

RUBBER PRODUCTION AND FOREST FUNCTIONS IN SMALL-HOLDER RUBBER AGROFORESTRY IN INDONESIA

Meine van-Noordwijk¹, Dominique Boutin^{1,2}, Gede Wibawa³, and Laxman Joshi^{1,4}

¹ICRAF SE Asia

²CIRAD

³Indonesian Research Institute for Estate Crops

⁴University of Wales, UK

ABSTRACT

Rubber production in Indonesia differs substantially from the pattern elsewhere in South East Asia, in its basic characteristics, areal extent and production. The dominant view of the extensive, less intensively managed jungle rubber among the development professionals is that it is backward and has low productivity. On the other hand the forest functions of these forest-like rubber gardens (biodiversity, watershed management, and carbon sequestration) are much higher compared to financially more profitable mono-culture plantations of rubber and oil palm. Over the last several decades, despite heavy World Bank and Asian Development Bank as well as Indonesian government investment for monoculture plantations, less than 15 percent farmers have adopted the very intensive technology. However, less intensive rubber agroforestry technology based on high yielding clones are likely to be more adoptable to the resource poor farmers. ICRAF in collaboration with national and international research institutions are working on developing such technology targeted to enhance productivity of jungle rubber while maintaining the important forest functions. In this paper, we discuss the aspects of productivity, sustainability and quality in relation to rubber production in Indonesia. The environmental services (or forest functions) provided by the jungle rubber are a key aspect of on-going research. The recent analysis indicates that the environmental services from jungle rubber farmers will not last unless specific incentives and compensations to the farmers. The main challenge remains - connecting the bottom end of the rubber producers (in terms of technology and status) to the top end (most environmentally conscious) of the consumers both at the national and international levels.

Keyword : rubber production, smallholder, agroforestry, Indonesia

INTRODUCTION

Rubber production in Indonesia differs substantially from the pattern elsewhere in South East Asia. In Indonesia rubber is mainly grown by smallholders and tapped with family labor or through a share tapping system, which means that the sale of rubber products provide the main income for millions of rural families. In Thailand and Malaysia, farmers adopted the techniques utilized in rubber estates: planting of high yielding clonal

rubber, application of fertilizers and agro-products and utilization of legume cover crops. Governments provided cheap credits and encourage farmers to establish new rubber plantations. In Indonesia, a limited number of smallholders obtained government assistance through various schemes but the wide majority still continues to manage rubber in an extensive way, using the jungle rubber approach.

Dominant views from government and large scale plantation oriented research on smallholder rubber agroforestry in Indonesia still see it in contrast to monoculture plantations common elsewhere, as:

- a lost economic opportunity and maintaining rural poverty; and
- a backward way of producing low quality bulk product.

Over the last decade an alternative view has emerged in which rubber agroforestry is :

- a low-cost, low-risk, multifunctional land use; and
- which maintains essential forest functions while providing employment up to population densities of 50 persons/km².

In the current efforts to regulate latex supply to the world market to a level that can provide acceptable rewards for the producers, the extensive production systems can be seen as:

- a threat to increased overproduction once the technology gap is closed, or as
- a safety-valve on the global production system due to its high elasticity, which means production responds faster to fluctuating prices than the plantation sector.

With the current consumer interest in the Western markets on green production, the rubber agroforest option may qualify for forms of ecolabelling and thus target a separate part of the overall market.

ICRAF, the World Agroforestry Centre, is working in partnership with Indonesian and Thai national research and development partners, as well as international partners, to explore these questions and contribute to new perspectives and opportunities for the smallholders involved.

In this presentation we will apply a generic Integrated Natural Resource Management (INRM) framework (van-Noordwijk *et al.*, 2002) to the analysis of rubber production systems. It starts with identifying perspectives on problems and opportunities in the current situation, specifying land use options that can then be compared in their impacts on productivity, socio-economic consequences and environmental impacts. The next step in the analysis is focussed on the tradeoffs between the multiple functions identified, and the discussion of policy options for modifying incentives that will induce land users to take decisions that support public goods as well as their direct interests.

