the demand requires natural rubber with specific characteristics in terms of heat and shock resistance for the tyre industry).

. no real other alternatives available up to the 1980's.

3.3 The ecological advantages of jungle rubber

It is clear that rubber initially triggered deforestation (Prasetyo et al, 1995). Timber concessions, (see the example of South-Sumatra), originally had less impact on forest cover than any other land use. The paradox lies in the fact that now jungle rubber is the main reservoir of biodiversity (Foresta, 1995) in areas where the forest has disappeared. In comparison with other land-use systems based on oil palm, coconut, coffee, cocoa or pulp trees, rubber agroforestry systems are among the best adapted to maintain a certain level of biodiversity. Jungle rubber thus proved to be better adapted to this "new" environment than estates, especially as yields were comparable, with 500 kg/ha/year of rubber⁴ (Dijkman, 1951) as long as both farmers and estates used the same unselected rubber planting material, which was the case up to the 1930's.

Conservation of biodiversity is a side product of jungle rubber. Plant biodiversity in a mature old jungle rubber system is close to that of primary forest or old secondary forest (H De Foresta, G Michon, 1992, 1995). Environmental benefits in terms of soil conservation (Sethuraj, 1996) and water management due to its forest-like characteristic are significant as well. The biomass of a 33-year-old rubber plantation (444.9 t/ha dry weight) is similar to that of humid tropical evergreen forest in Brazil (473 -t/ha, from Jose & al, 1986 cited in Wan Abdul Rahaman Wan Yacoob & al, 1996 or Sivanadyan, 1992) or in Malaysia (475-664 t/ha, from Kato & al, 1978 cited in Wan Abdul Rahaman Wan Yacoob & al, 1996).

According to Sethuraj (1996), the potential photosynthetic capacity of rubber leaves is comparable or even better than many forest species (about 1150 gm/m²/year in a well managed plantation). A total area of 10 million ha under rubber worldwide would annually fix about 115 millions tons of carbon (1/3 in Indonesia). Soil fertility is maintained or even improved (Sethuraj, 1996 and Dijkman, 1951) as rubber increases the nutrient content of the upper layer of soil due to leaf littering (4 to 7 tons/year/ha, Sethuraj, 1996) and low nutrient export through latex (Between 20 and 30 kg N.P.K.Mg/year/ha, Tillekeratne & al, 1996, Compagnon 1986). Of course, removing rubber trees for timber implies considerable nutrient output that must be replaced through equivalent rates fertilization at replanting. Soil moisture is very high under rubber, which probably also leads to a faster rate of decomposition and better nutrient turnover. From a nutritional point of view, mature rubber is a self-sustaining ecosystem, unlike oil palm for instance. Nutrient cycling is likely to approach that of forest ecosystems (Shorrocks, 1995 cited in Tillekeratne & al, 1996). Farmers do not view these benefits as main components of the system but rather as incidental "gifts", comparable to the "gifts" provided by the long-term fallow in the original system (S&B). These "gifts" may be included in what F. Ruf called « forest rent » (Ruf, 1994), which provides advantages comparable with planting tree crops in a forestry or agroforestry environment as oppose to degraded land or already cropped land.

⁴Rubber yield is always presented as Dry Rubber Content (DRC) 100 % and not as kg of raw material (rubber sheets or cup lumps) or litres (latex).

Historically, forest products formed the basis of commercial exchanges between « farmers-gatherers » and foreign traders like the Chinese as early as the 5th century AD (Wolters, 1967), or the Arabs after the 9th century, for various products including resins, aromatics, nuts, or latex (gutta percha for insulating marine telegraph cables in the 1840's (Dove, 1995). Rubber was also the extracted product of various other plants including creepers in the 19th century. Conserving biodiversity in agroforests is still an useful by-product for many farmers, in addition to the fact that agroforestry practices are labour and input saving methods. This is particularly true in degraded and depleted areas like the low altitude mountains in West-Sumatra in Pasaman or land that has been invaded by Imperata (West Kalimantan plains), as agroforests are a source of seeds for valuable fruit and timber trees. But of all these potentially profitable products, only rubber triggered the very large-scale development of agroforests (more than 2.5 million ha in Indonesia in 1997). Rubber became a strategic product as early as 1839 with the discovering of vulcanisation by J. Goodyear, and, later, with the development of the tyre industry which began in 1888 (78 % of world natural rubber consumption).

3.4 Jungle rubber sustains development in pioneer zones

Four factors explain the rapid change in local agrarian systems and the adoption of rubber by more than 1 million farmers in Indonesia⁵. The first reason was the availability of rubber seeds on a large scale and at no cost (from estates and an increasing number of smallholders' plantations) and the perfect adaptability of rubber as an enrichment species for fallows. The second reason was the apparently endless quantity of available land and the possibility to enlarge plantations at a very large scale originally using the network of rivers. Rubber is not perishable, so its transport and sale is problem free. The third reason was the availability of labour from a reservoir of migrants from over-populated Java encouraged by estates contracting labour for their plantations and also spontaneous migration, which was later followed by official transmigration programmes⁶. The last reason is the fact that planting rubber represents a land-acquisition process that gives the planter land and tree tenure very similar to that of full property, at least under the traditional law (*Adat*).

These factors relate to pioneer zones. Land and labour being almost inexhaustible (at least so it seemed up to the 1990's), success was guaranteed by a plant that required no capital and no major labour requirements at planting and could easily be integrated in local farming systems along with agroforestry practices that had already been developed in other agroforestry systems (such as Tembawang in Kalimantan or Durian/Durian/cinnamon and Damar agroforests in Sumatra).

3.5: The 3 stages of jungle rubber development

Historically, rubber expansion can also be explained in 3 stages. The first stage was the enrichment of fallow with unselected rubber ("improved fallow"). Rubber was considered as a source of income but priority was still given to rice production in shifting cultivation as the main staple food for obvious reasons connected with the supply of food (1900 to 1930's). Farmers rapidly shifted to the agroforestry rubber-cropping system and rubber became the main source of income as a result of the constant improvement due to selected farming practices. The second stage can be defined as the shifting from an improved fallow based on rubber to a real rubber-based complex agroforestry system that integrated some cultivation practices (planting in line, selected weeding at given times, selection of associated trees, etc.) (1930's to 1990's). The third stage is when external technical innovations (such as clonal

⁵ Contributing to 3 million ha of which 2.5 millions ha were under jungle rubber in 2001.

⁶ Some of them focused on tree crops and particularly rubber (NES/Nucleus Estate Scheme programme).

planting material, use of herbicides to control *Imperata cylindrica*, pesticides and fertilizers etc.) were integrated in jungle rubber in order to improve the productivity of land and labour. In this way jungle rubber was progressively transformed into improved Rubber Agroforestry Systems (called RAS) (1990's to the present day) for some farmers .

