Technological Change and Biodiversity in the Rubber Agroecosystem of Sumatra

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INTRODUCTION: DOMESTICATING TREES OR THE FOREST?

Large areas of the humid tropics have land-use patterns that do not fit into a simple culture/nature or agriculture/forest dichotomy and thus the term *deforestation* refers

to a gradual loss of forest functions, rather than an abrupt change. The definition of *agroforest* by de Foresta and Michon (1996), an intermediate stage between natural forest and agricultural plantations, captures the mixed heritage of the wild and the domesticated aspect of these systems. Outside perspectives on these systems have focused on either side of the coin: poorly managed, low productivity, because too wild or interesting biodiversity but not like a real forest, because too domesticated. Yet, these land-use systems should be understood from a farmer's/manager's perspective if we want to understand what scenarios exist for their future development. Can farmers increase productivity (and/or profitability) while maintaining the current biodiversity of the system? Or will any intensification beyond current practices lead to a further decrease of biodiversity values, which in the past were largely derived from the natural forest context of the system? This chapter discusses these perspectives on the basis of ongoing research by ICRAF and partners in Jambi, one of the main rubber-producing provinces in Sumatra (Indonesia).

A conceptual scheme for the analysis of complex agroecosystems such as rubber agroforests (Figure 5.1) should consider interactions between farmer management decisions (the human part) and a considerable wild, spontaneous, or natural component in the agroecosystem. Both the planned/planted and the spontaneous components can be harvested and contribute to farm profitability, but the nonharvested components contribute to long-term sustainability and environmental functions for outside stakeholders. While traditionally agricultural research has focused on the upper part of the diagram (the planted and harvested part), a more complete understanding is desirable.
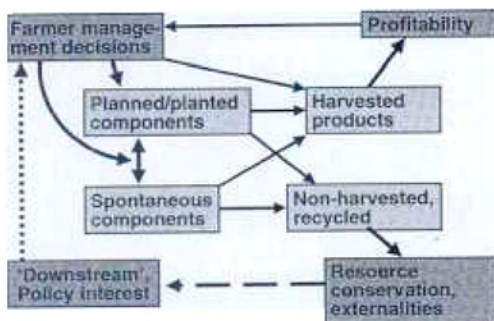
Figure 5.1   Conceptual scheme for analyzing complex agroecosystems in which farmer management decisions interact with a considerable spontaneous or natural component in the agroecosystem, and where both the planned/planted and the spontaneous components can be harvested and contribute to farm profitability, while the nonharvested components contribute to long-term sustainability and environmental service functions for outside stakeholders. (Modified from Swift and Ingram, 1996; Vandermeer et al., 1998.)

Complex agroforests (de Foresta and Michon, 1997, de Foresta et al., 2000) can be derived from forest in essentially two ways:

- By gradually modifying a forest through interplanting of desirable local (such as cinnamon, tea, fruit trees) or introduced (such as coffee) forest species
- By modifying forest succession in the fallow vegetation after a slash-and-burn land clearing and food-crop production episode, using local (benzoe) or introduced (rubber) trees

Both methods can be repeated (or exchanged) in subsequent management for rejuvenation of the agroforest, as we will see.

Agroforests represent an important stage in the domestication of forest resources (Wiersum, 1997a) or an alternative pathway for domesticating the forest rather than the trees as such (Michon and de Foresta, 1997, 1999). Domestication involves both the biological resource (and an increasing human control over reproduction and gene flow into subsequent generations) and the land used (with increasing private control over what starts as of as open-access resources, Figure 5.2). Wiersum (1997a,b) identified three thresholds in the process of domestication: *controlled utilization* (separating the open access from the controlled harvesting regime), *purposeful regeneration* (separating the dependence on natural regeneration from the interventions that generally require control over subsequent utilization), and *domestication* (into horticultural or plantation style production system). Agroforests contain trees planted, seeded, or otherwise regenerated by the farmer, as well as trees established spontaneously, but tolerated. Human control over the genetic makeup of the trees, however, is generally limited and there is thus scope for further *domestication*.
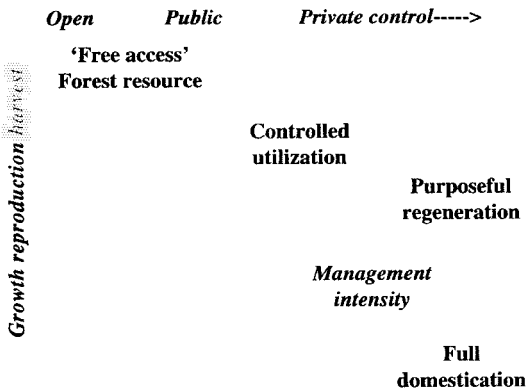

Figure 5.2 Stages in domestication of forest resources, on the basis of the type of control (tenure) of land and the type of control over reproduction and growth of the plants involved. (Modified from Wiersum, 1997b.)

