Promoting environmental friendly and socially responsible rubber cultivation

Conference 17-19 October, 2016
Xishuangbanna Tropical Botanical Garden (XTBG) by the Chinese Academy of Sciences, China. Menglun Township, Mengla County, Yunnan Province, China

Rubber agroforestry systems in Indonesia and Thailand for a sustainable agriculture and income stability.

Key note paper

Eric Penot, CIRAD IMR Innovation, 34398, Montpellier, France,
eric.penot@cirad.fr

Summary

Promoting environmental friendly and socially responsible rubber cultivation is relatively new in current agricultural policies in Asia. However, agroforestry systems based on rubber are very old, their interest and recognition is relatively recent since the beginning of the 2000's. If rubber has been introduced in South Asia as a colonial crop, it has been immediately adopted by local farmers as soon as the 1910's and developed as a very extensive agroforestry system based on unselected rubber seedlings: the jungle rubber, in Indonesia, Malaysia (North-Borneo) and southern Thailand. Very early, Malaysia in the 1950's and Thailand in the 1960's developed specific institutions and policies to replace jungle rubber by clonal monoculture and implement rapidly highly productive new plantations when Indonesia began in the 1970's to a lesser extend. If there is no more jungle rubber in Thailand and Malaysia (except a little bit in Sabah/Sarawak), there is still between 1 and 2 million hectare of jungle rubber in Indonesia. Meanwhile, local famers began to experiment by themselves in the 1990's agroforestry practices with clonal rubber trough association of rubber to fruits trees, wood/timber trees and other plants susceptible to produce a diversified source of income(roots, tubers, rattan, medicinal plants, vegetables and leaves for food, etc ……) or to produce timber and non-timber forest products that could be also used for self-consumption and save expenses (timber, health etc ..). Such systems have been documented in the 1990's in Southern Thailand (less than 4 % of the total rubber area), Kalimantan and Sumatra in Indonesia (jungle ruber and transformed clonal SRDP plantations) and research began to have interest in optimizing existing farmers agroforestry practices (PSU/TU/KKU in Thailand, the SRAP project with ICRAF in Indonesia…).
The rubber price volatility has left many farmers vulnerable to global market fluctuations. Strategies of income diversification became priority and in a context of land scarcity agroforestry appears as the best-bet alternatives to combine productions. The environmental and social consequences of current rubber cultivation practices as a monoculture, international rubber market developments and even climate change threaten potentially the sustainability of the industry in the region.
Local extension or research institutions began to recognize agroforestry as valuable practices to overcome monoculture constraints (relying on one source of income only, rubber prices volatility…) and profit from environmental services provided by complex agroforestry systems. This new opening of local institutions to alternative agroforestry systems lead to more recognition and now promotion of environmental friendly and socially responsible rubber cultivation. Meanwhile, studies in the 2000's in Indonesia and recently in Thailand in 2015/2016 show that agroforestry systems do limit various types of risks under different socio-economic conditions (erosion, price volatility …). The presentation focus on 20 years of research and improvement of rubber based agroforestry systems in Indonesia and Thailand.
Key words: rubber agroforestry, Indonesia, Thailand, resilience, price volatility, sustainability.

Rubber agroforestry systems in Indonesia and Thailand for a sustainable agriculture and income stability.

Introduction

Economic vs ecological sustainability: the role of agroforestry

The sustainability of agriculture is becoming a major concern in a world of global uncertainty. The main questions concerning "ecological sustainability" are linked to the problem of degraded environment and fragile soils and thus fertility, biodiversity, and protection of watersheds. Several cropping patterns offer potential solutions to these problems: agroforestry practices, conservation agriculture, agro-ecological practices, livestock-agriculture integration…..etc. Crop diversification and rapid technical change characterize the evolution of many existing farming systems. Agroforestry are among agro-ecological practices those may be the most currently developed in the world especially in Southeast Asia as it concerns more than 5 million hectares, especially in Indonesia.

The history of these innovation processes are key elements to analyze and understand farmers' trajectories and thus be in a position to make viable further recommendations for development. Agroforestry systems have been generally developed in a particular context, profiting from existing local opportunities (damar, Durian In Indonesia, Fruits and timber in Kalimantan, rubber in Indonesia/Thailand/Malaysia etc …) or to overcome local constraints. Most analysis on agroforestry systems have focused on ecological sustainability. The notion of "economic sustainability", places emphasis on the profitability of specific technical choices: (margins analysis, income generation, return to labour and capital as a function of a specific activity, analysis of constraints-opportunities, etc.) from the point of view of farming systems at the regional level. Knowledge about smallholders' strategies in these different contexts are thus key elements that should also be taken into account.

As sustainable development is becoming the new "priority objective", the rehabilitation of previously intensively managed agricultural or degraded land also merits consideration[1]. Perennial crops in particular are subject to very significative and sometimes very rapid changes in plantation/re-plantation strategies in pioneer and post-pioneer areas, as for instance the couple rubber/oil palm. These changes characterize farmers' strategies through phases of investment, capital or patrimonial building, capital conservation, re-investment and eventually intensification or diversification or both. A constant factor that underlies such strategies is innovation: both the process of technical innovation (technical pathways) and of organizational innovation (producers' organization, access to credit, etc.).

Most perennial crops (cocoa, rubber, coffee …) are now facing a post-boom crisis. Rubber is in a relatively sever price crisis as it has been the case in 1997/2004. Commodity prices are subject to volatility with large variations in time. Political changes have also resulted in new decentralization policies in most countries (indirectly linked with democratization in some countries) that can/may introduce new ways of local governance. The major economic trend is towards globalization since the 1980's accompanied by a general decrease in prices for most agricultural commodities. Concurrently, most Asian farmers enjoyed, willing it or not !, direct links to markets over

---

[1] With respect to the latter, two different types of areas seem to be important: ecologically degraded areas such as *Imperata cylindrica* grasslands, which cover 25 millions ha in SEA, and former mining areas that require rehabilitation in Southeast Asia for instance).

a relatively long period of time (absence of the commodity boards in Asia when it has been often encountered in Africa in the 1980's and 1990's), in particular in the case of rubber.

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

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

Impact of technical change should take into account effect on sustainability on both farmers‘ livelihood and environment. Success in diversification strategies required a certain number of conditions: capital or credit availability, technical options (innovations), information, markets, farmers' organizations in order to improve marketing etc …

While rubber area and production in Malaysia are decreasing, the trend in Thailand and Indonesia is on the rise. Rubber forms a major export commodity for both countries. Neighbouring countries (Vietnam, Laos, Cambodia, and China) in the region are rapidly developing their rubber sectors

This paper presents brief results of history of the development of different Rubber Agroforestry Systems mainly in Indonesia and Thailand.

1From jungle rubber to improved rubber agroforestry systems

1.1 Jungle rubber

Rubber has been developed in Indonesia since more than a century and since then Indonesia has as the largest rubber area in the world (3.5 millions ha). However the productivity of smallholder rubber in this country is very low (650 kg/ha/year in 2006), compared to that of Thailand (>1500 kg/ha/year). Smallholder rubber plantations in Indonesia (80% of the total rubber areas), are mostly multi-strata as most plantations were still jungle rubber in the 1990's. Rubber is not the only perennial crop in that area, but also mixed with timber trees (forest re-growth), fruit trees, and different annual crops. Scientists identified these multistrata systems or called “Jungle Rubber” have multiple functions such as main income source for many farmers; keeping certain level of the forest biodiversity; Carbon sequestration; soil and water conservation. Due to this extensive management, smallholder rubber areas in Indonesia are mostly under “jungle rubber” forms, where rubber present as the main species grows together with other species such as timber, fruits, rattan, medicinal plants

At the turn of the 19th century, the Sumatra and Kalimantan plains, at an altitude of lower than 500 meters were sparsely inhabited with a population density of less than 4 persons/km². The population relied mainly on shifting cultivation of upland rice. The introduction of rubber by private Dutch estates in the 1910's triggered a radical change in the landscape evolution but not in farming practices, at least in the beginning. Although estates adopted monoculture right from the beginning, trying to maximize rubber production, farmers immediately saw and exploited the possibility of growing rubber in a very extensive way by enriching their fallow ('*belukar*' in Indonesian) with unselected rubber seedlings that were freely available. Planting rubber during, or after, upland rice demanded only marginal extra work, with no risks and more importantly, no costs. Rubber was grown as a component of the secondary forest in a complex agroforestry system widely known as *'jungle rubber'*.