In the 1980's, only 8 % of rubber farmers were affected by government rubber programmes (16 % in 2002). A total of 350 000 ha have been planted or replanted as productive plantations. Meanwhile, 94 % of intensive irrigated rice farms took part in government programmes (green revolution) (A Booth, 1988). Consequently the diffusion of techniques, skills, and information on improved rubber was perhaps limited, although all farmers know about and would like to acquire clonal rubber. The commodity system did not benefit from a « first priority » government development policy, as was the case for rice with the objective of self-sufficiency. One major challenge is to ensure the diffusion of certain technical innovations, in particular clonal planting material, to farmers irrespective of the rubber cultivation system they use (monoculture or agroforestry), which would result in the full recognition of the advantages of agroforestry practices as a true component of cropping systems.

3.6 Tree tenure, policies and recognition of agroforestry.

During colonial times, each time a natural resource was the subject of a commercial boom, active restricting measures were taken by the government to control and restrict its exploitation. (Dove, 1995) Spices in the 18th century, in particular *Jelutong* (from *Dyera spp*), rubber (through the "international Rubber Regulation Agreement from 1934 to 1944), as well as other timber such as teak (in the 1820's) are examples of such policies. Even now, farmers do not have the right to exploit, cut and sell their timber trees if the land is classified as "forest area". Forests officially cover 74 % of all Indonesia and are under the control of the forestry department. This « tree tenure » policy is clearly restrictive and does not provide any incentive for the improvement or optimisation of timber production from agroforests outside the estate sector. Consequently, timber products from agroforests, and in particular from jungle rubber, cannot be adequately valorised. This shows that agroforestry practices are not officially recognized as « modern and efficient ». By comparison, oil palm monoculture, which uses large quantities of fertilizers and capital, is considered a « modern » tree crop.

Rubber drove "a shift from a tribal political economic formation to a peasant formation", as defined by Dove (1995) in Kalimantan. In other words, technically, it implied a shift from gatherers to real rubber planters after a stage of extensive rubber cropping through a fallow enrichment process. Politically, this situation led to a "contest" between the State and farmers, which today is still reflected in policies concerning rubber wood, timber, oil palm, and in policies developed in transmigration areas where tree crops were forbidden (such as West-Kalimantan food crops-based transmigration schemes until 1991). These policies did not take into account the fact that local traditional systems have proven their sustainability and their adaptation to economic development. They are in fact, astonishingly "modern" in this respect, at least in our opinion. Policies have been focused on monoculture (oil palm, rubber, coconut, etc.) as these are far easier to develop using the concept of well-identified « technological packages ».

4 From improved or enriched fallow to a complex agroforestry system: the importance of rubber planting material.

4.1 The different types of rubber planting material

In 2002, most farmers still rely on unselected rubber seedlings for jungle rubber, whereas estates and project farmers have now all adopted clones. Rubber clones⁷ have proven to be the best planting material in terms of yield and secondary characteristics⁸. Yields of clonal rubber lie between 1400 and 2000 kg/ha for estates in Indonesia as well as for the best farmers in the SRDP⁹ rubber scheme (In South-Sumatra for instance, Prabumulih, DGE). Other improved rubber planting materials are « clonal seedlings » (seeds from plots planted with 1 clone), which are not widely used due to poor performance and polyclonal seedlings (seeds from an isolated garden planted with several selected clones). In Indonesia, there is only one estate (London Sumatra in North Sumatra) able to produce real « polyclonal seedlings » called BLIG¹⁰. Polyclonal seedlings, which were in favour in the 1950's and 1960's in estates, have generally been abandoned for clones. Clones are homogeneous, suitable for a high level of production and have good secondary characteristics (disease resistance etc.), and this is particularly true of 3rd generation clones. Clonal rubber is therefore the first most significant technical innovation to be adopted by farmers. The clonal planting material revolution has not yet been accomplished, but, if it had, it would give rubber farmers a real « reservoir of productivity » when they move from jungle rubber to clonal rubber.

In the 1930's, researchers tried to compare the two systems "Estate" monoculture and smallholders' jungle rubber. Some, even tried to integrate low weeding level through the "bikemorse system" in Malaysia (cited by Sivanadyan & al, 1992) or the "jungle weeding" in Indonesia (mentioned by Dijkman, 1951 referring to a researcher with a private company in the 1930's). Experiments of this type were considered as failures in both cases, which resulted in rubber monoculture being considered as the only relevant technology for both estates and smallholders. This view was held until now in most private and public research centres.

4.2 Availability of planting material to farmers through development schemes: the limits of the government action.

In the 1970's the Indonesian government began to support the smallholder rubber sector, as did the Malaysian and Thai governments, as early as the 1950's in the case of Malaysia¹¹. This type of policy was inspired by the green revolution for rice and was funded with recent oil

⁷ Rubber clones have been selected in Research Stations (Bogor, Medan in Indonesia, Prang Besar and RRIM in Malaysia and RRIC in Sri Lanka are the best known). Multiplication of clonal planting material through grafting requires as a minimum a budwood garden, a rootstock nursery and skills in grafting techniques.

⁸The first clone "generation" was released in the 1930's, the second in the 1950's, the third in the 1970's. The fourth generation of clones, which was released in the 1990's, is still under investigation or undergoing preliminary testing on a small scale in estates. Currently, estates and rubber development projects are using the best third generation clones, which were released in the 1960's and 1970's, such as RRIM 600, PB 260, RRIC 100. However the most widely planted GT1 clones in Indonesia date from the first generation (released in 1922 in Bogor).

⁹SRDP = Smallholder Rubber Development Project", a World Bank scheme from 1980 to 1990 that was replaced by TCSDP = Tree Crop Smallholder Development Project (same scheme) from 1990 to 1998..

¹⁰BLIG = Bah Lias Isolated Garden, London Sumatra, North Sumatra.

¹¹ In 1990, around 80 of the smallholders in Malaysia (65 %in Thailand) have been reached by various rubber schemes and have adopted the estate model with clonal rubber

income (after 1973). Table 1 summarises historical relations between farmers and the government since the 19th century.

The technical model promoted by government development projects for smallholders drew directly on the estate model: rubber monoculture with high labour and input requirements and no intercropping during the rubber immature stage (cover crops were however promoted, though only 5 % of farmers used them). The objective was to develop a simple rubber system that could be used over a vast area without major adaptation to local conditions (adaptation generally being limited to the choice of clone and the rate of fertilization). This model proved efficient but costly. So far, 16 % of Indonesian farmers have been directly or indirectly affected by projects, and only some of the projects resulted in full production plantations. Several « partial approach » (ARP¹² and GCC) and « full approach » (NSSDP and WSSDP¹³) projects were implemented between 1973 and 1980.