While there has been a tradition of trading various types of resin and latex collected from the forest, the introduction a century ago of *Hevea brasiliensis* or "para" from the Amazone (Para) to Southeast Asia formed the basis of a large-scale spontaneous adoption of new agroforestry practices at a scale not easily matched elsewhere (Van Gelder, 1950; Webster and Baulkwill, 1989). An estimated 7 million people in Sumatra and Kalimantan islands currently make their living from rubber-based agroforests from an area of 2.5 million hectares. Smallholder rubber constitutes 84% of the total Indonesian rubber area; and 76% of the total rubber production volume (Ditjenbun, 1998). Rubber is a major export commodity supporting the Indonesian economy. Around 70% of farmers in Jambi province are engaged in smallholder rubber production and derive, on average, nearly 70% of household income from rubber (Wibawa et al., 2002).

This chapter discusses the origins of the rubber agroforest, their current value for biodiversity conservation, and the search for technological improvements that suit farmers' priorities but also maintain the environmental service functions that current systems provide.

RUBBER AGROFORESTS ARE HISTORICALLY DERIVED FROM CROP-FALLOW ROTATIONS

Fallow rotation systems, in the definition of Ruthenberg (1976), are an intermediate stage between "shifting cultivation or long rotation fallow systems" (where land is cropped for less than one third of the time, $R < 0.33$) and continuous cropping (where land is cropped more than two thirds of the time, $R > 0.67$). Ruthenberg's (1976) R value is the fraction of time (or land area) used for annual food crops as part of the total cropping cycle (area). The equivalence of time and area only applies in steady-state conditions of land-use intensity. Although crop yields per unit cropped field are directly related to the soil fertility of the plot, and hence to the preceding length of the fallow period, shortening the fallow period can generally increase total yields per unit land. According to a simple model formulation (Trenbath, 1989; van Noordwijk, 1999), the maximum sustainable returns to land can be expected where soil fertility can recover during a fallow to just over half its maximum value. More intensive land use (higher R values) are only possible if the soil restoring functions of a fallow can be obtained in less time, by a so-called improved (more effective) fallow, or that these functions have to be fully integrated into the cropping system. In practice, there is a danger of overintensification leading to degradation (Trenbath, 1989; van Noordwijk et al., 1997). *Imperata* fallows may on the one hand prevent complete soil degradation, but they are not productive, do little to restore soil fertility, and may lead to land abandonment. In the lowland peneplains of Sumatra, however, para rubber arrived in time to provide an alternative method of intensifying land use by increasing the forest productivity of the fallow and increasing the cycle length.

Fallows in various stages of their succession to secondary forests can be used as grazing land and for producing firewood, honey, thatching material, etc. The first step in intensification of farmer management of fallow lands is usually the retention or promotion of certain plant species that appear in the fallow and are considered

to be of value for one of the several functions of a fallow: its role with respect to a future crop, or its role as a direct resource. During further intensification, however, choices among the multiple functions may be necessary, as more effective fallows will tend to become shorter in duration while many elements for a more productive fallow impose an increased duration on the system.

The transition from swidden-fallow systems into more intensive land-use systems can essentially follow three routes (Cairns and Garrity, 1999; van Noordwijk, 1999) that focus on three elements of the system: food crops, tree crops, or fodder supply/pasture systems. Efforts to increase the harvestable output per unit area can be achieved in food-crop-based systems by reducing the length of the fallow period and the age at which secondary forests are reopened by slash-and-burn methods. Agroforest development emphasizes the harvestable part of the forest fallow and will lead to a reduction of annual crop intensity as the economic lifespan of the trees dominates decisions on cycle length. Specialization on fodder supply or pasture systems is relatively unimportant in the humid forest zone of Indonesia, but it is a dominant pattern in Latin America. In the Indonesian context, beginning at the start of the 20th century, the swidden lands were gradually transformed by slash-and-burn farmers into rubber agroforests.

A major incentive in this process was the local rule system that essentially allowed private ownership claims over formerly communal land resources to be established by planting trees (Gouyon, de Foresta, and Levang, 1993). This ownership claim strictly applies to only the trees planted, and, for example, durian fruits in such a garden are still treated as a village-level resource. However, in practice, planting rubber trees, even with a low rate of success in tree establishment and regardless of the genetic quality, yields full control over the land, including the right to sell (Suyanto, Tomich, and Otsuka, 2001; Suyanto and Otsuka, 2001). In Sumatra's lowland peneplains, nearly all shifting cultivation has now been replaced by rubber-based agroforestry (van Noordwijk et al., 1995, 1998), but small reserves for bush fallow rotations are maintained in some villages as an option for poor farmers to grow food crops. In addition to providing cash income for the farmer, jungle rubber agroforests also provide a range of nonrubber products and other environmental benefits.