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

Traditionally smallholder rubbers in Indonesia are established after a slash and burn of secondary forest or old jungle rubber, followed by planting of annual food crops in between rubber rows for 2-3 years. The system is based on extensive management both for rubber and intercrops, either during the first two-three years of intercrop establishment, or afterward. After completion of annual intercrops, farmers abandon the land to seek other portions of land to be planted with similar intercropping system. Weeding or slashing of the forest re-growths was done once to twice a year in the first three years after intercrop and maximum once a year before rubber starts to be tapped

These extensive and low management systems develop toward a complex agroforests based on rubber trees. De Foresta and Michon (1996) defined complex agroforests as forest structures managed by farmers for the production of various forest and agriculture products on the same piece of land, mimic natural forest structures, with a complex structure and a closed or almost closed canopy dominated by few tree species.
This system has been called "jungle rubber" (hutan karet) by Indonesian farmers who consider that it was basically a fallow enriched with rubber trees. The life-span 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 rubber gardens as "managed swidden fallows" (Cramb, 1988). "Swidden cultivators use simple land and labour resources within the swidden system to cultivate rubber", as clearly explained by Dove (1993). An important feature is the labour requirement that shift from a cyclic basis (upland rice) to a permanent basis for rubber (from 6 to 11 a.m. every day). There is no concurrence between the two systems as the afternoon is potentially still usable for "ladang" activities (upland farming). Rubber has proved to be adapted to meet the challenge with rice particularly in the rainy season. This is an Important feature because labour is the main available factor of production in the lack of any capital when land is still plentiful. So, from the beginning, rubber and ladang rice could merge with flexibility in existing farming systems. Rubber has never been seen as an alternative to rice, however that statement is becoming less and less true with the intensification and the increasing pressure on land in some provinces such as North and South Sumatra (e.g. in 1997).

It is important to notice that, historically, farmers move to rubber not because they have been forced to in one way or another or were under pressure to move to another or more intensive system (like Javanese farmers with the green revolution), but because it suited local environment and was sustained by a constant market, therefore it gave a very good opportunity to easily increase farm income. Rubber has given an opportunity for local farmers to improve their lives. Meanwhile it has enabled migrants to settle down in these areas in increasing number therefore triggering the change in population density and pressure on available resources. Average population density in Sumatra is now 35 inhabitants/km² 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 labor, and even in mutual enhancement, between the two systems". Jungle rubber and shifting cultivation are not at all antinomic as the two systems can coexist in local farming systems. The notion of "composite system" has been developed by Dove (1993) :

There is little analysis of the relationship between the two systems (rubber as swidden agriculture with rice) and thus little understanding of why this combination historically proved to be so successful".

The cost advantage of "smallholder versus estates" to establish a rubber plantation has been assessed as 13 to 1 during the colonial area (Dove, 1995), 6 to 1 related to estates in 1982 and between 3 to 1 and 11 to 1 related to governmental rubber schemes (Barlow et al, 1982), showing that there were very competitive cost advantages for rubber

Various consequences of this low farm management are identified such as a) slow and heterogeneous rubber growth and long immature period or late reaching tappable size (8 to 12 years after rubber planting) and; b) rapid growth of forest re-growth

1.2 Rubber and fertility

rubber increases nutrient content in upper 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 et al, 1996, Compagnon 1986). Of course, rubber wood extraction implies a large nutrient output that should be replaced through large fertilization at replanting. Soil moisture is very high under rubber, probably also leading to a faster rate of decomposition and a better nutrient turn-over. Mature rubber is a nutritionally self-sustaining ecosystem, unlike for instance, oil palm. Nutrient cycling is likely to approach that of forest ecosystems (Shorrocks, 1995 cited in Tillekeratne et al, 1996).

1.3 Biodiversity

With rapid deforestation taking place in Sumatra (since 1970s), rubber agroforests are becoming the most important forest-like vegetation that we can find covering substantially large areas in the lowlands (Joshi et al. 2001). It has become a major reservoir of forest species itself and provides connectivity between forest remnants for animals that need larger ranges than the forest remnants provide. While jungle rubber cannot replace natural forest in terms of conservation value, the question whether such a production system could contribute to the conservation of forest species in a generally impoverished landscape is very relevant. Jungle rubber however, provides a major reservoir of forest species itself and provides connectivity between forest remnants for animals that need larger ranges than the forest remnants provide. This leads to a diversified tree stand dominated by rubber, similar to a secondary forest in structure (Gouyon et al. 1993).

For vegetation Michon and de Foresta (1995) concluded that overall diversity is reduced to approximately 50 percent in the agroforest and 0.5 percent in plantations (Figure 2); but these estimates are based on plot-level assessments. Similar findings were reported for plants, birds, mammals, canopy insects and soil fauna by Gillison and Liswanti (2000) who covered a wider range of land use types, from forest to *Imperata* grassland, in their investigation. Studying terrestirail pteriodphytes, Beukema and van Noordwijk (2004), also found that average plot level species richness was not significantly different amongst forest, jungle rubber and rubber plantations, however at the landscape level the species-area curve for jungle rubber had a significantly higher slope parameter, indicating higher beta diversity.

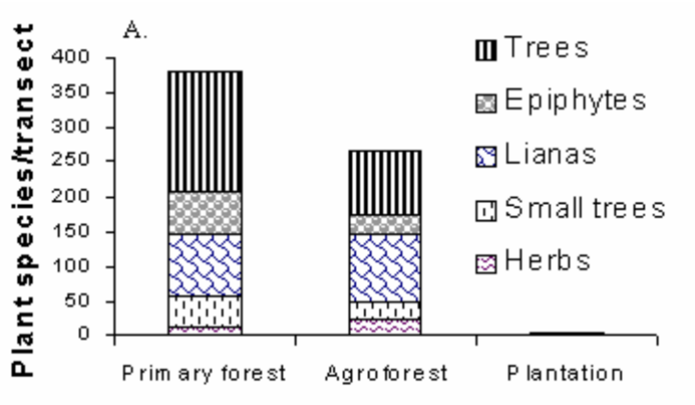


Figure 3.Comparisons of plot-level richness of plant species between natural forest, rubber agroforest and rubber plantation for higher plants (de Foresta and Michon 1995).

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

From all plants abundant in traditional rubber gardens, be it spontaneous ones or managed ones, about one third are used (see Table 3). These plants include timber and non-timber uses (i.e., timber species and non-timber forest products (NTFPs)). 'Timber' uses are divided into fuelwood (mainly low-quality timber) as well as house construction and furniture. In areas where no more natural forest is in the reach of the villages, however, traditional rubber gardens have become the main source of timber for the local people (De Foresta 1992). In these areas, timber from rubber gardens is already sold, indicating a prospective source of income that could be expanded by the planting of valuable timber species.

Non-timber uses include edible ones (i.e., fruits and vegetables (edible shoots and pods)). Planted fruit tree species include durian, stinkbean (*jengkol*), rambutan, locust bean (*petai*), mango, jackfruit and mangosteen (see Annex for Latin names). *Petai* and *jengkol*, both members of the family Mimosoidae, do not yield sweet, juicy fruits, but pods whose seeds are eaten raw or cooked as a vegetable. Both legumes as well as many other fruits are highly priced in urban markets and probably could be sold if transportation could be provided. Some fruit tree species, like longsat and carambola, are only planted in the village area because they are said not to grow well in shady forest conditions. In Sumatra, as opposed to Kalimantan, mango species (*macang, kwini, mangga golek, mempelam*) were also mainly found within the village area.

Other NTFPs are medicinal plants and handicraft materials, especially rattan, pandanus and tree bark, but also timber used to craft special items (e.g., machete sheaths). Latex and resin from rubber agroforestry systems are also sold (e.g., *Hevea*-latex, the latex of some *Sapotaceae* (nyatu) and *Apocynaceae* (especially *Dyera costulata*)). Besides these, products harvested for cash-generation are few. Worth mentioning, however, is *tengkawang*, or illipe nut, harvested from Dipterocarpaceae and cultivated in West Kalimantan by the local Dayak population. Forest gardens, including *tengkawang,* are named *tembawang*. They are usually mixed with fruit trees and sometimes with rubber (Werner 1993). Other uses of plants growing in rubber gardens are for ceremonial purposes, as ornamentals, thatching materials for field huts, fruits used as fish feed, or latex used to trap birds and the like.