The « partial approach » consisted in providing farmers with certain specific components of the cropping system i.e. planting material, fertilizers, and a small credit with limited extension. The « full approach » was based on a complete technological package provided to farmers, generally under a full credit scheme. In 1979/80, the government decided to launch two types of projects: the NES/PIR¹⁴ projects that targeted transmigration areas with the settlement of migrants in virgin areas and SRDP/TCSDP¹⁵ projects for existing local farms¹⁶. As a general rule in the « full approach » projects, farmers were provided with a whole credit package, which was supposed to be refunded within 15 years, and included the following components: clonal rubber plants, fertilizer, pesticides, cash to help farmers with terracing, a land certificate and a monthly wage for the first 5 years (in NES/PIR only for transmigrants). Table 2 lists the distribution of rubber planting among the various projects.

Table 2 : Rubber planting

Land planted to rubber in projects between 1970 and 2000

	TCSDP	TCSSP	SRDP	NES	PRPTE	GCC/ ARP	NSSDP WSSDP	TOTAL
Period	1990-2000	1990-99	1980-90	1978-90	1980-90	1974-80	1973-79	
Area	75000	78000	110000	168571	15697	112 600	20 019	501887
%of total	15 %	15,5 %	21,9 %	33,5 %	3,1 %	22,4 %	4 %	
Class A & B	80 % estimated	80 % estimated	89 %	60 %	39 %	< 25 %	80 % estimated	309330 estimated

Source A Gouyon, 1995 et E Penot, 1999: Class 1 & B indicates that plantations are good and productive.

¹²ARP = Assisted Replanting Project, GCC = Group Coagulating Center.

¹³NSSDP = North Sumatra Smallholder Development project, WSSDP = West Sumatra Smallholder Development project

¹⁴NES = Nucleus Estate Project (PIR in Indonesian) funded by the World Bank (NES) or directly by the Indonesian government (PIR).

¹⁵SRDP = Smallholder Rubber Development Project. From 1980 to 1990, TCSDP: Tree Crop Smallholder Rubber Development Project: continuation of SRDP since 1990 funded by the World Bank. A similar TCSSP project is funded by ADB.

¹⁶ Former projects, as well as SRDP-like schemes funded directly by the Indonesian government have been grouped in the PRPTE.

5 Historical analysis of innovation processes in rubber farming.

Introduction

In this section we analyse the production of innovation and the process of its adoption in the three following steps:

innovations in the jungle rubber system by non-project farmers: smallholders produced their own innovations mainly through the development of agroforestry practices, resulting in what can be defined as "indigenous knowledge". The farmers shifted from slash and burn agriculture to enriched fallows, then to a type of complex agroforestry system, jungle rubber (between 1900 and the 1980's).

innovations made to the "estate-like" rubber monoculture system by former project farmers. After having adopted rubber monoculture (external technical innovation) in the 1980's and 1990's, in the case of most farmers as a result of development schemes, smallholders used innovations to adapt the system to their own needs and strategies including the reintroduction of agroforestry practices by some of them (20 to 40 % of farmers depending on the project) (Chambon 2001).

Recombination of knowledge: the Rubber Agroforestry Systems (RAS) developed by Research project farmers combining endogenous innovations with exogenous innovations provided by SRAP/CIRAD/ICRAF¹⁷ (in the 1990's).

Table 1: historical relations between Indonesian government and smallholder commodity producers.

Date	Action	Result
1870	<u>Government</u> passes the Agrarian Act claiming all fallow land as The state's, to grant it to European estates	<u>Swidden cultivators</u> decide to plant more perennial crops in their fallow fields.
1910-1943	<u>Government</u> restricts the gathering Of forest latex by smallholders To protect European concessions.	<u>Smallholders</u> decide to cultivate rubber instead.
1910-1930	<u>Smallholders</u> out-plant estates And increase their market share.	<u>Government</u> decides to protect the estates. <u>Smallholders</u> increase the quantity and
1935-1994	<u>Government</u> imposes punitive export taxes on Smallholders to force a decrease in their production	quality of their production to maintain a constant level of income
1951-1983	<u>Smallholders</u> increase their market Share from 65 to 84 % by Extending the area of cultivation	<u>Government</u> focuses all capital and technical assistance on the estates to minimize their loss of market share and to Increase yields.
1980-1990	<u>Government</u> promotes nucleus Estate schemes to provide markets for cloves, oranges, and coffee. Smallholder cultivation under estate control	<u>Smallholders</u> resist the loss of autonomy implicit in these schemes.
Present	<u>Government</u> support restrictions	<u>Smallholders</u> abandon each Commodity in turn as prices drop.

* The Agrarian Act of 1870 classified as state dominion any land not kept under constant cultivation (Holleman, 1981).

¹⁷SRAP = Smallholder Rubber Agroforestry Project: a research programme based on farm experimentation using participatory approach with : CIRAD = Centre de coopération Internationale en Recherche Agronomique pour le Développement, FRANCE, and ICRAF = International Centre for Research in Agroforestry.

This gave swidden cultivators in disputed areas a strong incentive to plant perennial crops in their swidden fallows (Potter, 1988).

Source: Michael R. Dove, 1995

In the shift from jungle rubber to improved "RAS", farmers looked beyond the limits of jungle rubber and integrated external components either through the SRAP project or endogenously with systems called "RAS sendiri" or "endogenous RAS" (up to 60 % of SRAP farmers developed their own systems between 1997 and 2002 after RAS experimentation). Such systems proved to be economically competitive with other alternative crops (rubber or oil palm monoculture). In the 3 phases mentioned above, we see that the innovation process more resembles an "innovation elaboration process" than simply an adoption process consisting of step-by-step integration of different technical components or agricultural practices, re-appropriation or adaptation of technologies. The traditional endogenous/exogenous division of innovations is not relevant here as innovation processes integrate technologies, the transfer of techniques, management and the development of specific "know how". Re-combination of knowledge, techniques and "learning by doing" is the basis for the development of know-how.

5.1 The beginning of the agroforestry system and innovation in the jungle rubber system.

Farmers initially adapted the "Estate" model that then became a complex agroforestry system. Farmers introduced five major technical innovations in the jungle rubber system:

. The first innovation concerns the planting material and its use in an agroforestry system. Clonal rubber stumps are currently relatively expensive and are often not available in many rubber-producing areas. Initially, access to planting material was through collecting seeds from nearby estate plantations. After the 1930's, estates introduced the massive use of clonal planting material. Farmers collected these "clonal seedlings" (generally from the GT1 clone, which is the most widely planted). The innovation lies in the fact that rubber was not cropped in monoculture by smallholders (a « copy effect ») but as jungle rubber in an agroforestry system for which it proved to be highly suitable.