JUNGLE RUBBER AGROFORESTRY SYSTEMS IN JAMBI

At the turn of the new millennium, smallholder rubber production systems in Indonesia still spanned a wide range of intensities of management. Despite decades of government efforts, only about 15% smallholder rubber farmers have adopted the improved monoculture plantation (Ditjenbun, 1998) with selected (domesticated) tree germ plasm of higher (up to fivefold in on-station experiments) latex production per tree. A vast majority of rubber producing areas in Indonesia, located mainly in North Sumatra, Jambi, South Sumatra, Riau, and West, South, and Central Kalimantan provinces, are still in the form of jungle rubber agroforests with varying levels of dominance of native nonrubber flora. The majority of the rubber area is still in the form of complex multistrata agroforests (de Foresta and Michon, 1993, 1996).

Around 70% of farmers in Jambi province are directly involved in smallholder rubber production and derive on average nearly 70% of household income from rubber (Table 5.1). Rubber agroforests have been primarily established by slash-and-burn techniques on logged-over forest land or land under some form of secondary forest, previously used for food crop/fallow rotations.

Mostly established in the 1940s to 1960s, the existing rubber agroforests in Jambi are old with very low latex production potential (Hadi, Manurung, and Purnama, 1997), essentially still based on rubber germ plasm that came directly from Brazil and became naturalized in Indonesia, spreading by seed. Latex productivity per unit land from these jungle rubber agroforests is very low, at about 600 kg dry rubber/ha/year, less than half that of estate plantations (Wibawa et al., 1998). Returns to labor, however, are similar if land is not valued in the profitability assessment (Tomich et al., 2001) and can only be surpassed by collection of nontimber forest products (with low returns per hectare), illegal logging, or (at least before the economic crisis of 1997) oil palm production. Rubber is a major livelihood provider, but many of the rubber gardens are getting old and productivity per hectare declines. Occasionally, trees that according to the villagers are 100 years old and that survived from the earliest plantings, around 1920, close to the river, are still being tapped.

Many farmers rejuvenate their rubber agroforest only after production from the old rubber becomes very low by slash-and-burn to start a new cycle of jungle rubber system. The system is also known as cyclical rubber agroforestry system, or CRAS, (Figure 5.3), using either locally obtained rubber seedlings or improved clonal planting material. In the first year or two, farmers often plant upland food crops

Table 5.1 Household Annual Income and Expenditure Figures for Villages in the Lowland Peneplain of Jambi (Sumatra, Indonesia)

Source/Expense	Indonesian Rupiah* in 2000	Percentage of Total
Income Sources		
Rubber	4819	69
Nonrubber farm	1424	20
Off farm	768	11
Subtotal	*7011*	*100*
Expenses		
Consumption (mainly food)	4344	68
Education	46	1
Miscellaneous	2028	31
Subtotal	*6418*	*100*

Note: *1 U.S. dollar = 7500 Indonesian rupiah approximately.

Source: From Wibawa et al., *ASA Proceedings*, in press. With permission.
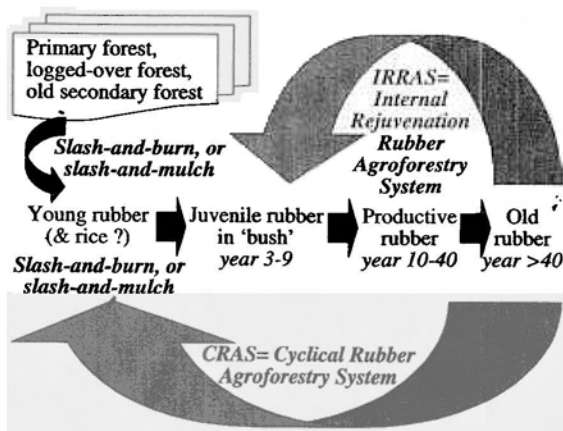
Figure 5.3 Schematic representation of cyclical and internal-rejuvenation forms of rubber agroforests.

such as rice, maize, soybean, mungbean, pineapple, or banana, while estates plant leguminous cover crops during the establishment of young plants. Small-scale rubber producers are often reluctant to rejuvenate their rubber agroforest, primarily because of the following:

- Potential loss of income during replacement/establishment of rubber trees, especially for heavily rubber dependent households
- Limited financial capital (particularly money and labor) for replacing old rubber trees with new ones, and for clonal material, high management costs (input material)
- High risk of pig and monkey damage on young rubber plants; this forms a major constraint in establishment of rubber gardens in Jambi — in up to half of the newly established plots, insufficient rubber trees survive to tappable age

Rubber trees spread by seed, and in the more extensively managed rubber gardens, spontaneous rubber seedlings are common. Some of these may grow to reach tappable size, but techniques of assisted natural regeneration are required to promote this. Recent observations in the smallholder jungle rubber system in the Jambi region in Indonesia indicate that many farmers practice a technique of rubber tree rejuvenation in order to fill in gaps or replace unproductive trees with productive rubber seedlings in rubber gardens. This is a strategy to cope with the decreased or declining productive rubber tree population without a need for the drastic slash-and-burn of the plot. Locally known as *sisipan* (literally meaning planting new plants between old plants), new rubber seedlings are transplanted over a number of years within gaps in the forest to replace dead, dying, unproductive, and unwanted trees. A permanent forest cover is maintained, but we cannot as yet expect the agroforest to be permanent; hence, the system is called the internal-rejuvenation rubber agroforestry system (IRRAS). The system can be recognized from its range of development stages and forms of rubber trees.