Table 3. **Used plants of traditional rubber gardens in Jambi, West Sumatra and West Kalimantan**

Province	W-Sum	Jambi	W-Sum	Jambi	Jambi	Jambi	Jambi	W-Sum	Jambi	Jambi	W-Kal	W-Kal
Plot-No.	LM 9	DB 2	LM 7	P 8	P 9	DB 16	P 5	LM10	P 6	P 16	E 1	S 1 *
plot age	65	25	20	20	60	50	20	65	60	60	60?	70?
Cleared/ not	(yes) [2]	yes	yes	No	no	(yes)[2]	No	(yes)	no	no	no	no
TIMBER												
Construction, furniture	3	6	3	5	6	6	6	5	8	9	17	35
Fuelwood	3	14	14	6	3	20	6	11	6	6	n.a.	n.a.
NON-TIMBER												
Fruits	7	2	3	8	5	2	6	7	8	11	20	25
Vegetables		1	2	2	3	1	1	1	2	2	1	4
Medicinal	4	2	6	2	3	5	4	12	3	4	2	3
Handicraft		1			2	1	2	1	3	2	5	4
Latex & resin	1	1	1	2	2		2	1	2	2	5	-
Cash-generation						1					1	1
Other	7	7	5	10	8	9	9	10	11	12		1
Total **	23	30	30	33	32	37	35	44	40	45	37	49
Total Biodiversity	40	40	48	48	50	61	55	73	61	73	69	126

* Plot size 2,500 m² as opposed to 1,000 m² of the other plots. *Tembawang*, no rubber abundant.

** Less than sum of uses, because some species have more than one utilization.

The data presented above prove the strong relationship between rubber garden biodiversity and presence of useful species. About two-thirds of all species present in rubber agroforestry systems have one or more uses. In the quest for yield increases of rubber gardens, it is therefore important to search for systems providing optimal growing conditions for improved rubber varieties, but still allowing a major part of the biodiversity of traditional gardens to be present : one of the objective of SRAP activities CIRAD/ICRAF (1994/2007).

[2] not recently

Useful spontaneous vegetation within rubber gardens not cleared by farmers in West Sumatra and Jambi

Fruit tree species		Medicinal plants	
Durian	Durio zibethinus	Sicerek	Clausena cf. excavata
Nangka	Artocarpus heterophyllus	Sidingin	Kalanchoe pinnata
Rambutan	Nephelium lappaceum	Jirak	Eurya acuminata
Macang	Mangifera foetida	Sitawa	Costus speciosa
Mango	Mangifera indica	Bidaro	Eurycoma longifolia
Langsat & Duku	Lansium domesticum	Daun kasai	Pometia pinnata
Jambu	Eugenia aquea	Sikarau	Cyrtandra sp.
Petai	Parkia speciosa	Kunyit	Curcuma domestica
Mangosteen	Garcinia mangostana	Kunyit balai	Zingiber purpurteum
Jengkol	Pithecellobium jiringa	Sikumpai	indet.
Kabau	Pithecellobium bubalinum		
Timber species		**Plants with other uses**	
Sungkai	Peronema canescens	Rimbang	Solanum torvum
Meranti	various genera and families, but esp. Shorea spp.	Daun kayu sibuk	indet.
Kulim	Scorodocarpus borneensis	Damar	Dipterocarpaceae
Petaling	Ochanostachys amentacea	Kopi	Coffea robusta
Kumpabok	Indet.	Jambu monyet	indet.
Maraneh	Elaeocarpus palembanicus	Sitarak	Macaranga cf. nicopina
Tamalun	Indet.	Dalo	Macaranga javanica
Kawang	Indet.		
Madang	Various genera and families but esp. Lauraceae		
Surian	Toona sureni		

Modern rubber agroforestry systems have to be able to integrate local wisdom about useful plants because in times of shrinking forest reserves, these systems might soon be the only ones still harboring these species over large areas. Preserving biodiversity, therefore, also means guaranteeing the access of local people to these plant resources for their daily needs (Werner 1998 …).

2 Monoculture as the main trend for the govermenent

2.1 The governmental projects

The most important government action on the development of the commodity was started at the beginning of 1970-ies and mainly on the 1980-ies. Various development and rehabilitation projects for smallholder tree crops have been established, which were mainly, are grouped into two schemes: Perusahaan Inti Rakyat/Nucleus Estates of smallholder (PIR/NES) and Project Management Unit (PMU), later the government has also developed partially funded projects. Except for the later, all those projects were based on monoculture and credit scheme. These schemes have had rather successful in transferring various technology innovations.
As a general rule of PRPTE/SRDP/ TCSDP/NES approach, farmers were provided with a whole credit package, supposed to be refunded within 15 years, including the following components : i) clonal rubber plants; ii) fertilizer; iii) pesticides for diseases; iv) cash money to help farmers to do some terracing, about Rp 100,000;, v) land certificate and vi) a wage for the first 5 years (in NES/PIR only).

2.2 The way to RAS

Farmers with access to clonal rubber in monocultures also began to develop additional innovations such as inter-cropping during the immature period and planting perennials (or selective protection of those from natural regeneration) such as fruit and timber trees. They thus created an "improved rubber-based complex agroforestry system" where the original aim of improving the fallow disappeared in favor of the desire to establish a more productive cropping system. Such practices were forbidden in rubber development projects until 1990. Population increases, land scarcity in some areas, and introduction of other more remunerative cropping opportunities combined to force farmers to evolve a more productive Rubber Agroforestry System (RAS). In one village, at least, in Sanjan (Sanggau area in West-Kalimantan), some farmers began to select timber and fruits trees among the emerging vegetation, first to shade the inter-row and suppress *Imperata*, and second to expect a production from these new “associated trees” such as meranti (*Shorea spp*), teak (*Tectonia grandis*), nyatoh (*Ganua spp*) (for timber) and 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*) for fruit trees. The same trend has been observed in the southern tip of North Sumatra province in both SRDP plantations. farmers have always thought that is was possible to grow perennial inter-crop (trees) with rubber, as is the case in jungle rubber and then decide to proceed further on: but they do not know to what extent associated trees can be combined to rubber without severely decreasing rubber production. In the Sanjan village, a rough assessment shows that at least 20% of farmers are selecting and growing associated trees out of 50 SRDP farmers

2.3 the importance of clone adoption

Yields of clonal rubber are between 1400 to 2000 kg/ha in estates in Indonesia or with the best farmers in the SRDP[3] rubber scheme (In South-Sumatra, Prabumulih, DGE).

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

Other improved rubber planting material are clonal seedlings (seeds from plots planted with 1 clone), not (often really) used due to poor performances 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 (BLIG)[4]. Polyclonal seedlings, in (popular favour) in the 50's and 60's in estates, have generally been abandoned to the profit of clones which are more homogeneous better adapted to high level of production and wich have good secondary characteristics (resistance to diseases), in particular for the clones of the 3rd generation, available since the 70's Clonal rubber is therefore the first most important innovation to be adopted by farmers (as is also the case for improved varieties for other systems). In other words, the IGPM revolution has not yet finished giving rubber farmers a confident reservoir of productivity ?

In Sanjan, 13 years after introduction of monoculture, 15 out of the original 50 farmers (30 %) have reintroduced associated trees in their originally monoculture clonal rubber plots. The density of associated trees was between 94 to 291 trees/ha (average of 167) for 500 rubber trees /ha with emphasis on the following species by decreasing order of importance : Pekawai and Durian (Durio spp), Belian (*Euxyderoxylon zwageri*), Rambutan (*Nephelium lappaceum*), cacao, assam (*Tamarindus indica*), cempedak (*Artocarpus integer*), petai (*Parkia speciosa*) and Nyatoh (*Palaquium* spp). Pekawai, Durian and Rambutan were present in all the plots showing farmers preference for fruit trees. Sixtee four percents of the trees were planted, the rest resulting from natural regrowth and selection. In the study area, income diversification and reintroduction of an economically interesting plant diversity in former monoculture are part of Dayaks farmers strategies.

[4] BLIG = Bah Lias Isolated Garden, London Sumatra, North Sumatra.

Figure 1: Re-introduction of associated trees in former rubber monoculture plots : the case of Sanjan village in West Kalimantan.