The increase in productivity due to using clonal seedling is low though yields may reach 700/800 kg/ha with pure GT1 seedlings (Gouyon, 1995, Dijkman, 1951)¹⁸. The real proportion of clonal seedlings (like GT1 seeds) in the « unselected rubber » population after several generations of jungle rubber is unknown (the lifespan of the system is between 30 and 40 years). At the first replanting cycle, farmers may use seeds from jungle rubber that are already mixed with clonal seedlings but seeds do not conserve the parents' characteristics. No jungle rubber includes clones, as clones cannot survive the competition with secondary forest for light unless they are planted in lines.

. The second innovation concerns planting techniques. In the 1970's, farmers began to plant rubber trees in rows in jungle rubber in order to facilitate tapping and improve the return on labour.

. The third innovation concerns weeding. In the 1980's, farmers tended to weed once a year with selective cutting in order to conserve useful timber and fruit trees as well as some other species such as rattan. With such limited weeding (compared to 6-12 weeding/year in the estate model), tapping of rubber trees can take place the 7th or 8th year after planting, instead of 10 years in Sumatra (or even 10-15 years in Kalimantan) with traditional jungle rubber.

. The fourth innovation is intercropping. Many farmers traditionally implemented intercropping for several reasons: i) the presence of a market for some products (chilli and pineapple in Palembang in South Sumatra for instance), ii) the need to grow food crops if land is scarce (which is the case in the transmigration areas) or iii) some farmers' need for continuous

¹⁸ Yields from original unselected seedlings were around 350 kg/ha/year in the 1920's. Yields from jungle rubber are around 500 kg/ha/year (including an unknown proportion of clonal seedlings).

upland food cropping in a very intensive way (the case of the MinangKabau farmers in West-Sumatra in the East-Pasaman district). Such practices were extremely limited in project areas before 1993 due to a ban by project management authorities. However research programmes in several different countries (IRRDB annual meeting, Colombo 1996) showed that intercropping, in fact favours rubber growth and does not have a negative impact on rubber.

. The last innovation concerns the control of *Imperata cylindrica* in particular in transmigration areas and in West-Kalimantan where this noxious weed is rampant. *Imperata* control is very time- and labour consuming. Due to competition from *Imperata*, production can be delayed up to the 8th or the 9th year. Farmers now very often use a specific herbicide called Round up (Glyphosate) at a rate of 2 to 5 litres/ha to kill *Imperata* and enable rice to grow. The cost is largely compensated by savings in the cost of labour (between 50 and 70 man days¹⁹) required for rice crops in the 4th to 5th months of cropping.

Farmers are gradually adopting some of the components of the "Estate" package, at least those which seem to be advantageous for jungle rubber such as a reduction in the immature stage (weeding), an improvement in the return on labour (row planting decreases the amount of labour needed for tapping, the use of herbicide lowers labour requirements for weeding of *Imperata*). So far, these innovations have been developed in the jungle rubber system without external help (herbicide is an "external" technical innovation but its use is a labour-saving strategy on the part of the farmer). The "production" of these innovations enabled the transition from producing/adopting selected technologies or practices one-by-one to the building of a more complex real agroforestry systems, (more sustainable), in other words, from fallow enrichment to a real cropping system.

When questioned about the main reasons they chose agroforestry systems instead of monocropping, smallholders gave the following answers:

. The lack of enough cash to purchase the complete "Estate" rubber package and the lack of enough labour for the system.

. The savings in time and money for weed control. Farmers said that they weed only once a year and this had proved to be sufficient in the jungle rubber system.

. The labour returns per farm-plot are far higher during the immature rubber stage.

. Land was, and in many areas, still is available, and enables a reasonably extensive rubber cropping system.

. Smallholders noted the efficiency of agroforestry systems in the control of erosion, and as a sustainable source of biodiversity through timber and fruit species.

These practices cost little and require only a very limited amount of additional labour except for intercropping, which still is an important step towards intensification. Intercropping is used by farmers who are progressively abandoning shifting cultivation. In fact intercropping may not require cash or inputs, but only labour. However, without any inputs, particular fertilizers, yields may remain very low and intercropping might be considered as a relatively risky activity due to the labour investment required.

The reasons why it will be impossible to maintain this system in the very near future (except in remote and pioneer zones) are the following:

. other perennial crop alternatives emerged in the 1980's and 1990's such as oil palm, cinnamon (in Jambi and West-Sumatra) and, more recently, pulp trees and pepper.

. other off-farm opportunities are becoming available with industrialization, expanding city markets and the development of trade.

. jungle rubber productivity is limited and all farmers now know that rubber clones enable production to be doubled or tripled (one very positive outcome of rubber development

¹⁹Labour cost is generally around 3500 Rp/day so the weeding cost for 50/70 man days is 175 000/200 000 Rp.

schemes), which means that jungle rubber farmers will eventually have to use clonal rubber, irrespective of which system they use.

The first step in the transition was from improving fallow by enrichment with rubber to jungle rubber. The second step will be from jungle rubber to improved rubber-based Agroforestry Systems with a high rate of productivity and reasonable initial investment costs. In other words, the jungle rubber system has reached its limits and now needs to be upgraded. The only areas where it still can be considered as a potential alternative are remote or pioneer areas inhabited by poor farmers who have no capital.

The future of this system can be secured by planting clonal rubber to boost rubber production while conserving agroforestry practices that not only provide income diversification and are better suited to farmers' limited resources but also benefit the environment and biodiversity. These aspects will be developed in the third stage of innovations based on RAS systems, and is the subject of current research by ICRAF/CIRAD.

5.2 Process of innovation of the rubber monoculture system by former project farmers.

Some farmers realize that productive complex agroforestry systems can be developed by re-introducing certain agroforestry practices in monoculture plots.

5.2.1 Farmers re-introduce agroforestry practices in monoculture.

Rubber development projects are well described in the literature (Gouyon, Barlow, CPIS, DGEetc.). For project farmers, a major innovation was the planting and/or the selection of emerging trees in what were originally monoculture plots. Personal observations of such trends in North-Sumatra, South-Sumatra and West-Kalimantan provinces (Sanggau area) in 1993-1998 provided evidence of such practices. B. Chambon²⁰ investigated the frequency of this practice in the West-Kalimantan Province (Table 3) and her results show that it is not an isolated phenomena but a real trend. Although the trend is still limited to 18 % in NES projects (transmigrants) due to the influence of extension, the proportion goes up to 45/50 % in SRDP and partial approach projects concerning local farmers. In the latter case, 24 % of the plots are in fact replanted with a sufficient number of associated trees to be able to describe them as complex agroforestry systems. Table 4 shows that up to 65 % of farmers use clones for planting new plantations in agroforestry systems.

Table 3: Agroforestry practices on clonal project plots in West Kalimantan.