Thus, two methods exist for rejuvenating the stand (Figure 5.3): slash-and-burn followed by a replant, depending on natural regeneration, or the technique of *sisipan* for gap enrichment planting. The *sisipan* technique is emerging as an important, farmer-developed solution to investment constraints associated with slash-and-burn. Gap-level enrichment planting most often leads to a permanent cover rubber agroforestry in contrast to the (supposedly) more common cyclical system involving slash-and-burn.

The low-input internal-rejuvenation technique deserves full evaluation of its development prospects and environmental aspects. The sustainability of farmers' *sisipan* method and its viability as an alternative to slash-and-burn in the jungle rubber agroforestry system can be debated. These, including possible interventions that could assist in promoting this interesting technique, are discussed in this chapter. But first we will review data on the biodiversity of rubber agroforests as systems intermediate between natural forest and monocultural rubber plantation.

BIODIVERSITY ASSESSMENTS: SPECIES USED, SPECIES TOLERATED

Biodiversity in jungle rubber gardens is a result of farmers' management decisions that (implicitly) determine the structure and composition of the vegetation, providing a habitat for birds, mammals, insects, and other organisms. Weeding is usually restricted to the first few years after slash-and-burn when rice and annual crops are grown with the newly planted rubber. Thereafter, the farmer relies on the quick growth of bushy and woody vegetation to shade out harmful weeds like *Imperata cylindrica* (Bagnall-Oakeley et al., 1997). Perennial species are managed by farmers through planting and through positive and negative selection of spontaneous seedlings. Apart from rubber, a few other perennial species such as fruit trees are planted, usually in small numbers and around the temporary dwelling farmers may construct to live on site during the first year. In addition, many tree species that establish spontaneously are allowed to grow with the rubber as far as they are considered useful. Those tree species are mainly used for timber and fuelwood and for constructing fences around new rubber plots. Spontaneous seedlings of desired species, including rubber seedlings, are protected or even transplanted to a more suitable spot in the garden. Slashing or ring barking removes unwanted species. Thus, the perennial framework of jungle rubber is created by steering the secondary forest succession in addition to planting. This leads to a diversified tree stand dominated by rubber, similar to a secondary forest in structure (Gouyon, de Foresta, and Levang, 1993). In addition, there are numerous species, especially undergrowth species and epiphytes, that are not of direct use to the farmer but are not considered harmful either. They are left to grow as most farmers find that slashing of undergrowth or removal of epiphytes does not pay in terms of higher output. Keeping undergrowth may even be beneficial: rubber seedlings are hidden from pigs (the main vertebrate pests); the microclimate on the ground is kept moist and cool, which is conducive for latex flow when tapping; and (at least in the farmer's perception) soil moisture is kept, which allows for continued tapping during periods of drought.

However, benefits for the farmer result from selected species and from the vegetation structure as such, not from species richness.

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 of 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 that 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 (1990) were the first to draw attention to this issue, including the need for researchers to take both the farmer's 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 program 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 the Jambi province (Kheowongsri, 1990) and one in the South Sumatra province (de Foresta, 1997), including lists of tree species and analysis of structure. In addition, a 100-m transect line was sampled for all plant species in a natural forest, a jungle rubber garden in Jambi, and a rubber plantation in South Sumatra (Figure 5.4A). 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 (1999) 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
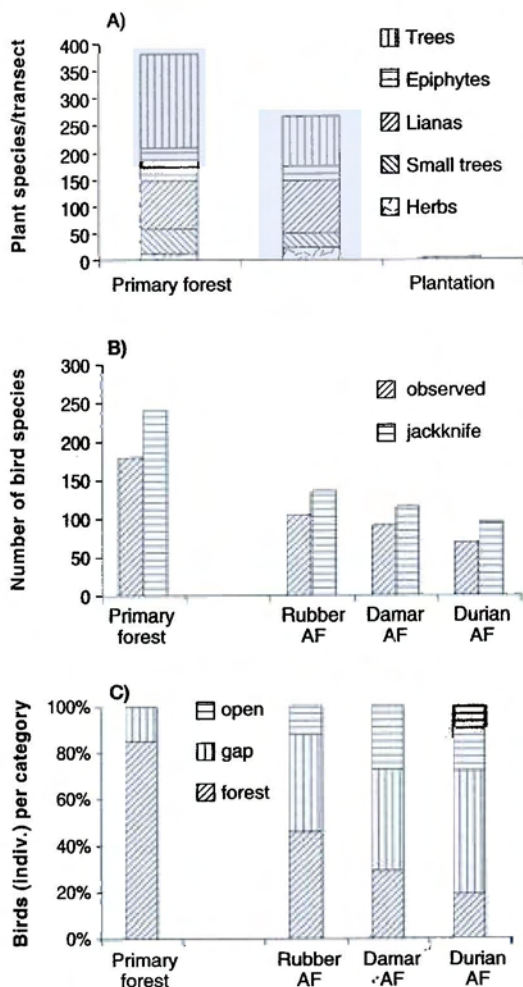
Figure 5.4   Comparisons of plot-level richness of plant and bird species between (A) natural forest, rubber agroforest, and rubber plantation for higher plants (Michon and de Foresta, 1999), (B) and (C) natural forest and three types of agroforest for birds based on total species richness (directly observed or extrapolated by the jackknife method) and contribution of forest, gap, and open land bird species. (For C, from Thiollay, J.-M., *Conserv. Biol.*, 9:335–353, 1995. With permission.)