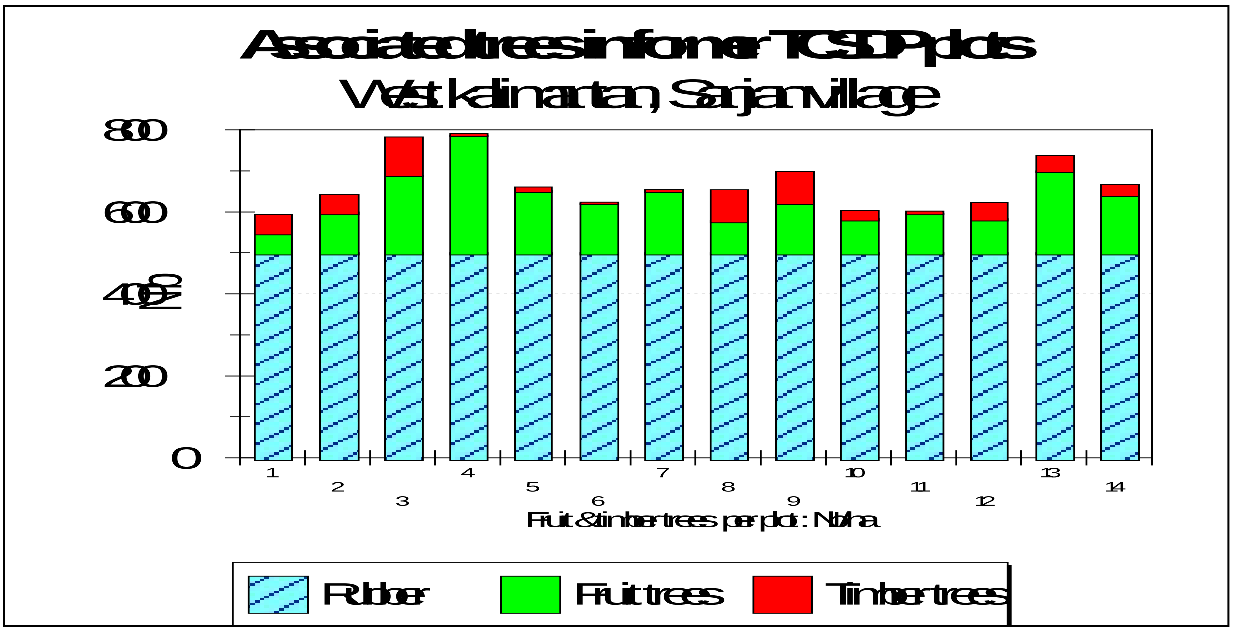
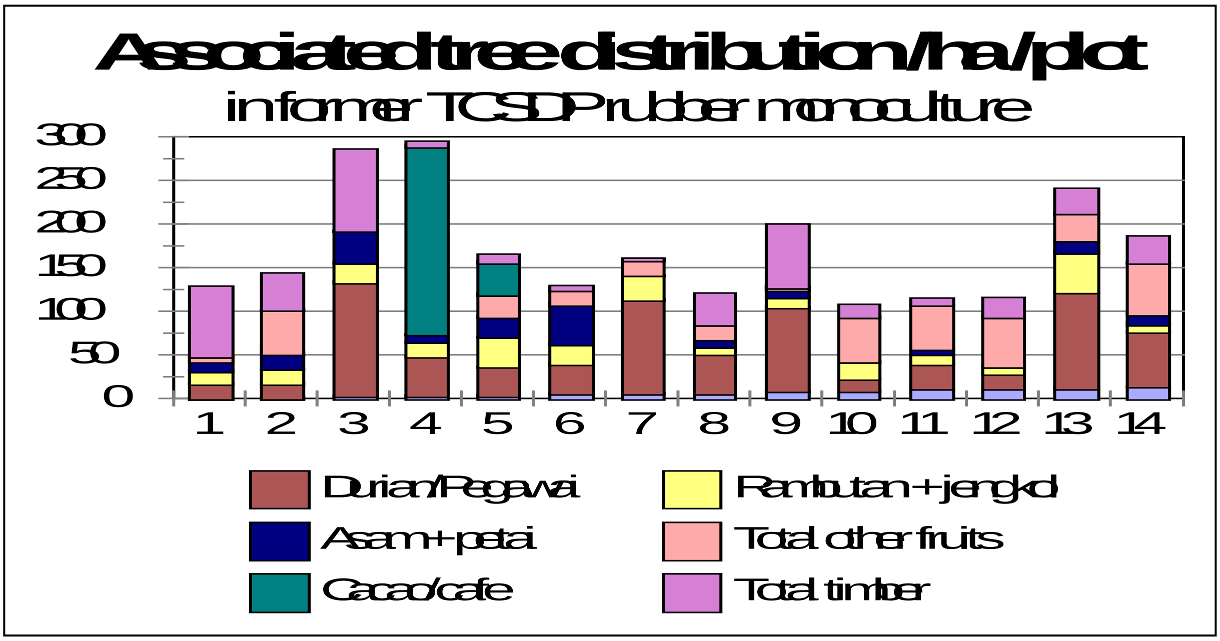


Figure 2:



2.4 Current Rubber Agroforestry systems (RAS) in Indonesia

The main challenge for researchers is to search and to test new models for improving smallholder rubber production systems, based on the current farmer practice ones rather than replacing them with estate-like or monoculture, conserving the biodiversity and environmental benefits of agroforestry practices.
Clonal planting material has been historically selected for estate monoculture management and optimized for the highest level of maintenance. Testing clonal rubber

in agroforest environments with a certain level of extensive practices means that clone will be selected for other environments where competition is far higher than that of monoculture and based on reduced inputs and labour.

Since1994 and planned up to 2007, World Agroforestry Centre (ICRAF) in association with CIRAD-France and Indonesian Rubber Research Institute (Sembawa Research Station) established a network of trials to study rubber agroforestry systems and test different approaches suitable for different conditions under SRAP (Smallholder Rubber Agroforestry Project) and SRAS (Smallholder Rubber Agroforestry System) project. The project was funded by various funding agencies such as: USAID, French Embassy, Gapkindo, and CFC (the Common Fund for Commodities) (penot, 2001, Wibawa et al 2006).

Frame 1: The global methodology used in SRAP/SRAS (1994/200/) byCIRAD/ICRAF team.

It is based on the following implementation framework:

- ***Diagnosis***

---> **a preliminary diagnosis based on the study of all available information (bibliography, data collection, key-persons) and an exploratory survey.**
Implemented in 1994-1995 and later in 2002-2004 for new areas.

- ***A farming system characterisation survey*** *:*

---> to understand constraints, opportunities, income and labour productivity of each cropping systems and farm activities. The data analysis should provide an operational farming system typology and later on a "behaviour" typology. Implemented in 1996 (Pasaman/West Sumatra), 1997 (Kalimantan and central Sumatra) with farming system trajectories analysis in 2000 and farming system modelling in 2001, 2003 and 2005.

- ***On-farm experimentation programme identification***

---> the identification of a potential on-farm experimentation programme aimed to solve technical constraints (technical innovations) or social constraints (organisational innovations). On Farm trials protocols should be identified according to typology.

- ***Implementation of On-farm experimentation***

---> **Implementation of on-farm identification using participatory approach in a on-farm trials network**.
Experiments of SRAP have been implemented in1995-96 and new trials of SRAS in 2002 and 2004-2005.

- ***Farming systems monitoring***

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

- **Analysis and re-assessment of the research programme**

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

The network trials were developed since the last 10 years either at controlled environments (on-station) or at farmers' circumstances (on-farm). Increase of productivity of jungle rubber in Indonesia may be attained by providing improved planting materials of the tree components to the farmers and evaluating which are the most appropriate and affordable for smallholders. This research program is based on four major components: a) the characterization of selected areas to achieve a “situation typology” covering a wide range of conditions, b) a network of on-farm trials using participatory approach, c) a farmer typology reflecting all strategies and constraints encountered in the rubber growing areas of Kalimantan and Sumatra, and d) in-depth studies on particular relevant agronomic and ecological topics.

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

RAS 1, is similar to the current jungle rubber system, in which unselected rubber seedlings are replaced by adapted clones. Vegetations in between rubber rows are expected to be kept by farmer in order to conserve certain level of biodiversity. The main objectives are to determine if clonal rubber germplasm succeed to grow well under jungle rubber environment, to increase yields significantly, and to assess the minimum required management level of RAS. A secondary objective is to assess the level of biodiversity conservation in the jungle rubber system. It is expected that the rubber clones be able to compete with the natural secondary forest growth.