Practices/type of projects	NES/PIR	SRDP/TCSDP	Partial approach
Re-introduction of agroforestry practices	18%	44,5%	51%
Type of trees			
fruit trees	72%	85,7%	54,5%
Fruit trees + Cash crop trees	28%	4,7%	18,2%
Cash crop trees	0%	9,5%	27,3%
Number of associated trees per ha			
2 to 10: no AF system	62,5%	56%	36,7%
11 to 100: simple agroforestry system	25%	34%	40%
> 100: complex agroforestry system	12,5%	10%	23,3%
Age of rubber trees when associated trees were introduced			
< 3 years	0	45,5%	57,5%
4 to 7 years	20%	27,3%	42,5%
> 7 years	80%	27,2%	0

Source: survey by B. Chambon, 1998-1999, SRAP.

²⁰ B Chambon, CIRAD/University of Montpellier I/France, did her PhD field research in 1997-2000 under the supervision of the author for the field activities.

Table 4: replanting by project farmers in the West-Kalimantan province

Type of plantation		Distribution	Average planted area	Type of cropping system
No replanting		42 %		
Jungle rubber		8.5 %	1.3 ha	Traditional system.
Replanting with seedlings		27.5 %	1.5 ha	47 % with associated trees 53 % in monoculture
Replanting with clones (22 %)	<u>New plantation (project)</u>	7.5 %	1.5 ha	45 % in monoculture
	Purchase of a plantation	6 %	2.25 ha	78 % in monoculture
	Setting up of a new plantation	8.5 %	1.5 ha	69 % in monoculture

Source: survey by B. Chambon, October 1998 to April 1999 & April-June 2000

In this case innovation is clearly diversification through planting or selection of fruit and timber species in the rubber inter-rows leading to a tree-tree association, something that was strictly forbidden by both rubber research and extension services²¹. Farmers have always been told by extension services that clonal rubber should be cropped in monoculture. In projects the farmers were generally forced to maintain clean inter-rows (at least during the immature stage of rubber).

In one village, Sanjan in Sanggau area (West-Kalimantan), 35 % of project farmers have re-introduced “associated trees” such as meranti (*Shorea* spp), teak (*Tectonia grandis*), nyatoh (*Ganua* spp) for timber, durian (*Durio zibethinus*), pegawai (*Durio* spp), rambutan (*Nephelium lappaceum*), duku (*Lansium domesticum*), petai (*Parkia speciosa*), jengkol (*Archidendron pauciflorum*), jackfruit (*Artocarpus, heterophyllus*) cempedak (a wild jackfruit, *Artocarpus integer* etc.) for fruit trees (Shueller & Penot, 1997). In the case of Sanjan, Dayak farmers have already integrated traditional agroforestry practices with jungle rubber and the “*tembawang*” system (a fruit/timber based complex agroforestry system).

This innovation is remarkable for two reasons. First because farmers always thought that it was possible to grow perennial intercrop (trees) with rubber, as is the case in jungle rubber, and consequently decided to proceed. Their problem was knowing to what extent associated trees can be combined with rubber without inducing a severe decrease in rubber production. Unselected rubber seedlings had the same yield in estates as in jungle rubber in the 1920's-50's, which led to the hypothesis that the same is probably true for clonal rubber based on the same density of associated trees. Experiments on improved agroforestry systems (RAS) were based on this hypothesis, and it has been partly confirmed by observations made in the village of Sanjan where no decrease in yield has been observed so far.

5.2.2 Agroforestry practices increase the sustainability and flexibility of cropping systems.

Another important advantage of combining rubber with associated trees, in addition to income diversification and the biodiversity aspect is that it is possible to change crops when the rubber reaches the end of its lifespan (35 years). The plot may then be developed into a fruit and timber agroforest (« *tembawang* ») with the progressive disappearance of rubber trees. At 35 years old, clonal rubber wood can also be marketed and provide an important source of income which will give the farmer enough capital to fund replanting.

²¹ Meanwhile, in Thailand, RRIT (Rubber Research Institute of Thailand) has for the last 10 years been experimenting with fruit and timber trees associated with rubber (Sompong, 1996). ORRAF (rubber extension service for rehabilitation) and RRIT has been promoting such systems since 1991.

It is also possible to grow rubber trees as timber tree but in this case no tapping is possible. It is not yet the case in the smallholder sector. In other words, for a short return on investment, a choice must be made between latex or wood production. There are no clones able to provide both products at the same rate, but the economic lifespan of rubber may be considered from two different viewpoints: latex production or rubber wood. However growing rubber for timber is not economically viable. Apparently the best economic option in monoculture is to grow clonal rubber at a rate of 550 trees/ha (this planting density has been adopted in Indonesia) first for latex and then to extract the timber as a residual product in a 15-year cycle (Gan Lian iong & al, 1994). With CAF systems, farmers have the choice of cutting and extracting all timber in the 15th (as mentioned above) or the 35th year after planting (the end of the rubber lifespan) or to keep the field and shift from a rubber-based to a fruit and timber-based agroforest with a total lifespan of 45 to 50 years. Agroforestry gives farmers many options that can be adapted to the market and to their own needs. In other words, agroforestry practices also provide more flexibility in changing systems.

5.2.3 Farmers' constraints and the slowdown factor in the process of innovation

From an institutional point of view, there are no major constraints to associating fruit and timber trees with rubber as long as project officials no longer have authority over farmers' plots. On the other hand, problems of competition between rubber and associated trees may arise after 10/15 years in the case of fruit trees (such as Rambutan) and after 15/20 years in the case of timber trees (Meranti or even Durian trees) if the planting density of the associated tree is too high, and this density varies with the species. So far no scientific data is available on this type of competition, as no experimentation has been conducted on long-term associations of this type²². The planting density of associated trees observed in Sanjan suggests that farmers are aware of this potential threat and keep planting density fairly low, between 100 and 200 trees/ha (compared to 550 rubber trees /ha on average) while limiting the number of tall trees that have a canopy above rubber trees, such as durian. Other important constraints are land and tree tenure. At present planting rubber is, under the traditional law "adat", a factor that ensures land acquisition, similar to that of property. As far as tree tenure is concerned, it appears that farmers are currently not technically allowed to cut and sell their timber trees. A tax is also collected on rubber wood.

5.3 Agroforestry systems: from constraints to new opportunities: RAS as the main research topic.

As a result of the previous analysis, ICRAF, CIRAD and GAPKINDO²³ shared their resources in implementing a development-oriented research programme. The object of the Smallholder Rubber Agroforestry Project (SRAP²⁴) is to improve the productivity of system through optimisation of labour and a reduction in the use of inputs and costs, while conserving the benefits of agroforestry practices and not moving too far from current practices in order to increase the adoptability of technical innovations. Even though agroforestry systems are in fact very close to what the farmers currently practice, in our opinion it is very important to base innovation processes and technologies on the analysis of the constraints and opportunities of existing farming systems, taking into account farmers' strategies and trends, and integrating them into an operational classification of farming systems. In this respect, irrespective of the innovation concerned, the viewpoint of a farming system is still relevant in order to integrate

²² The current experiments (in Malaysia, Thailand and SRAP in Indonesia) are less than 15 years old on average.