reduced to about 60% of that in primary forest (Figure 5.4B), with a shift from typical forest birds (including ground dwellers) to birds of more open vegetation (Figure 5.4C). Danielsen and Heegaard (1994, 2000) confirmed the results of Thiollay (1995) that different groups of birds were affected differently by changes in

vegetation structure, floristic richness, and the 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% in the agroforest and 0.5% 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 forests as well as agroforests. Another multitaxa 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 signaling 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, because 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) found that average plot-level species richness was not significantly different among 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. 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).

We can conclude from all these studies that jungle rubber is indeed diverse, but also that it is different from forest both 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, because they depend on taxonomic or functional group and on the scale of evaluation.

Biodiversity studies in jungle rubber have been integrated with socioeconomic and agronomic studies from the beginning (Gouyon, de Foresta, and Levang, 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; Philippe, 2000), 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. Direct conflict between rubber farmers and top carnivores (such as the tiger) have been largely settled to the detriment of the latter ("people have eaten the tiger," as a villager expressed, where eating implies the concept of getting benefit from the sale of skins and bones).

We will now return to the question of whether productivity of rubber agroforests can be increased while conserving complexity and biodiversity values.

FACTORS INFLUENCING FARMERS' CHOICE OF RUBBER REJUVENATION METHOD

There is limited access to new land for clearance, and intensification within the existing rubber domain is the main option available. Four major classes of factors seem to be important to farmers when selecting a method for rubber agroforest rejuvenation: economic resources (including labor), forest resources, land resources, and knowledge of and confidence in the *sisipan* method (Figure 5.5). Lack of income during the rubber establishment period (5 to 8 years after planting), aversion to risk by vertebrate pests, and inability of farmers to finance large costs of clearing and rubber establishment are the primary factors promoting farmers' choice for the *sisipan* strategy. Other influencing factors include availability of new land for clearance, household income and assets, alternative sources of household income, and knowledge about the *sisipan* technique.

The *sisipan* method is not a new invention, but it has escaped researcher attention until recently. In Rantau Pandan and Muara Buat villages in Jambi, some farmers estimate that around 75% of the farmers practice *sisipan*, although most also slash and burn, but not on the same plots.
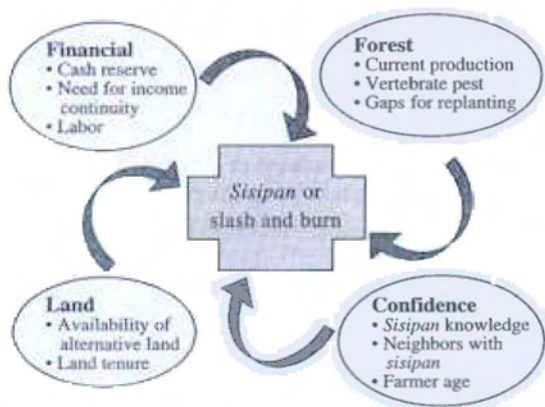

Figure 5.5 Determinants influencing farmers' choice between *sisipan* and slash-and-burn to rejuvenate rubber forests.

The practice of *sisipan* for gap rejuvenation of the jungle rubber agroforestry system is of much interest among the development professionals for the following reasons:

- It is environmentally friendly because there is no need to slash and burn the old *kebun* (garden), avoiding the smoke problems and greenhouse gas emissions of slash-and-burn fires and maintaining a higher time-averaged carbon stock (estimated difference around 20 Mg C/ha).
- It mimics the natural continuity of forest flora and fauna (biodiversity) and, by reducing the scale of management decisions from the field to the gap or tree level, provides more opportunity for maintaining valuable nonrubber trees.
- It does not require large capital investment because the work can be spread over a number of years.
- There is no break in farmer's income because the existing production trees continue to be harvested while new trees mature.
- It is a farmer-initiated strategy that is appropriate to the farmers' socioeconomic and biophysical conditions.