INTENSIFICATION AND DEVELOPMENT PATHWAYS FOR SMALLHOLDER RUBBER PRODUCERS

Tomich et al. (2001) and Murdiyarso et al. (2002) compared the overall productivity and environmental impacts of rubber agroforests, rubber plantations and a number of other land use systems for Jambi and concluded that rubber was losing out from oil palm under current price regimes, and that specific efforts are needed to keep rubber systems competitive. This is also reflected in the rapid expansion of oil palm plantations in the province (ICRAF unpublished data).

A number of intensification pathways exist for current rubber agroforest owners.

1. Smallholder Rubber Development Project (SRDP) style projects for monoculture plantations — despite heavy World Bank & Asian Development Bank investment only around 15% of the target farmers may have been reached, with very limited spontaneous adoption of the clone-based technology outside of project areas.
2. Clear-and-replant based on the introduction of robust, productive clones (such as PB260), as in the Smallholder Rubber Agroforestry Project (SRAP of CIRAD/ ICRAF/ GAPKINDO/ IRubRI, Sembawa), that can be used with reduced weeding and fertilizer compared to current technical recommendations, intercropped with fruit or timber trees, or while allowing secondary forest development in the inter-rows.
3. *Sisipan* (Joshi et al., 2002)— gap-level interplanting of rubber and enrichment planting of other trees into existing rubber gardens (Figure 1), potentially using in-situ grafting techniques to reduce the non-productive period associated with a clear-and-replant.

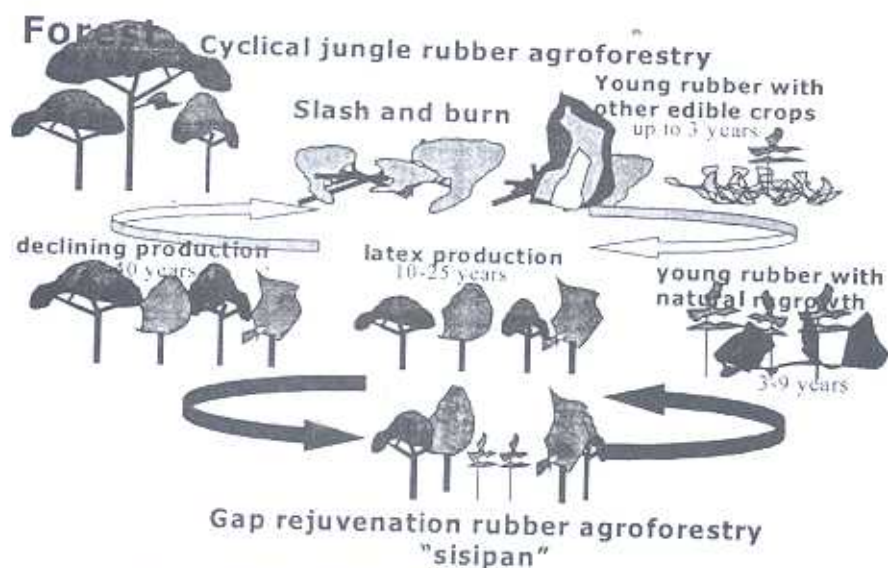


Figure 1. Rejuvination of traditional rubber agroforestry system either through a whole plot slash and burn or gap level interplanting (*sisipan*)

4. Intensified management efforts on the non-rubber components of rubber agroforests for higher timber or fruit output.
5. Shift towards oil palm.

RUBBER PRODUCTIVITY, SUSTAINABILITY AND QUALITY

In 1994 ICRAF in association with CIRAD-France and Indonesian Rubber Research Institute (Sembawa Research Centre) established a network of trials to study rubber agroforestry systems and test different approaches suitable for different conditions under SRAP (Smallholder Rubber Agroforestry Project). Three different systems suitable in most conditions were tested in trials with active participation of farmers:

- **Rubber agroforestry system-type 1 (RAS1).** In this system natural vegetation is left in the inter-row and minimum weeding is performed on the rubber planting row only. The aim is to reduce maintenance cost and to recreate an environment similar to jungle rubber.
- **Rubber agroforestry system-type 2 (RAS 2).** Clonal rubber is associated with food crops and tree crops (fruit trees and timber trees) in order to optimize land use and generate additional incomes.
- **Rubber agroforestry system-type 3 (RAS 3).** In Imperata grass lands rubber is associated with legume shrubs and fast growing trees in order to control Imperata by shading. The system aims at reducing investment cost (limited use of herbicides, no legume cover crops).