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

RAS 3, planted only in West Kalimantan, intend to provide a solution to fields invaded by Imperata. It is also a complex agroforestry system with rubber and other trees planted at the same density as that as in RAS 2, but with no intercrops except in the first year, followed by a combination of leguminous cover crops, and Fast Growing Trees (FGT). It is established on degraded lands covered by alang-alang grass (*Imperata cylindrica)* (Penot, 1995). The grass bounds the growth of annual crops so selected cover crops *(Mucuna, Flemingia, Crotalaria*) or MPTs (*Calliandra*, Wingbean, *Gliricidia*) and FGTs (*G. arborea, P. falcataria., A. mangium)* are established with various density between 50-110 trees/ha. It had been assumed that the FGT could be harvested in 7 or 8 years to provide timber and wood for the existing pulp industry. The objective of RAS 3 is to reduce the weeding requirement by providing a favourable environment for rubber and the associated trees to grow, cover the soil as soon as possible to bound imperata growth

The clones tested are PB260, BPM1, RRIC100, and RRIM 600, compared to seedling originated rubber tree

Table Specific constraints to RAS adoption

Topic	West Kalimantan	Jambi	West Sumatra
Previous and/or current projects, access to information	SRDP/TCSDP	ASB	Pro-RLK
Indigenous knowledge and agroforestry practices	**+++**	**+++**	**+/-**
Clone availability	**+**	**+/-**	**-**
BLIG availability	**-**	**-**	**+++**
Fertilizer use	**+**	**-**	**-**
Upland rice (HYV)* availability	**-**	**---**	**--**
Seed quality	**-**	**-**	**-**
Covercrop seed availability	**-**	**-**	**-**
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	with selected local rice varieties : average potential	may be good in peneplains	excellent weeding, requires soil and water conservation techniques
RAS adoptability potential			

RAS 1	**+++**	**+++**	**0**
RAS 2.2/RICE	**++**	**+**	**+++**
RAS 2.5/cinnamon	**0**	**+++**	**++**
RAS 3	**+++**	**0**	**+**

***** HYV: High Yielding Varieties

3 Main results

3.1 Indonesia

The performance of clones in RAS1 environments is encouraging (Fig. 10). Compared to seedling originated plants, clones perform better in term of growth since the beginning of the establishment. Up to 40 months, among clones, BPM 1 has the best growth followed by other clones, and seedling growth was the slowest. After 40 months, due to white root disease attack on BPM 1 and RRIM 600, the growth of those two clones was reduced and the growth of the other two clones RRIC 100 and PB 260 was very good and ready to be tapped at 5 years. However the seedling originated plant can be tapped at about 5.5 years after planting. The frequencies of weeding (in rubber rows) of the plots in this trial were between 3-4 times per year.

Farmer knows that growth of rubber will be reduced due to competition with other vegetations. In West Kalimantan, farmers did not follow entirely the protocol of trials and di adapt to local conditions and They slash the vegetation in intra-rows since the second year (once a year) with only few tree species kept especially those plants that have monetary value These result in slower rubber growth (compared to Jambi) and no significant difference of rubber growth was observed due to weeding level

The effects of perennial intercrops on rubber growth vary from year to year, except for treatment with durian, there is no significant difference observed due to intercrops, at 54 months. However difference rubber performance was due more by sites/farmers participant of the trial rather than by different intercrops

Due to shading of the trees, those fruit trees can not produce fruit as good as the fruit trees planted in open areas. The RAS 2 trials in West Kalimantan were not as intensive as it was expected. The annual intercrops (upland rice mainly) was only practiced during the first two years. It is also clear that if the spacing of rubber is 6m x 3m, planting perennial plant under rubber is not encouraging in term of the fruit production

For RAS 3: The creeping legumes were clearly the top performers in controlling *Imperata*. *Pueraria* was slightly better than *Mucuna* for rubber growth (statistically significant). Both *Pueraria* and *Mucuna* grew well and managed to suppress re-growth of Imperata. However, the creeping legumes required to be 'weeded' regularly from the rubber rows as they entangled the trees.

While among the erect legumes, *Flemingia* was good for rubber; but *Crotalaria* proved disappointing. Rubber trees with no cover crops but with *Imperata* or *Chromolaena* had not yet reached tapping size. This finding is consistent with earlier work done in Sembawa Research Station where it took over 10 years for rubber trees without proper Imperata control (Wibawa, 2001).

The fast growing trees may control imperata

The FGT in trials in Trimulya village were showed that all FGT were relatively successful in controlling Imperata re-growth, although nearly in half of the plots, Imperata was still encountered. This is not surprising as the young trees in their early stage only had small crowns and could not shade out Imperata effectively. There was no significant difference between the FGT species tried – *Acacia*, *Paraserianthes*, *and Gmelina*, either on controlling Imperata or on rubber growth. The negative effect of *Acacia* on rubber trees was obvious from the early years, however the reduction in rubber growth was quickly recovered after *Acacia* was cut down after three years.

The analysis of results obtained from on-farm participatory trials is more difficult due to the un-control factors that may be interfered to the main factors set previously. The inventory of possible factors influencing the growth needs to be carried out very carefully. Implementing participatory trials need a close relationship and continuous communication with farmers. Planning, implementing and modifying the trials have to be carried out under close discussion with farmers. Trust building between researchers and farmers is needed since the beginning of the activity, in order to achieve the objective of the on-farm trial. Once the trust is built, then the following programs and activities could be carried out more efficiently.

It is very common that farmers not follow all protocols that designed and fixed by researchers previously. This kind of problems is observed both in Jambi and in West Kalimantan. Again, a close relationship with farmers and try to understand why they do not follow the protocol is one of the tasks of the on-farm participatory trials. Beside that, intensive discussion is important to choose better technical options that adapted to farmers' needs

Results summarised from this paper indicated that the trade-off between inputs (fertilisers, labours, chemicals) and growth or plant diversity is always of interest of most peoples. Due to many constraints faced by farmers, especially cash money for most Indonesian farmers, they have to choose between spending money and allocating family labours. The maximum rubber growth is not always the objective of farmers in establishing various RAS. The critical question is how providing technology options to farmers considering their constraints and opportunities.

Labour and modelling

In order to develop a prospective analysis tool to model price and yield evolution of multiple farming systems, data on input and output for major rubber-based systems were collected from West Kalimantan and Jambi. The OLYMPE model (CIRAD) was used to input the data including detailed labour input. RAS technologies were included in the survey and data entry in order to compare these technologies against other technology already available. Here we show only the data from Jambi. Level of maintenance refers to a combined parameter depending on fertilizer application and frequency of slashing and weeding mainly during the establishment phase, first 6 years. In some high pest (deer, boar, and monkey) risk area labour for fencing can be significant, but for comparative purpose, this has been excluded as it is independent of technology.

Much of the labour prior to planting goes into preparing land that includes cutting down trees, slashing ground vegetation, burning and fencing. The text task is the planting of latex plants. Other regular management tasks include fertilizer application, weeding (manual and chemical), tapping latex as well as harvesting other products.

Low maintenance of RAS-1 requires a low intensity of weeding, either manual or chemical weeding. Weeding is conducted only between rows. External labour is usually not hired but may be required for land preparation. RAS-1 high maintenance requires more weeding and slashing during the establishment phase (Figures 7 and 8); the use of chemicals is limited to first two years only. Minor weed slashing is carried out during tapping. In case of RAS-2 low maintenance, the use of external labour is rare as is the use of chemical fertilizers. RAS-2 high maintenance category involves very high weeding, including weeding in rubber rows and inter-row.

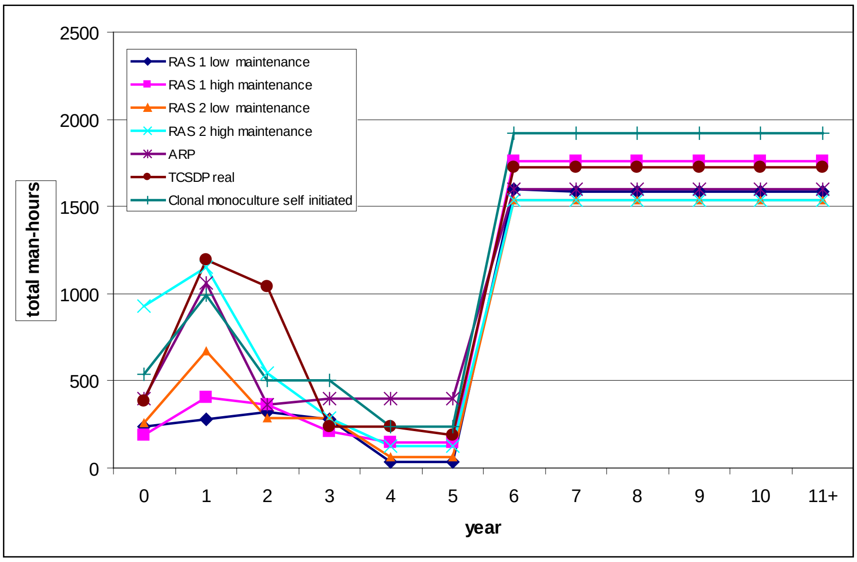
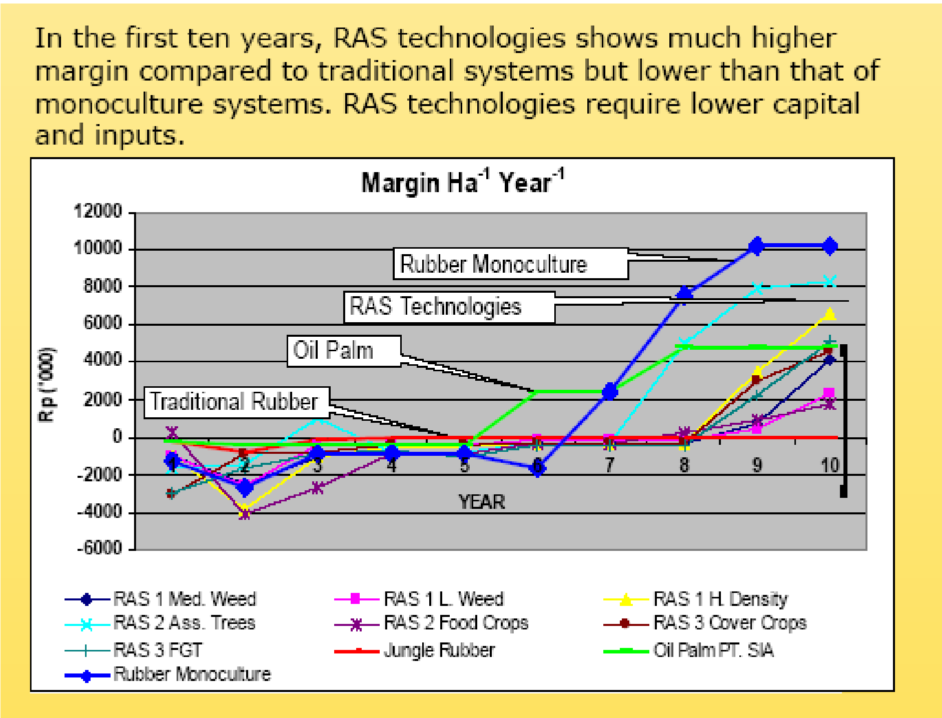