²³SRAP = Smallholder Rubber Agroforestry Project: a research programme based on farm experimentation using a participatory approach with CIRAD = Centre de coopération Internationale en Recherche Agronomique pour le Développement, France, ICRAF = International Centre for Research in Agroforestry and GAPKINDO (the rubber association of Indonesia).

²⁴A CIRAD-CP/ICRAF joint research programme.

apparent or hidden farming constraints into strategies leading to the adoption of innovations. The main innovation in this case is the implementation of 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).

5.3.1 The need for improved Rubber Agroforestry Systems (RAS).

The objective of this new approach is to demonstrate the advantage of experimenting in real farming conditions using a participatory approach and improved rubber agroforestry systems (RAS) as alternatives to traditional “jungle rubber” practices or to classical rubber-based development schemes based on estate technology. The main challenge for research is to test different improved clonal planting materials and appropriate levels of inputs and labour to see which materials grow and produce best in these agroforestry systems, and which are most appropriate – and affordable – for smallholders (Penot ; 1996). In other words, it means trying to optimize the natural trend of endogeneous farmers’ experimentation with *RAS sendiri*.

A network of on-farm experiments has been set up with 100 farmers in 3 selected provinces: Jambi and West-Sumatra in Sumatra and West-Kalimantan in Borneo. All innovations tested in this programme were initially discussed with farmers in order to improve the adoptability and suitability of RAS technologies to farmer’s resources and requirements. Experimentation is based on the minimization of inputs and labour while conserving agroforestry practices and their advantages i.e. income diversification, income generation during the rubber immature stage through intercropping, maintenance of a certain level of biodiversity and an environmentally friendly approach. SRAP is currently using a participatory approach to conduct on-farm experimentation with three main kinds of rubber agroforestry systems (RAS) Each is being tested for its suitability in local agro-ecological conditions, labour and cost requirements, and to determine the optimum level of intensification.

The first system (RAS 1) is similar to the current jungle rubber system, in which unselected rubber seedlings are replaced by clones selected for their potential capacity for adaptation²⁵. These clones must be able to compete with the natural secondary forest growth. Various planting densities (550 and 750 trees/ha) and weeding protocols are being tested to identify the minimum amount of management needed for the system. This is a key factor for farmers whose main concern is to maintain or increase labour productivity. The biodiversity is presumed to be very similar to that of jungle rubber, which is quite high and relatively close to 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, 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 slashing and burning. It is very intensive, with annual crops being intercropped during the first 3 or 4 years, with emphasis on improved upland rice, and with various rates of fertilization as well as dry-season cropping with groundnuts, for instance. Several variations of crop combinations are being tested including food crops or cash crop such as cinnamon. Several planting densities of selected species are being 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 will regenerate naturally and will thus(?) be selected by farmers.

The third system, RAS 3, is also a complex agroforestry system with rubber and other trees planted in a similar way to RAS 2; the difference being that this system is used on degraded lands covered by *Imperata cylindrica*, or in areas where *Imperata* is a major threat. Labour or

²⁵The selected clones are PB 260, RRIC 100, BPM 1 and RRIM 600.

cash (for herbicides) for controlling *Imperata* are the main constraints. In RAS 3, annual crops, generally rice, are grown in the first year only, with non-vine cover crops planted immediately after the rice harvest (*Mucuna spp*, *Flemingia congesta*, *Crotalaria spp*, *Setaria and Chromolaena odorata*), multipurpose trees (*wingbean, Gliricidia sepium..*), or fast growing trees for use as pulpwood (*Paraserianthes falcataria, Acacia mangium and Gmelina arborea*) can be planted (several combinations are currently being tested). The objective here is to eliminate the weeding requirement by providing a favourable environment for rubber and the associated trees to grow, thus preventing the growth of *Imperata* with limited labour requirements. The association of non-vine cover crops and MPT²⁶'s for shade is aimed at controlling *Imperata*. Biodiversity is expected to be similar to that of RAS 2.

These RAS systems are currently under experimentation. In 2002, at the end of the immature stage, results showed that RAS systems are very well adapted to local constraints and are easily adopted by farmers. There is a considerable demand from surrounding farmers who want to join the project or develop similar systems on their own (« RAS *sendiri* »). Impact analysis carried out in 2000 (Trouillard, 2000) shows that 60 % of SRAP farmers have replanted in the last 5 years and that 60 % of them have replanted with RAS *sendiri* systems. RAS *sendiri* systems can be considered as « RAS types » that are entirely re-appropriated by farmers (and which were sometimes originally developed by them) . Non SRAP farmers have also begun to develop RAS *sendiri* in the area after witnessing the efficiency of RAS (demonstration effect).

5.3.2 Farmers' constraints and the slowdown factor in the adoption of innovation

The main output of the rubber projects, in addition to the creation of a large productive sector, is a very significant « demonstration effect » in traditional rubber areas of the supremacy of clonal rubber over all other type of planting material to improve rubber productivity. In terms of extension, following 20 years of the "full project approach" where projects provided all inputs, credit and technical information, came the time for a partial approach where only inputs for the first year (including planting material) are provided to farmers who are supposed to have acquired the necessary know how and capital. In the latter case, farmers are free to choose whatever system they want, monoculture or RAS type.

Farmers are now all aware that clonal rubber definitely requires more weeding and inputs than unselected seedlings in jungle rubber, even in an improved agroforestry system such as the RAS type. They sometimes under-estimate the minimal necessary requirements that have been tested at different levels in RAS experimentation. One of the main constraints is the ability of farmers to integrate in their current practices a minimal amount of inputs and labour, between what is currently used in jungle rubber (very low) and that used in the "Estate" model (very high). Current research is aimed at identifying what level would be acceptable to farmers in terms of capital for investment and labour during the immature stage.

An important challenge in terms of development is also to determine which is the best approach between a « complete approach » (such as current development schemes) and a « partial approach » based on the supply of only key components of RAS. Surveys by B Chambon (1997-2000) show that « partial approach » works well in a context where farmers' awareness has already been raised by previous development projects.

6 Economic comparison of rubber-based cropping systems.

6.1 A preliminary comparison between jungle rubber and other cropping systems

²⁶MP : multi purpose tree.

Most rubber farmers rely on rubber production. Rubber is the main economic driving force of rubber-based agroforestry. Rubber generally contributes up to 80-90 % of their income (A Gouyon, 1995, Penot, 2001). Non-project farmers generally have between 2 to 5 ha of jungle rubber. Old jungle rubber plots (aged more than 30) with very low yields still cover vast areas. Young jungle rubber (15 years old) has already profited from some innovation. Project farmers generally have 1 hectare of clonal rubber in SRDP/TCSDP and 2 ha in NES/PIR in transmigration areas.