The RAS explanation in detail is as follows :

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 adaptation¹. 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

Note : ¹The selected clones are PB 260, RRIC 100, BPM 1 and RRIM 60

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. Labor or 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 MPT's for shade is aimed at controlling *Imperata*. Biodiversity is expected to be similar to that of RAS 2.

In 2002, at the end of the immature stage, results showed that RAS systems are very well adapted to local constraints. There is a considerable demand from surrounding farmers who want to join the project or develop similar systems on their own. Impact analysis carried out in 2000 shows that 60% of SRAP farmers have replanted in the last 5 years using agroforestry techniques. The low availability of improved rubber planting material in villages is considered as the major limitation for new field development.

During the research on the RAS 1-3 systems, we realized that all three of these systems rely on a clear-and-plant approach, with the clear often in the form of slash-and-burn. In fact Indonesian farmers use a different strategy as well: *sisipan* or interplanting into existing vegetation.

Our current understanding that *sisipan* techniques have been the response of smallholders who do not have resources to invest in a clear and replant operation, and who want to maintain the options of deriving continuous income, even at a low level, from the garden during the immature period of the newly planted trees. Financial profitability calculations (Wibawa et al., 2002) suggest that as long as yield levels can be maintained above 700 kg DRC per ha per year and for the high discount rates that smallholders face, the *sisipan* system is superior.

Note : -MPT : multi purpose tree

FARMER KNOWLEDGE, HOUSEHOLD DECISION MAKING,
RETURNS TO LAND AND LABOR

A comprehensive assessment of profitability for land use alternatives in lowland Sumatra was reported by Tomich *et al.* (2001). Rubber agroforests in their current or intensified form can provide employment opportunity for population densities up to 60-80 persons/km² at a return to labour that is just about competitive with urban wage rates (at the official minimum wage rate that may reflect a target rather than the real minimum) (Table 1). Oil palm in this calculation offers about double the returns to labor - still below what legal/illegal logging can provide.

The data show that the historical switch from upland food crops to tree crops has allowed a substantial increase in rural population density - and has during peak prices for rubber actually attracted the migrant flows to reach close to the potential population densities in much of the range.

Table 1. Returns to labor, labor requirements for establishment of the various land use type and average annual labor requirements in the operational phase and the human population density that can be supported assuming 150 work days per year per average person and 80% of the land area available for productive land use (Modified from: Tomich *et al.*, 2001)

| Land-use type | Returns to labor, relative to minimum wage rate | | Labor requirement (Person-days/ha) | | | Equivalent population density, people/km ² |
|------------------------------------|---|---------------|------------------------------------|-----------------|-----------|---|
| | Private prices | Social prices | Establish phase | Operation phase | Total | |
| Community forestry | 2.9 | 2.8 | — | 0.2 - 0.4 | 0.2 - 0.4 | 0.2 |
| Logging | -4.3 - 0.5 | 2.0 - 7.8 | 15 - 100 | 17 - 41 | 31 | 17 |
| Rubber agroforest | 1.0 | 1.0 | 271 | 157 | 111 | 59 |
| Rubber agroforest - intensified | 1.0 - 1.7 | 1.1 - 1.9 | 444 | 74 | 150 | 80 |
| Rubber plantations | 1.7 | 0.7 | 344 | 166 | 133 | 71 |
| Oil palm plantations | 1.5 | 2.5 | 532 | 83 | 108 | 58 |
| Shifting cultivation - upland rice | 0.75 | 0.95 | — | 15 - 25 | 15 - 25 | 11 |
| Cassava | 1.05 | 1.05 | — | 98 - 104 | 98 - 104 | 54 |

ENVIRONMENTAL IMPACTS

Watershed functions

The main concerns about rubber effects on watershed functions relate to erosion in the initial land clearing from forest, as well as in subsequent clear-and-replant cycles. Recent measurements in Jambi have shown that the combination of rubber and upland rice can provide sufficient filter functions that prevent sediment transfer to streams. Water use of rubber agroforests is probably less than that of oil palm plantations. Overall the issue of watershed functions does not differentiate strongly between the various alternatives.