ECONOMIC EVALUATIONS OF IRRAS VS. CRAS

Although attractive from an environmental perspective and requiring less intensive management and less initial capital investment, the *sisipan* method has a principal drawback: its low productivity and a long establishment period for rubber trees compared to the slash-and-burn method. Latex production from farmers' jungle rubber system is around 590 kg dry rubber per hectare, while for private rubber estates it is 1065 kg/ha and for government estates it is 1310 kg/ha (Penot, 1995). Farmers in general do not use the higher yielding domesticated planting material in jungle rubber agroforests.

Economic evaluation carried out on previous survey data (Wibawa et. al., in press), however, indicated a higher profitability of the internal-rejuvenation system than that of the cyclical system primarily because the former is almost free of cost, while the second requires a substantial financial investment for establishing new trees. *Sisipan* activities are carried out while the farmer is in the plot tapping trees and are not regarded as requiring additional labor. However, both systems are economically feasible even at an interest rate of 20% (Wibawa et al., in press). Assumptions made for the analysis included 208 days of tapping in a year, at 4.2 kg dry rubber/ha/tapping day, or an average of 870 kg dry rubber/ha/year and the absence of a waiting period in the *sisipan* approach; planting of new seedlings can be spread over a number of years. Economic indicators such as net present value (NPV), internal rate of return (IRR), and cost benefit analysis (CBA) reflected the higher profitability with the internal-rejuvenation system. Even at a lower yield of 680 kg dry rubber/ha/year, the *sisipan* system was still viable while CRAS became uneconomical.

FARMER KNOWLEDGE

Research and development professionals have only recently focused on *sisipan* methods in Jambi. The practice most probably also exists in other rubber-growing provinces in Indonesia. Hence, scientific understanding of the ecological factors and processes, particularly for growth of rubber seedlings within the mature rubber system, hardly exists whereby improvements can be developed. On the other hand, farmers who are practicing *sisipan* have observed and understood the ecological processes occurring in the system. A knowledge-based systems approach (Sinclair and Walker, 1999; Walker and Sinclair, 1998) was adopted to understand farmer knowledge and perception related to rubber seedling growth in the jungle rubber agroforests. Thirty farmers in five villages (Rantau Pandan, Muara Buat, Sepunggur, Lubuk, and Muara Kuamang) in Jambi Province were consulted for investigating local knowledge. Examples of ecological relationships between various components that occur as understood and known by local farmers are reported in the following sections.

Factors Influencing Survival and Growth of Rubber Seedlings

Planting materials of rubber for *sisipan* come from the following:

- Clonal seedlings: 1-year-old seedlings uprooted from rubber plantations and usually available at local markets. These are believed to have a higher latex yield potential than the local seedlings.
- Seedlings raised by farmers in nursery from seed collected from existing forests, either local or from clone plantations. These may be raised in polybags or in seedling beds from which seedlings will be uprooted when ready, kept in running water for a few weeks before planting in the field.
- Naturally regenerated seedlings or wildlings growing in the rubber agroforest and translocated to another site without any prior treatment.

In a mature rubber agroforest, seeding and seed germination is generally not a problem where underground vegetation is not very dense. However, even in the presence of *in situ* wildlings, farmers still prefer to plant seedlings brought from outside, trusting that these seedlings have a higher genetic potential for latex production. High-yielding grafted plants are rarely used in the *sisipan* system.

Many development professionals hold the view that rubber for latex production should be grown in plantations and intensively managed. This is the general message conveyed by development agents to rubber farmers. It is now known from experimental trials that clonal rubber plants can also be successfully grown under less intensive management, *viz.* less weeding intensity and less fertilizer application (Williams, 2000). It is also possible to grow rubber seedlings inside existing stands of mature rubber trees. However, rubber is still a poor competitor when compared to other natural flora, and this is well understood by rubber farmers. Young rubber plants, whether natural or planted, require deliberate management if they are to grow into productive trees. Local knowledge and perception of gap, both at the canopy level for light infiltration and at the ground level for nutrient and moisture, is quite

robust. In a jungle rubber context, gap is a concept of farmers that reflects sufficient space for seedling growth. Loosely, this is space of 6 m or more between two live rubber tree trees. Gaps can develop naturally through natural death or deliberate removal of trees and other vegetation. Farmers often create gaps by selectively killing, through ring barking, of undesired trees, including unproductive and old rubber trees, and/or debranching of existing trees to increase light infiltration through the canopy. At the ground level, light weeding is carried out to reduce competition from weeds.

On the one hand, overly large gaps or intensive removal of vegetation encourages weed dominance; on the other hand, rubber seedling growth is very slow if the size of the gap is too small. Rubber seedlings can tolerate a reasonable amount of shading in their establishment years. However, for continued growth, gradual opening of canopy and underground vegetation is essential. Hence, a gradual opening with careful monitoring of both rubber seedlings and weed growth in the gaps is essential. Insufficient light infiltration leads to increased height of rubber seedlings with little or no growth in diameter and branching. Too much light encourages weedy vegetation (Figure 5.6).