Figure 8. Manpower (hours) required in different rubber systems.

Figure : gross margin/ha evolution for different cropping systems



Conclusion

From what has been observed in 1993 in sanjan and SRP plots to RAS experimentation, it has been proven that clonal rubber can be associated to other trees, in complex agroforestry under specific conditions, with both good rubber and associated trees

production. Their rubber production data are comparable to those from intensive monocultures. RAS-1 technology requires less labour and chemical input but allows natural regrowth, including timber and fruit species and medical plants, between rubber rows. RAS-2 combines rubber trees with other high value timber and fruit species. RAS-3 is suitable for rehabilitation of Imperata grassland through mixture of rubber, non-rubber and cover crops. While attractive price of rubber, as at present, encourages farmers to adopt intensive monocultures, the paper advocates diversification of rubber agroforests as a better alternative to monocultures for rubber smallholders
diversification of the economic basis of rubber agroforests, with value accruing from rubber wood and other timber and fruit trees provide an incentive for maintaining diversity while ensuring tangible benefits to the farmers.

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

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

3.2 RAS in Thailand

Thailand, in South-East Asia, is the first world producer of natural rubber, ahead of Malaysia and Indonesia (International Rubber Study Group [IRSG], 2005).
In Thailand, rubber trees are grown on about two million hectares of land, characterised by three main systems: i) the "jungle rubber" system, which is gradually being abandoned by farmers in favour of monoculture (<10% of the total rubber area), ii) the intensive agroforestry system, based on an association with different crops (fruits, vegetables, cereals), estimated at 5% of the rubber growing area and iii) the monoculture system, which is now the most widely-used system (more than 85% of land under rubber trees).

Smallholders mainly use rubber clones (RRIM 600) in monoculture which represents more than 90% of rubber plantations. The average yield of these rubber trees was 1360 kg/ha/year in 2000 and aroud 1500 kg/ha/year in 2016.

The environment, both institutional and ecological is very favourable to the development of agroforestry practices based not only on food inter-cropping during immature period but also to fruit/timber/rubber association in complex agroforestry systems.The vast majority of farmers used RRIM 600. This single clone policy is relatively risky in case of a major disease strike However, the policy of using clonal rubber on a large scale has been successful.

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

- TIMBER TREES : neem tree or "thiem" (*Azadirachta excelsa)*, "Thang" (*Litsea grandis)*, a timber tree that grows naturally from natural regeneration in rubber fields, 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 : coffee (Robusta c), "Salak" (S*allaca spp),* durian (*Durio zibethinus),* "longkong" (*Lansium domesticum)*, "petai" (*Parkia speciosa or* Nita tree), "jack fruit" (*Artocarpus heterophyllus),* "cempedak" (*Artocarpus Integer),* "mangoustan" (*Garcinia dulcis),* and banana.

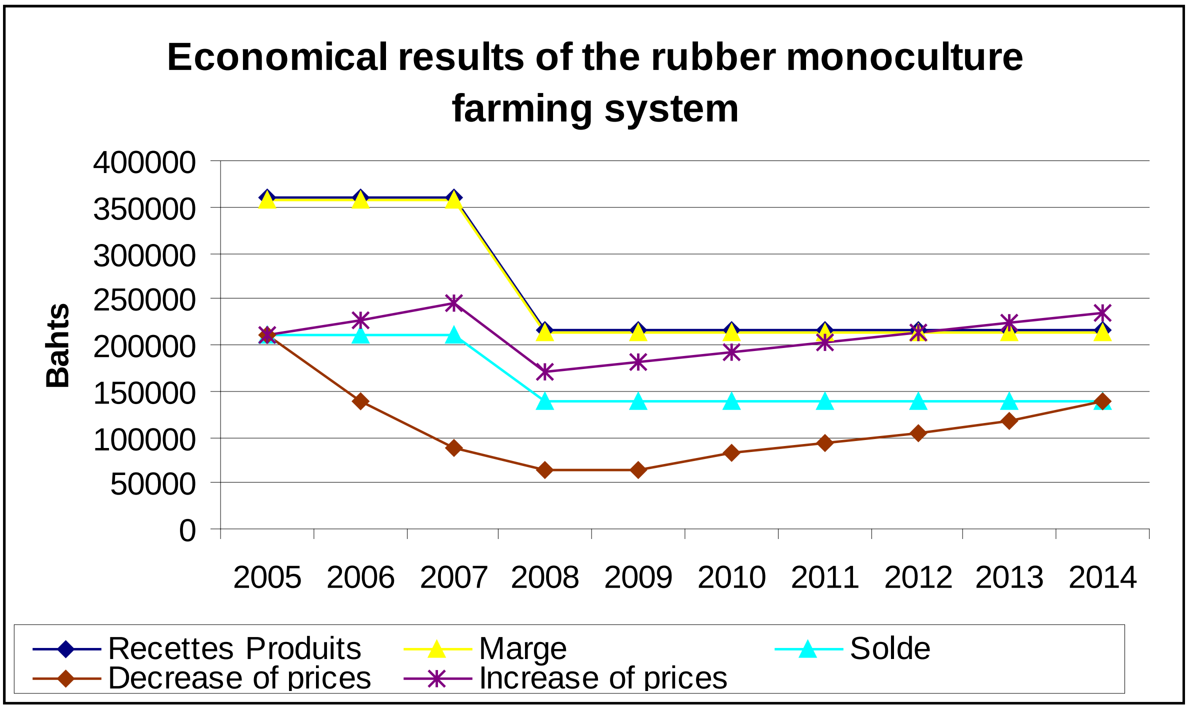
In the Pangha province (South Thailand), there is also a rubber-based agroforestry system with old jungle rubber (more than 40 years old) that also has been enriched with bamboos, rattan species, and multi-purpose trees (timber + consumption of leaves) such as "Miang" and Manboo" (no available Latin names) (Pramoth 1997, personal com.)