Biodiversity conservation: rubber agroforests as last reservoir of lowland forest species

Since the early 1970s forests in the Sumatran lowlands are being rapidly transformed by large-scale logging and estate development (oil palm, trees for pulp, and paper factories), turning the extremely species-rich lowland rainforest into large, monotonous monoculture plantations. In terms of forest biodiversity, not much can be expected from such plantations, while on the other hand strict conservation of sufficiently large areas of protected lowland rainforest has not been a realistic option in the process of rapid land use change. The ongoing development is changing the role of rubber agroforests in the landscape: from adding anthropogenic vegetation types to the overall natural forest diversity, rubber agroforests are probably becoming the most important forest-like vegetation that we can find covering substantially large areas in the lowlands. 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 ecologists are aware that 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. However, jungle rubber farmers are not interested in biodiversity in the sense conservationists are. They make a living by selectively using species richness and ecosystem functions, and base their management decisions on maximizing profitability and minimizing ecological and economical risks. Michon and De Foresta (1992) were the first to draw attention to this issue, including the need for researchers to take both the farmers perspective and the ecologist's perspective into account. They started the discussion on complex agroforestry systems and the conservation of biological diversity in Indonesia, and pleaded for assessment of existing and potential capacity of agricultural ecosystems to preserve biological diversity.

As part of a research programme on complex agroforestry systems, researchers from ORSTOM and BIOTROP started working on biodiversity in rubber systems in the Sumatra lowlands (de Foresta and Michon, 1994). Vegetation profiles were drawn of four jungle rubber plots in Jambi province and one in South Sumatra province (de Foresta, 1997), including lists of tree species and analysis of structure. In addition, a 100 meter transect

line was sampled for all plant species in a natural forest and a jungle rubber garden in Jambi and a rubber plantation in South Sumatra. Bird species (Thiollay, 1995) and soil fauna were compared between natural forest and jungle rubber, and an inventory was done to document the presence of mammal species in jungle rubber. In an overview paper presenting the results, Michon and de Foresta (1995) conclude that different groups are affected differently by human interference. Levels of soil fauna diversity are quite similar between forest and agroforest, while bird diversity in the agroforest is reduced to about 60 percent of that in primary forest, with a shift from typical forest birds (including ground dwellers) to birds of more open vegetation. Danielsen and Heegaard (1994) confirmed the results of (Thiollay, 1995) that different groups of birds were affected differently by changes in vegetation structure, floristic richness and associated variety of food resources. Some groups were drastically reduced while others were thriving in agroforests.

Almost all forest mammals were found to be present in the agroforest, but population densities were not studied yet, and occasional recordings of rhinoceros or elephant do not indicate that agroforests are in themselves a suitable habitat for charismatic megafauna. 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. These statements on relative diversity, however, apply to plot-level assessments only and cannot be extrapolated to larger scales, until we have data on the scaling relations beyond the plot for forest as well as agroforests. Another multi-taxa study (including plants, birds, mammals, canopy insects and soil fauna) was reported by Gillison *et al.* (1999) and covered a wider range of land use types, from forest to Imperata grassland, with similar results for the relative diversity of agroforest. From these studies it is clear that jungle rubber is an interesting system potentially combining biodiversity conservation and sustainable production, but some questions remain. Apart from signalling changes in overall species richness, understanding the ecological significance of differences in species composition between forest, jungle rubber and rubber plantations is necessary to be able to judge the value of jungle rubber for the conservation of forest species. Another problem to be solved is the problem of scale. Results from studies based on few plots or relatively small plots in a limited area cannot be safely extrapolated, as some land use types are more repetitive in species composition than others (alpha versus beta diversity).