Farmers have knowledge about the importance of gap on the ground in addition to space in the canopy for survival and growth of rubber seedlings; hence the practice of spot-weeding around rubber seedlings, which is essential until these seedlings have developed a sound root system. This is particularly important with transplanted seedlings whose root systems are always drastically cut back during uprooting the plant and root trimming prior to transplanting. Seedlings grown in polybags suffer less from this transplanting stress. Farmers report that this intensity of stress depends on the intact root system and the size of the seedling. The larger the seedling size (girth), the greater the stress to the seedling and the lower its chances of survival.

Weeding and Pig Damage

Vertebrate pests, especially wild pigs (*Sus scrofa*), are the biggest constraint in the rubber production system in Jambi, surpassing other management practices (Williams et. al., 2001). Although wild pigs do not eat seedlings (some farmers perceive that pigs like to chew the sweet root collar of these seedlings), the seedlings are often uprooted and broken off when pigs dig soil in search of soil insects and rubber seed. Farmers are quite adamant that the decreasing size of natural forests has led to a decline in populations of tiger, which hunted pigs, and consequently allowed the pig population to increase. Another factor is what seems to be a change in the feeding habits of wild pigs, a shift toward rubber seeds and other agricultural crops from their fast-disappearing feed in natural forests. Village communities in Jambi are predominantly Muslim, and pigs are generally not hunted. Hence, the pig problem is of a higher severity in Jambi than in other pig-consuming provinces such as North Sumatra of West Kalimantan.

The relationship between weeding and pig damage to seedlings was well articulated by farmers. Seedlings in a clearly weeded plot are highly prone to pig damage due to increased visibility and access to seedlings as well as easier digging of soil. However, farmers also are aware that high weed biomass in their rubber gardens
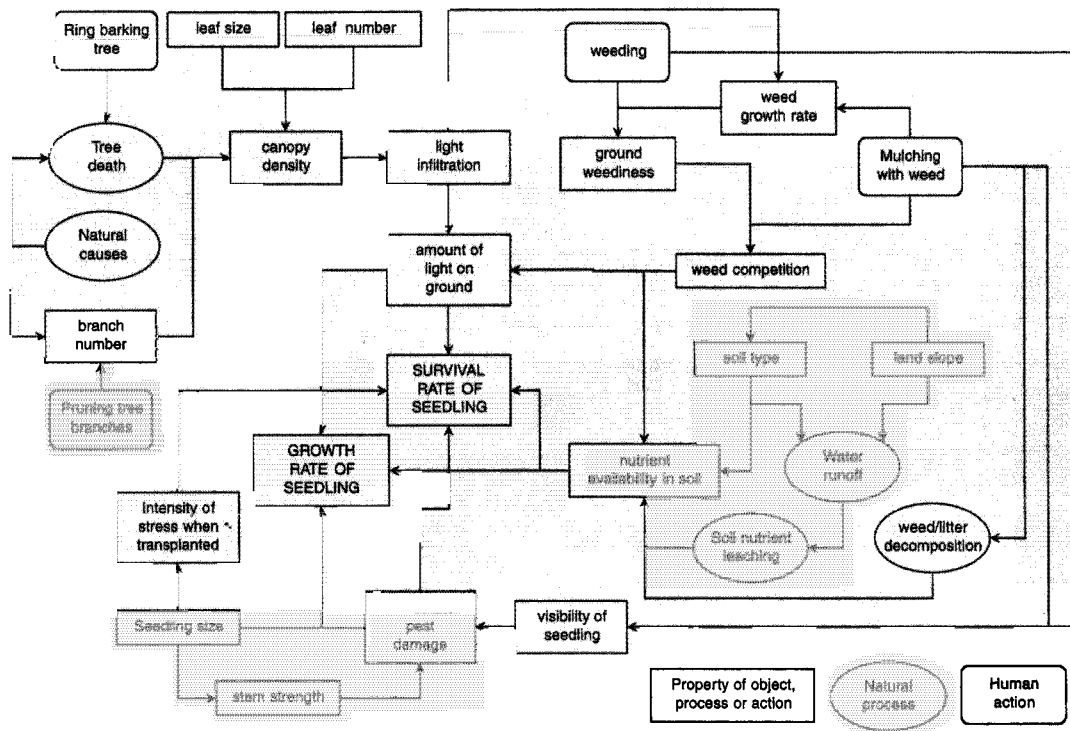
Figure 5.6 Diagrammatic representation of farmers' ecological knowledge about factors influencing seedling survival and growth in *sisipan* system. Arro indicate source node causing an effect on target node.

provides hiding places and nests for pigs. Annual crops, normally available in the first 2 to 3 years after planting rubber, become attractions for wild animals. Farmers must stay on guard to scare away the animals during this crucial period for a reasonable chance of successful establishment of rubber plants. The conversion of sites recently cleared and planted with rubber to *alang-alang (Imperata cylindrica)* encroachment is not uncommon, mostly because of high seedling mortality due to damage from pig and other vertebrate pests.