Figure 1 compares several different alternatives between food crops in shifting agriculture (rice etc.), cash crops (pepper, coffee, oil palm) and rubber systems (old and young jungle rubber, class I and I SRDP monoculture, and RAS systems). The benefits are far higher and sustainable over longer periods (20 years for coffee and oil palm, 30 years for rubber) with improved tree crop systems. Return on labour is also higher by a factor of 4 for jungle rubber compared to rice in shifting cultivation and by a factor of 30 for rubber monoculture and RAS. In the best conditions, like in West-Pasaman (West-Sumatra province) oil palm gives the best returns after the 10th year (complete credit reimbursement). However in other regions, such as South Sumatra or West-Kalimantan oil palm does not yield as much. In this case, profits and return on labour are very similar to those of clonal rubber systems. The main challenge for rubber agroforestry systems is to match oil palm in terms of income per ha and return on labour.

(Figure 1)

6.2 Cost-benefit analysis of RAS

A complete cost-benefit analysis of RAS has been carried out and published (A Penot, 1996) with an incremental Net Present Value (NPV) analysis compared to jungle rubber). The main conclusion was that return on labour (here similar to value for labour for NPV = 0) is significantly better than that of the "Estate" model (figure 2). Net value of Benefit (figure 3) is also similar or even higher than that of monoculture, and, of course, of jungle rubber due to associated annual or perennial crops (through an incremental cost/benefit analysis). Figure 4 gives the NPV of various RAS crops compared to monoculture. This economic analysis of future trends is very promising for RAS systems and shows that farmers now have the choice between monoculture and reliable RAS systems.

(Figure 2 ; 3 and 4)

A characteristic feature of rubber is its market flexibility as a non-perishable product. It provides a weekly income (weekly because in the countryside markets are generally held weekly). Smallholders sometimes appear to follow an inverse curve to market conditions. If prices are low, as in the early 1930's, they increase the planting area (Boeke, 1930 in Dove 1995). If prices are high, as in the 1940's, they reduce the number of trees to be tapped (Boeke, 1953). This is no longer true and farmers have become very sensitive to price and demand, and by using all available means, try to increase their income due to changes in family needs in a society that has been significantly improving its welfare since 1966. . From a historical point of view, rubber has been a good « opportunity ». The farmers' economic strategy has shifted to increased optimization of land and labour. From being a complement to swidden crops, rubber has become the main crop in a move towards the progressive abandonment of rice cropping when the income generated by rubber is sufficient to buy all staple food. Return on labour is far more profitable with rubber, even jungle rubber, than with upland rice (Penot, 2001).

Conclusion

In the past, rubber farmers developed a series of innovations in order to integrate rubber in their extensive agroforestry practices (jungle rubber) and, later, in the "Estate" monoculture model by associating rubber with annual or perennial crops. But by the end of the 1980's they had reached a point where innovation was limited and a further increase in productivity could only be obtained by including rubber clones and other external technologies that required a different management strategy. After passing through two intermediary stages first between shifting cultivation and improved fallow, and second between improved fallow and a complex agroforestry system (jungle rubber), they now face the challenge of how to significantly improve the productivity of their system. *"Complex agroforestry systems can no longer compete with other agricultural systems which may be more risky but are more profitable in the short term"* (Levang, 1996). Agroforestry systems based on improved clonal rubber can meet this challenge with reduced risks and an increase in environmental benefits. Farmers have shown their ability to develop remarkable innovations, endogenously or through participative experimentation with SRAP. Jungle rubber covered more than 2.5 millions ha in Indonesia in 2002. The challenge now is to help farmers to continue to acquire suitable innovation and to adopt RAS.

Indonesia is still going through a stage of « late agricultural transformation » (Barlow, 1996). Historically, political instability up to the 1960's and subsequently the priority given to a policy for self-sufficiency in rice production (achieved in 1984) did not allow farmers to acquire improved technologies for rubber on a large scale. Jungle rubber is still the most widely used system in Indonesia, while sustained economic growth and new crop opportunities, in particular oil palm, invite farmers to increase the productivity of their rubber systems. The introduction of external technical innovations (improved availability of planting material), taking into account indigenous knowledge (agroforestry practices), micro-credits and relevant technical information are key factors for the future of the rubber sector in the very near future.

Another major challenge is to ensure that all the different types of farmers have access to improved technologies suited to their particular strategies and to local resources; in other words, to promote equity as well as sustainability whether through agroforestry or monoculture. In a country that has been able to develop millions of hectares of different types of sustainable complex agroforests, agroforestry still has a great potential as long as environmental concerns are taken into account, and, if necessary, considered as a priority.

Dove (1995) raises 3 important questions that 'highlight the challenges of future development of the rubber sector':

* *Is it possible to promote exploitation of ...rubber, in the absence of a hierarchical political economic structure?* This raises the question of "producers' organizations" and their ability to themselves control future changes in the commodity system. Up to now the answer has been yes, as most farmers developed rubber without help of any kind. But the use of external components (inputs) and the need for capital (investment) may change this.

* *is it possible to attain goals of both ecological sustainability and socio-economic equity within a hierarchical structure?* The answer is probably yes if improved systems such as RAS, based partly on existing proven systems, are eventually adopted by farmers; and this seems to be the case, since signs of a move in this direction are becoming apparent.

* *if both preceding solutions are not possible , what then?*

The organization of rubber farmers and the availability of a wide range of rubber cropping patterns from semi-intensive rubber based agroforests (RAS 1) to intensive monoculture systems are the main preconditions in terms of policy and technology development that will

give environmentally friendly systems a chance to continue and to maintain the equilibrium of regional development with other crops.

Rubber agroforestry systems may be options amongst others, but these systems do not entail risks (crop failure) or uncertainties (in terms of rubber market and output), as there is a steady and reliable demand for natural rubber.

As Barlow stated as early as 1989, "*It is assuredly appropriate to look seriously at policies which basically aim to help people to transform themselves, in an evolutionary approach where steady improvements are made from within the beginning framework of traditional agriculture*". Isn't this exactly what farmers have been doing with their agroforests since the beginning of the last century?