Studying terrestrial pteridophytes, Beukema and van Noordwijk (in press / 2002) 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 a higher beta diversity (Figure 2). When pteridophytes were grouped according to their ecological requirements, the species-area curves based on forest species alone were far apart, showing that jungle rubber supports intermediate numbers of forest species as compared to natural forest (much higher) and rubber plantations (much lower).

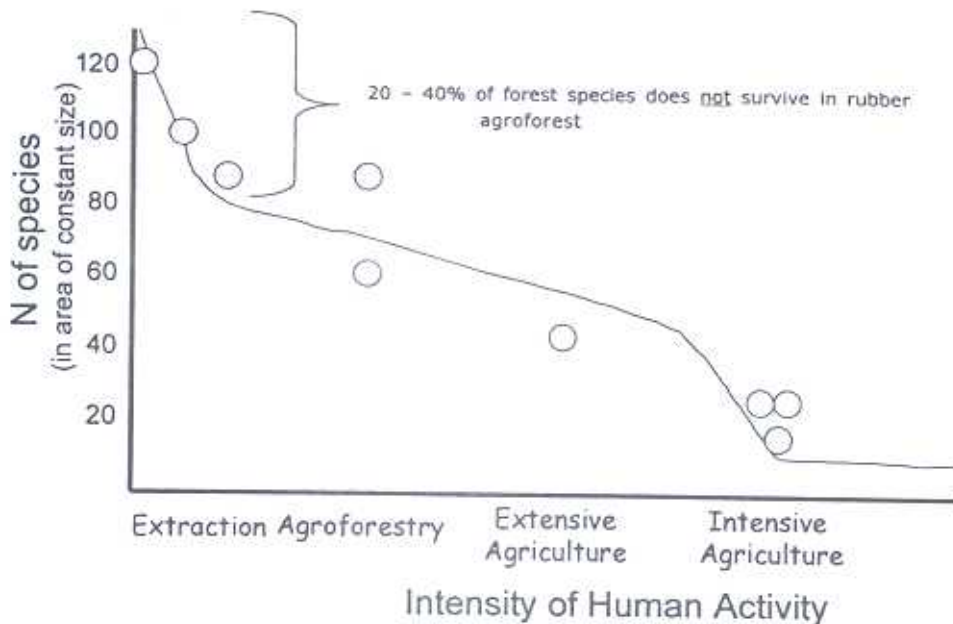


Figure 2. Plant species richness across a land use intensity gradient in Jambi (Murdiyarsa *et al.*, 2000); the accolade indicates species that go locally extinct when humans are active: they are either exploited or sensitive to disturbance (van-Schaik and van-Noordwijk, 2002)

We can conclude from all these studies that jungle rubber is indeed diverse, but also that it is different from forest as a habitat that has more gaps and open spaces, and in scaling relations. The percentages of forest species conserved in complex agroforestry systems such as jungle rubber are not easily estimated from the relative richness at plot-level, as they depend on taxonomic or functional group, and on the scale of evaluation.

Biodiversity studies in jungle rubber have been integrated with socio-economic and agronomic studies from the beginning (Gouyon *et al.*, 1993). To optimally use limited research capacity, further biodiversity studies should ideally be targeted at taxonomic groups that are either of direct interest to farmers, such as timber trees and other secondary products (Hardiwinoto *et al.*, 1999), or that are important to ecosystem functioning (soil fauna, pollinators, seed dispersers). There is also an important role for biological research in studying effects of the secondary forest component such as competition for light and nutrients (Williams, 2000), or the ecology of vertebrate consumers of rubber seeds and seedlings (pigs) or young leaves (monkey) (Gauthier, 1998) and fungal diseases of rubber.

C stocks

Tomich *et al.* (2002) compared data for the time-averaged C stocks for the different land use systems. Whereas natural forest will have C stocks of 250 Mg C/ha, for sustainably logged forest the time-averaged C stock will be around 150 Mg C/ha, and that of the cassava/*Imperata* cycle would bring this down to around 40 Mg C/ha, the values for rubber plantations and agroforests will be 100–120 Mg C/ha, the *sisipan* technique can increase this to say 120 – 140 Mg C/ha, and oil palm plantations operate at about 90 Mg C/ha (Figure 3).