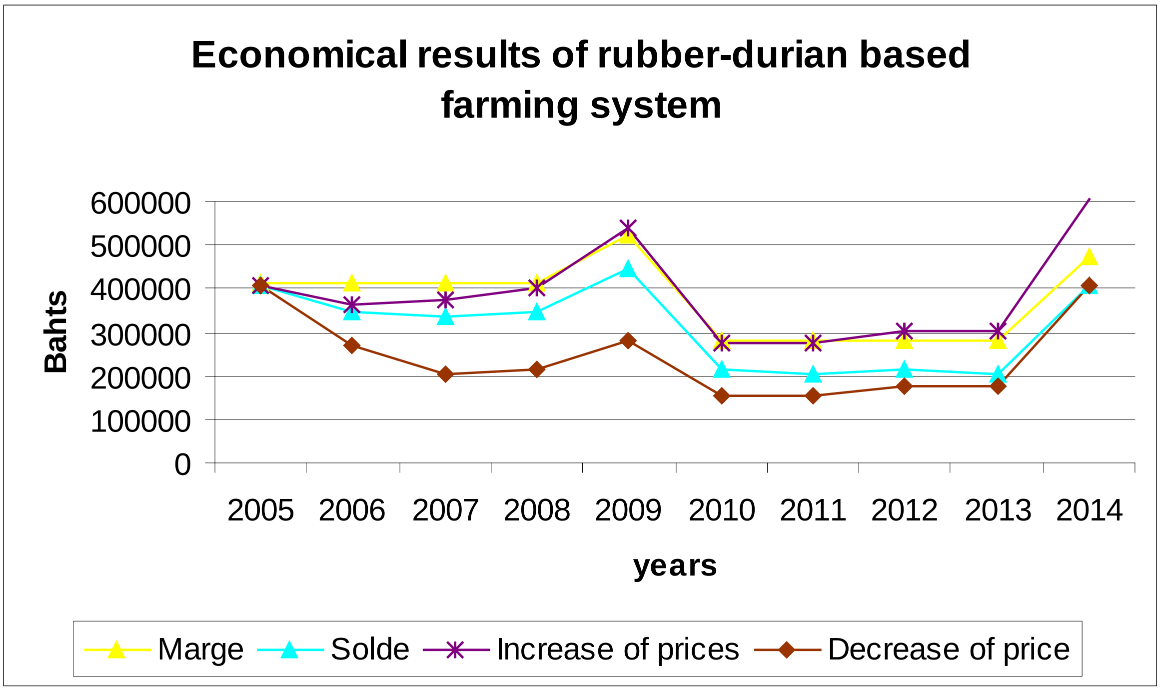
2005:! a situation with high rubber prices.

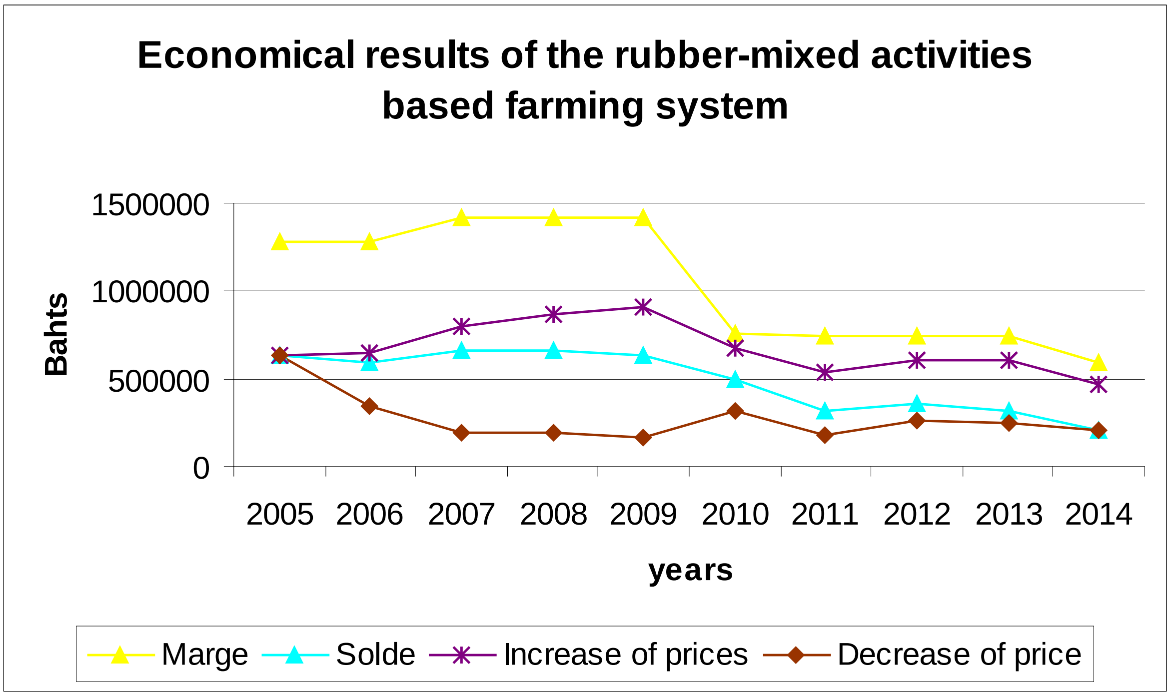
In 2005, the particularly high price of rubber benefited producers. The results of a 2005 study on 20 farms in southern Thailand indicate that it is advisable to diversify and to cultivate another crop in addition to rubber to be able to survive in times of crisis. The larger the share of income from the other crop, the better it would help the farmer withstand a decline in the price of rubber. Durian plays especially an important role in the study area as a way to diversify farm income. To grow durian at the same time as rubber enables the farmer to minimize the impact of a decrease in income if rubber prices decrease. Durian and rubber are very complementary crops, and the market for durian is currently very good and long-term prospects are very promising.
However, both systems have certain drawbacks. They are intensive, very demanding in both labor and inputs, and farmers require a good knowledge of the necessary technical itineraries. Diversification, intercropping and tree-rubber association (timber of fruits) for income diversification and risk management strategy, however more intensive, seem to be a good alternative to the current trend to specialization in rubber. Some farmers cultivate fruit trees as an intercrop, or in agroforestry systems that appear to be promising to overcome rubber price volatility when fruits market is well developed in Thailand, sustained by an important urban demand (in particular Duku/Langsat in the studied 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 in southern Thailand (double spacing with large inter-rows).

place at a period when rubber was extremely profitable due to relatively high prices compared to rubber prices during the slump in 1997-2002. Farmers' behaviour and strategies are closely linked and depend on their type of production system as well as access to diversification opportunities (fruits and in particular Durian). The smaller farms grow either rubber in monoculture or rubber with some upland rice plots. They are relatively efficient as far as intensification is concerned.

Durian clearly plays the role of economic buffer in the eventuality of a new drop in rubber prices. In other words, after having specialized in rubber production, southern Thailand will probably have to diversify in order to strengthen its economy and be more resilient in the face of possible future crises that affect commodity prices


Economical results of the rubber monoculture farming system
Bahts
400000
350000
300000
250000
200000
150000
100000
50000
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Recettes Produits
Marge
Solde
Decrease of prices
Increase of prices


Economical results of rubber-durian based farming system
Bahts
600000
500000
400000
300000
200000
100000
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
years
Marge
Solde
Increase of prices
Decrease of price



4 Conclusion

Rubber farmers have developed a series of innovations in order to adapt rubber into their extensive agroforestry practices (jungle rubber) and later in the "estate" monoculture model (SRDP development scheme), through associating rubber with perennial or annual crops. However they have obtained a stage where innovations are limited and productivity increase cannot be reached without including rubber clones and some other external innovations that require a different management. After an intermediate stage between shifting cultivation and improved fallow, and then from improved fallow to a complex agroforestry system, they now face the challenge to improve the productivity of 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). Improved rubber based agroforestry systems can meet the challenge with reduced risks and environmental benefits.

Agroforestry practices are also considered as labour saving agricultural practices and, in some cases, as, for instance, the best anti *Imperata cylindrica* strategy. In an environment of decreasing land availability for local agricultural expansion, improved RAS also reduce the amount of land required per family, by supplying a variety of marketable as well as subsistence crops within a single system. RAS offer income diversification and household needs which otherwise would have to be sought elsewhere, thereby contributing to local economic sustainability.

Another important role is the generation of a "forest rent" as defined by Ruf (1987), i.e., the reduction of costs and risks of perennial plantation establishment – thanks to the forest's positive externalities such as on soil quality, weed and pest control. This concept has been extended to agroforests by Penot (2001), who showed that agroforests did maintain (sometimes improve) the forest rent while conventional monoculture plantation crops (such as cocoa: *Theobroma cacao*, coffee: *Coffea* spp., and oil palm: *Elaeis guineensis*), generally consumed (part of) it.

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

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

The sustainability advantages of agroforests come from a trade-off between ecological and socioeconomic attributes. Conventional economic approaches may be inadequate for integrating these two sets of attributes in a comprehensive manner because (1) farmers manage agroforests with a variety of objectives in mind, (2) ecological benefits are not internalized in existing analyses, and (3) some ecological attributes have no present market value.

the analysis will exclude a series of agroforests' outputs, which are not traded in the market or insufficiently taken into account in farm economics. Indonesia's jungle rubber provides an example. While it has been a major opportunity for poor farmers at the agricultural frontier for years, it is now becoming obsolete compared to clonal rubber monoculture, in terms of yields and labor productivity (Penot 2001). However, it is difficult to measure or assign economic values to intangible services and positive externalities. For instance, C sinks values of treecrops and forests are currently available but no one can choose among various prices suggested by various experts as long as the market is not open for them. Risk-buffering potential of agroforests, as in situations of climatic variations and commodity price volatility, also deserves to be measured. The overall key question behind this is: how to make a measurement of the agricultural sustainability of agroforests? Perhaps farm-system models used in farming system research could be a useful tool for such comparative measurements.