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Figure 1

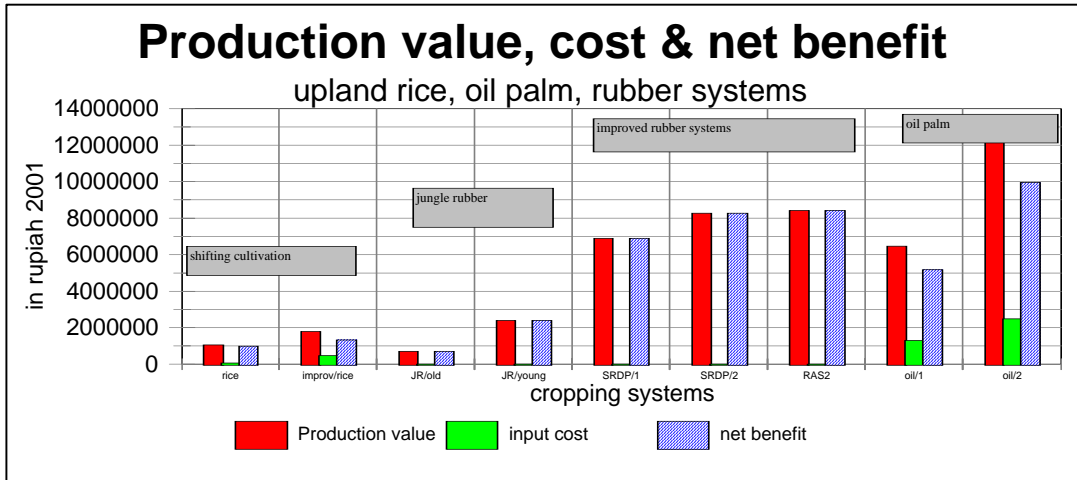


figure 2 : value of labour cost when NPV = 0 : equivalent to return to labour for each system.

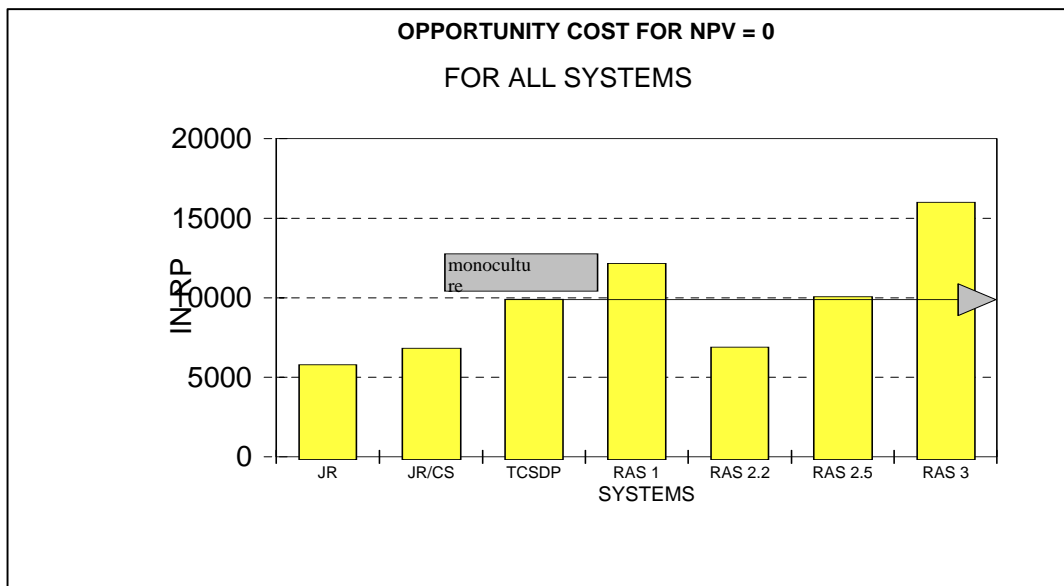
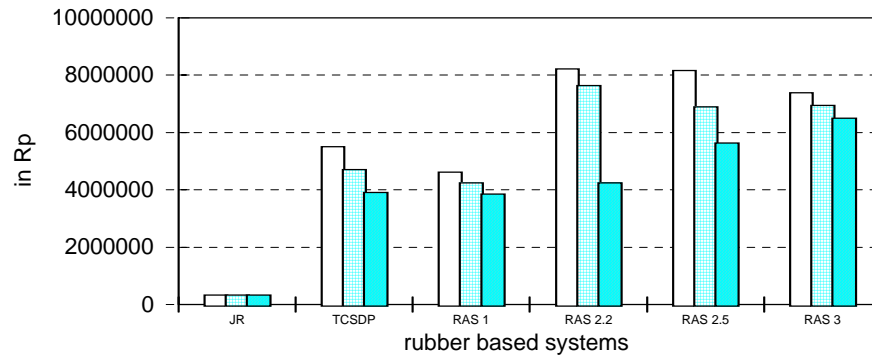


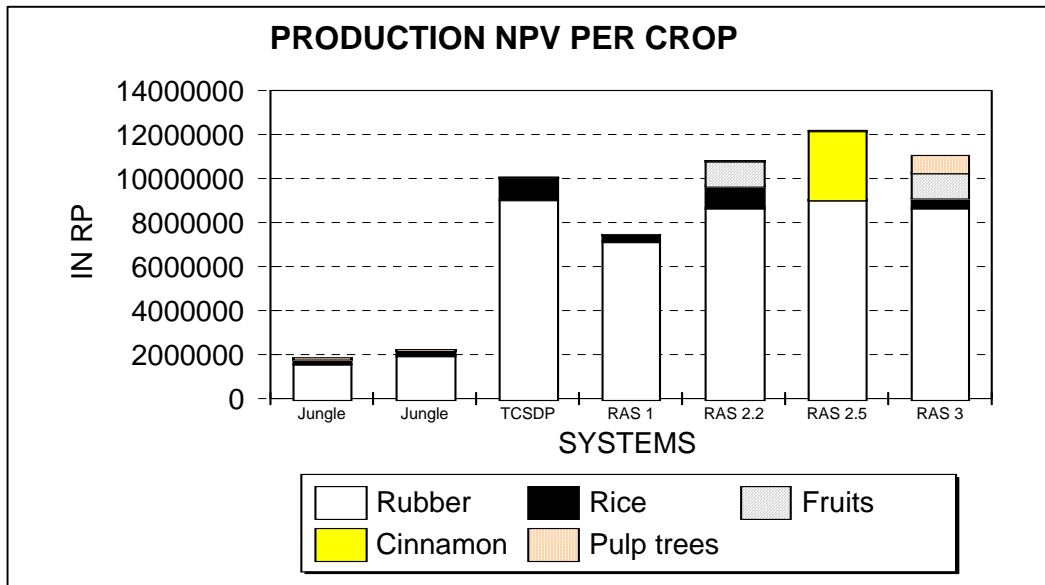
Figure 3 : Net incremental benefit (NPV) of each system compared to jungle rubber.

NET INCREMENTAL BENEFIT (NPV) for rubber based systems



Labour cost = 2000 Labour cost = 3500 Labour cost = 5000

Figure 4 : production value (NPV) for each system.



Map n° 1 : Rubber producing areas in Indonesia and selected studied reas.