TRADE-OFFS BETWEEN PRIVATE AND PUBLIC BENEFITS: IS THERE A ROLE FOR 'ENVIRONMENTAL SERVICE PAYMENTS'? – ECOLABELLING??

Overall, the tree crop systems are 'win win' solutions from a environment & development perspective, as they allow for higher population densities, income as well as C stocks when compared to food crop production. Within the tree crops, however, there is a negative trade-off between environmental attributes and income (Figure 4).

By far the most distinguishing element in comparisons between tree crop systems is the biodiversity issue – with the extensive rubber agroforests indeed in a very special position. Although 20–40% of forest species does not survive in rubber agroforest, the other 60–80% can and in the absence of effectively conserved lowland forest in Sumatra, makes the current rubber agroforests a major reservoir of biodiversity.

ICRAF and partners are currently interested in the options of an eco labelling type approach to capture a higher price for these extensive forms of rubber production. A full analysis of this issue is beyond the scope of the current presentation.

SCENARIOS, LIKELY TRENDS

— RELEVANT POLICY RESPONSE, PRIORITIES FOR RESEARCH AND DEVELOPMENT

Although still rather sketchy, our current understanding of the farmer decisions in Jambi that have led to the current old jungle rubber situation and the options available, points to access (roads) and specific subsidies or cheap credit still being the major drivers towards oil palm conversion (along with expansion of local processing capacity), while improving markets for farmer-grown timber and fruits being the main incentive to the enrichment planting strategies and clonal rubber polyculture as idealized target.

It seems likely, however, that the current environmental service provided by jungle rubber farmers in the form of biodiversity conservation will not last – unless there are specific incentives that reward for this service. This reward may have to be areas based (paying farmers for not-intensifying in part of the domain), based on higher value of the rubber (green rubber) or on the direct value of other products from these extensive systems. The latter will be the most sustainable, but may need help in a transition period. The main challenge thus is: can we connect the bottom end of the rubber producers (in terms of technology and status) to the top end (most environmentally conscious) of the consumers?

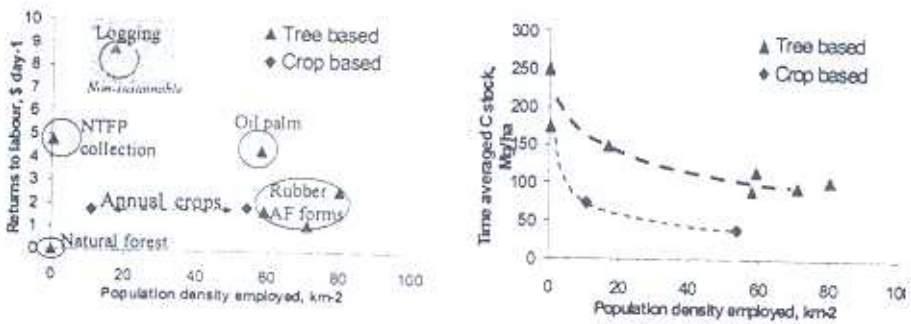


Figure 3. Tradeoffs between population density, returns to labor and time-averaged C stock for land use alternatives in Jambi