Farming system level approach

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

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

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

Be it for commercially oriented agroforests or subsistence oriented homegardens, a long-term perspective must be part of farmers' strategy. However, there is obviously a biased debate between short-term (economics) vs. long-term (ecology). In both cases, farmers have developed long-term farming practices through a long haul innovation process that eventually takes into account economics through the risk buffering capacity of agroforests. In most cases, social organisation is deeply linked with technical constraints in production, food reliance, income securing and, eventually, land control. There is a strong coherence between technical systems (technical pathways) and social systems (Penot 2003a).

Economic analysis methods using farming system modelling which integrate the outputs of mixtures of plants with different cycles and allow for the smoothening of long-term and patrimonial strategies are required to explain with accuracy what farmers do and why they do so. Agroforests, despite their positive externalities and advantages are not a "panacea" but seem to be an ideal compromise between sustainability and risk spreading

Bibiograpphy

Albrecht A. and Kandji S.T. 2003. Carbon sequestration in tropical agroforestry systems. Agric Ecosyst Environ 99: 15-27.

Kumar B.M. and Nair P.K.R. 2004. The enigma of tropical homegardens. Agrofor Syst 61: 135-152.

Montagnini F. and Nair P.K.R. 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. Agroforest Syst 61: 281–295.

Penot E. 2003a. Cohérence entre systèmes techniques et systèmes sociaux et territoires. Evolution des systèmes de production hévéicoles et gestion de la ressource foncière : le cas de la province de Ouest-Kalimantan, Indonésie. In : Dugué P. and Jouve P (eds) Organisation spatiale et gestion des ressources et territoires ruraux. International Conference, Montpellier, France, 25-27 February 2003. UMR SAGERT (CIRAD – CNEARC - ENGREF), pp 60-68.

Barlow, C. and Muharminto ,1982. Smallholder ruber in South Sumatra, towards economic improvement., Balai Penelitian Perkebunan Bogor, Australian National University.

Compagnon P. 1986. Le caoutchouc naturel. Ed Maisonneuve et Larose, PARIS.

Dove M. 1993. Smallholder rubber and swidden agriculture in Borneo: a sustainable adaptation to the ecology and economy of tropical forest. Economic botany, 47/2.

Dove M. 1995. Political vs techno-economic factors in the development of non timber forest products: lessons from a comparison of natural and cultivated rubbers in Southeast Asia and South America. Society and natural resources, vol. 8.

de Foresta H. 1992. *Botany contribution to the understanding of smallholder rubber plantations in Indonesia: an example from Sumatra*. 9pp. Paper presented at the workshop “Sumatra: Lingkungan dan Pembangunan” (Sumatra: Its Environment and Development), 16.-18. 9. 1992, BIOTROP, Bogor.

Gede Wibawa Laxman Joshi and Meine van Noordwijk Eric Penot. Rubber based Agroforestry Systems (RAS) as Alternatives for Rubber Monoculture System. IRRDB Conference 2006.

Michon, G. and De Foresta, H. 1998. Agro forests: incorporating a forest vision in agroforestry. In: Louise E. Buck; J.P. Lassoie and E.C.M. Fernandes. (Eds.) Agroforestry in Sustainable Agricultural System. CRC Press. Boca Raton, London, New York and Washington, D.C. p: 381-406.

Penot E. 1995. Taking the jungle out of rubber. Improving rubber in Indonesian agroforestry systems. In Agroforestry Today.

Penot, E. 1997. L'amélioration des agroforets à hévéa: un enjeu pour 1 millions de paysans en Indonésie. Published in CIRAD-CP PRD publication. December 1997, Montpellier.

Pramoth Kheowvongsri, (1990). Les jardins a hevea des contreforts orientaux de bukit Barisan, Sumatra, indonesia. Diplome d'Etudes Approfondies de Biologie vegetale tropicale. Paris, France, Univ. de Montpellier.

Sompong, 1996 in Buranatham, W., S. Chugamnerd, et al., 1997. Agroforestry under rubber plantation in Thailand. Thailand/Malaysia Technical Seminar on Rubber, Phuket, Thailand.

Sethuraj MR. 1996. Impact of natural rubber plantations on environment. Paper presented at the International seminar on natural rubber as an environmentally friendly raw material and a renewable resource. Trivandum, India

Gouyon, A., de Foresta, H. and Levang, P. 1993. Does ‘jungle rubber’ deserve its name? An analysis of rubber agroforestry systems in southeast Sumatra. *Agroforestry Systems*, **22**: 181-206.

Joshi, L., Wibawa, G., Vincent, G., Boutin, D., Akiefnawati, R., Manurung, G., van Noordwijk, M. and Williams, S.E. 2002 Jungle rubber: a traditional agroforestry system under pressure. ICRAF SEA, [Booklet] 38 pp. ISBN 979-3198-04-4.

Laxman Joshi, Gede Wibawa, Ilahang, Ratna Akiefnawati, Elok Mulyoutami, Diah Wulandari and Eric Penot, 2006. Diversified rubber agroforestry for smallholder farmers – a better alternative to monoculture. Workshop on “Rubber Development in Lao PDR: Exploring Improved Systems for Smallholder Rubber Production”, Vientiane, Lao PDR, 9-11 May 2006.

Levang, P. (1996). De la jachere arboree aux agroforets, des strategies paysannes adaptees a des milieux de fertilite mediocres. Seminaire CIRAD, Montpellier, France, fertilite du milieu et strategies paysannes sous les les tropiques humides.

Penot, E. (1994). Improving the Productivity of Smallholder Rubber Agroforestry Systems: sustainable alternatives. Project frame, general proposals and on-farm trial methodology. Bogor (IDN):ICRAF-28 p., 4 table. ST: Working Paper (IDN).

Penot. E and G. Wibawa. 1997. Complex rubber agroforestry systems in Indonesia : an alternative to low productivity of jungle rubber conserving agroforestry practices and benefits. Proc. Symp. on Farming System Aspects of the Cultivation of Natural Rubber. (Hevea brasiliensis). IRRDB. p :56-80.

Penot, E. (2001). Stratégies paysannes et évolution des savoirs : l'hévéaculture agro-forestière indonésienne. Thèse de doctorat. Faculté des Sciences Economiques. Montpellier, Université Montpellier I.: 360p.

Penot E, Werner S. 1997. Prospects for the conservation of secondary forest biodiversity within productive rubber agroforests. Paper presented at the CIFOR/USAID International Workshop on "Management of Secondary Forests in Indonesia", Bogor, November 1997. To be published in seminar proceedings.

Wibawa, G; M.J. Rosyid. 1996. Farmers' Weed Management on Rubber Based Intercropping System in South-Sumatra. Prosiding Konferensi HIGI XIII: 481-490 (Indonesian).

Wibawa, G; Thomas, D. Tambunan, M.J. Rosyid and A. Gunawan. 1997. Study of the Component Interactions in Hevea Based Intercropping Systems. Proc. Symposium on

Farming System Aspects of the Cultivation of Natural Rubber (Hevea brasiliensis). IRRDB, United Kingdom. p: 25-40

Wibawa, G. 2001. Rubber Based Agroforestry Research In Indonesia. Proceeding of Indonesian Rubber Conference and IRRDB Symposium. Bogor, 12-14 September 2000.

Van Noordwijk M and Tomich T.P. . 1995. Agroforestry technologies for social forestry: tree crop interactions and forestry farmer conflicts. Social forestry and sustainable management, P 168 -193. Jakarta.

Tillekeratne LMK. 1996. Role of hevea rubber in protecting the environment in Sri Lanka. Paper presented at the International seminar on natural rubber as an environmentally friendly raw material and a renewable resource. Trivandum, India.

Tomich T, 1992. Smallholder Rubber development in Indonesia. In Reforming economic systems in developing countries, ed by D.H.Perkins and M Roemer. Harvard University.

Wan Abdul Rahaman, Wan Yacoob & Jones K. 1996. Rubber as a green commodity. Paper presented at the International seminar on natural rubber as an environmentally friendly raw material and a renewable resource. Trivandum, India.

Werner, S. 1993 Traditional land use systems of Dayaks in West Kalimantan, Indonesia: Ecological balance or resource destruction? A study of vegetation dynamics and soil development. MSc Thesis, Institut of Geography, Free University of Berlin, Germany.