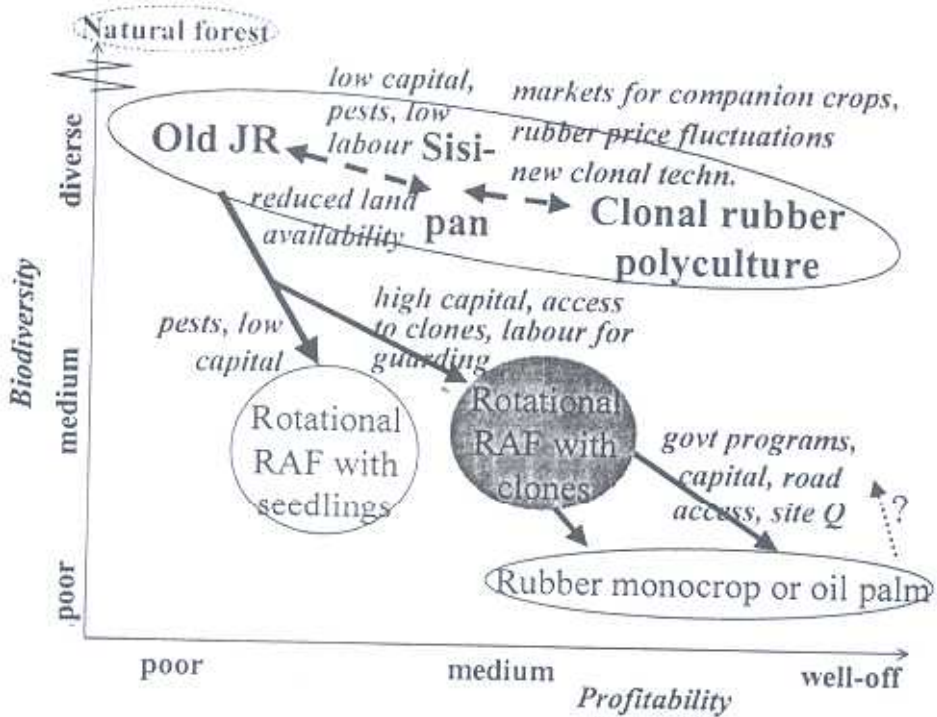


Figure 4. Current understanding of the driving forces that influence farmer decisions in the tree crop domain, and their consequences for profitability and biodiversity

REFERENCES

- Beukema, H. and M. van-Noordwijk. 2002. Terrestrial pteridophytes as indicators of a forest-like environment in rubber production systems in the lowlands of Jambi, Sumatra. *Agriculture, Ecosystems and Environment*, in press.
- Danielsen, F. and M. Heegaard. 1994. The impact of logging and forest conversion on lowland forest birds and other wildlife in Seberida, Riau, Riau Province, Sumatra. In: O. Sandbukt and H. Wiriadinata (eds). *Rain forest and resource management*. Indonesia Institute of Science, Jakarta, Indonesia, pp.59-60.
- de Foresta, H. and G. Michon. 1994. Agroforests in Sumatra where ecology meets economy. *Agroforestry Today* 4(6):12-13.
- de Foresta, H. 1997. Smallholder rubber plantation viewed through forest ecologist glasses: an examples from South Sumatra. SRAP Workshop, Rubber Agroforestry Systems in Indonesia, 29-30 September 1977, Bogor, Indonesia, 9pp.
- Gauthier, R. C. T. 1998. Policies, Livelihood and Environmental Change at the Forest Margin in North Lampung, Indonesia. A Coevolutionary Analysis. Wye College, University of London. 405pp.
- Gillison, A. N., and N. Liswanti. 1999. Biodiversity and productivity assessment for sustainable agroforest ecosystems, Mae Chaem, Northern Thailand: preliminary report. Part D in A. N. Gillison. Above-ground Biodiversity Assessment Working Group summary report 1996-99: impact of different land uses on biodiversity. International Centre for Research in Agroforestry (ICRAF), Nairobi, Kenya.
- Gouyon, A., H. de Foresta, and P. Levang. 1993. Does jungle rubber deserve its name? An analysis of rubber agroforestry systems in southeast Sumatra. *Agroforestry Systems* 22(3):181-206.
- Hardiwinoto, S., D. T. Adriyanti, H. B. Suwarno, Aris D., M. Wahyudi, and M. S. Sabarnurdin. 1999. Stand Structure and Species Composition of Rubber Agroforests in Tropical Ecosystems of Jambi, Sumatra. Draft Report.
- Joshi, L., G. Wibawa, H. J. Beukema, S. E. Williams, and M. van-Noordwijk. 2002. Technological change and biodiversity in the rubber agroecosystem in J. Vandermeer (Ed.) *Tropical Agroecosystems: New Directions for Research*. CRC Press, Baton Rouge, FL.
- Ketterings Q. M., M. van-Noordwijk, and J. M. Bigham. 2002. Soil phosphorus availability after slash-and-burn fires of different intensities in rubber agroforests in Sumatra, Indonesia. *Agriculture, Ecosystems and Environment* 92:37-48.
- Ketterings, Q.M., T. T. Wibowo, M. van-Noordwijk, and E. Penot. 1999. Slash-and-burn as a land clearing method for small-scale rubber producers in Sepunggur, Jambi Province, Sumatra, Indonesia. *Forest Ecology and Management* 120:157-69.

- Michon, G., H. De Foresta, *et al.* 1992. Complex agroforestry systems in Sumatra. Symposium "Sumatra, Lingkungan dan Pembangunan", Bogor.
- Michon, G and de Foresta, H. 1995. The Indonesian agro-forest model. In: Conserving biodiversity outside protected areas: The role of traditional ecosystems, Halladay, P and Gillmour, DA (eds), IUCN, Gland, Switzerland and Cambridge, UK, p:90-106.
- Murdiyarso D., M. van-Noordwijk, U. R. Wasrin, T. P. Tomich, and A. N. Gillison. 2002. Environmental benefits and sustainable land-use options in the Jambi transect, Sumatra, Indonesia. *Journal of Vegetation Science* 13:429-38.
- Thiollay, J. M. 1995. The role of traditional agroforests in the conservation of rain forest bird diversity in Sumatra. *Conservation Biology* 9:335-53.
- Tomich, T. P., M. van-Noordwijk, S. Budidarseno, A. Gillison, T. Kusumanto, D. Murdiyarso, F. Stolle, and A. M. Fagi. 2001. Agricultural intensification, deforestation, and the environment: assessing tradeoffs in Sumatra, Indonesia. In: Lee D.R. and C. B. Barrett, (eds.) Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment. CAB-International, Wallingford pp.221-44.
- Tomich, T. P., H. de Foresta, R. Dennis, Q. M. Ketterings, D. Murdiyarso, C. A. Palm, F. Stolle, S. Suyanto, and M. van-Noordwijk. 2002. Carbon offsets for conservation and development in Indonesia? *American Journal of Alternative Agriculture* 17:125-37.
- van-Noordwijk, M., T. P. Tomich, B. Verbist. 2002. Negotiation Support Models for Integrated Natural Resource Management in Tropical Forest Margins. *Conservation Ecology* 5(2):21.
- van-Noordwijk, M., S. E. Williams, and B. Verbist (Eds.). 2001. Towards integrated natural resource management in forest margins of the humid tropics: local action and global concerns. ASB-Lecture Notes 1 – 12. International Centre for Research in Agroforestry (ICRAF), Bogor, Indonesia. Also available from: <http://www.icraf.cgiar.org/sea/Training/Materials/ASB-TM/ASB-ICRAFSEA-LN.htm>
- van-Schaik, C.P. and M. van-Noordwijk. 2002. Agroforestry and biodiversity: are they compatible? In: S. M. Sitompul and S. R. Utami (Eds.) *Akar Pertanian Sehat*. Proc. Seminar Ilmiah, 28 June 2002, Brawijaya University, Malang. pp.147-56.
- Wibawa, G., S. Hendratno, and M. van-Noordwijk. 2002. Permanent smallholder rubber agroforestry systems in Sumatra, Indonesia: environmental benefits and reasons for smallholder interest. In : Sanchez P. *et al.* (eds.) *American Society of Agronomy*, Madison (W, USA) in press.
- Williams, S. E., M. van-Noordwijk, E. Penot, J. R. Healey, F. L. Sinclair, and G. Wibawa. 2001. On-farm evaluation of the establishment of clonal rubber in multistrata agroforests in Jambi, Indonesia. *Agroforestry Systems* 53(2001):227-37.
- Williams, S. E. 2000. Interactions Between Components of Rubber Agroforestry Systems in Indonesia. School of Agricultural and Forest Science, University of Wales, Bangor. 256pp.