One of the strategies to minimize seedling damage is to use large-sized seedlings (often over 5 cm in diameter). But this strategy has other drawbacks. Farmers are well aware that survival and growth of seedlings are lower due to damage during uprooting and preparation for transplanting. This increases transplanting stress and decreases their chances of survival.

In the *sisipan* system, farmers weed around seedlings but leave the weed litter in order to physically hide the seedlings. In addition to physical protection of seedlings, weed litter upon decomposition provides mulch, a source of soil nutrients and moisture (Figure 5.7). Farmers have observed that rubber seedlings are susceptible to weed competition in the first 3 years after planting, after which they are able to outgrow weeds and their crown is dense enough to retard further weed growth.

Local knowledge reflects ecological knowledge that farmers have acquired and put into practice. However, the dilemmas that farmers often face, such as weeding method and intensity, fertilizer application, selecting planting material, and tolerating nonrubber vegetation in the system, pose considerable but researchable constraints.

INTRODUCING GENETICALLY IMPROVED CLONAL RUBBER TO THE JUNGLE RUBBER SYSTEM

A logical approach to enhance the productivity of the jungle rubber system is to incorporate high-yielding clonal material into the system whereby both production and environmental functions can be optimized. There is a great need to improve the productivity of rubber agroforests, with moderate changes in management, if they are not to disappear from the landscape under pressure from monocultural oil palm systems that may be more risky, but that are more profitable in the short term, especially in terms of income per unit area of land (Tomich et al., 1998). Genetically improved planting material will contribute to improved yields per unit area and to closing the technology gap (Kumar and Nair, 1997) between smallholders and plantations.

This gap has developed since the 1920s, due to great advances in the plantation rubber sector, with the breeding of higher yielding, genetically improved material, and the development of the technique of grafting buds of this onto well-developed rootstock stumps to produce clones. These clones are capable of yielding two to three (or even up to five) times more than the unselected material (regenerated seedlings collected from existing agroforests) being used by smallholders in the jungle rubber system. Smallholder farmers would benefit greatly from the increased yields possible from this improved genetic material if it could be integrated into their agroforests (van Noordwijk et al., 1995).
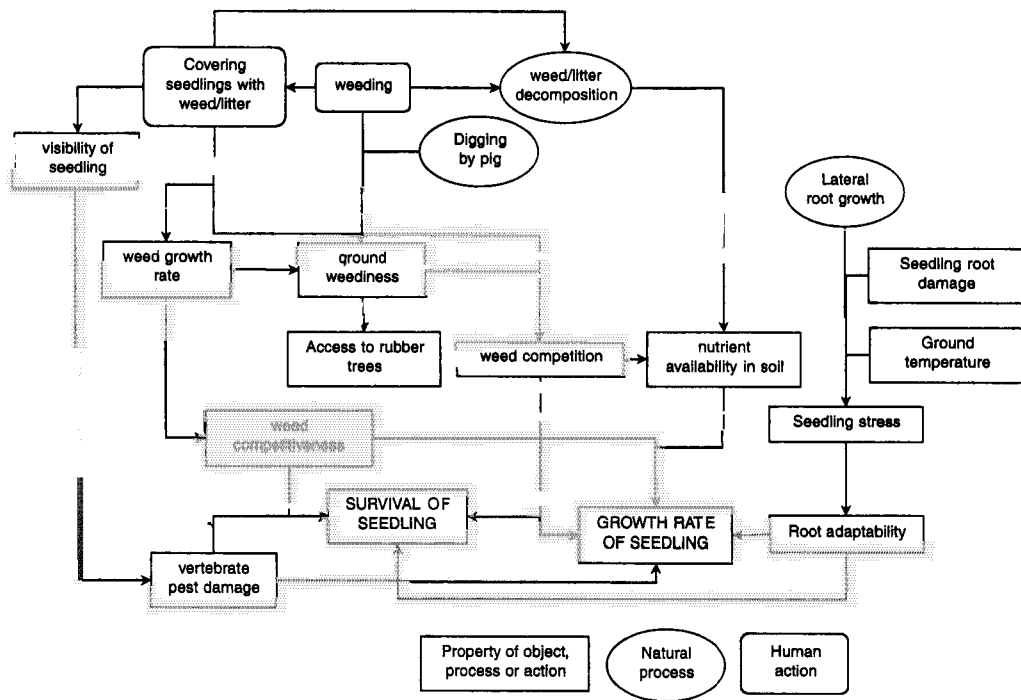
Figure 5.7 Farmers' knowledge about interaction between weed, weeding, and seedling performance in *sisipan* system. Arrows indicate source node causing an effect on target node.

Therefore, an improved rubber agroforestry system, modeled on the traditional jungle rubber system in its cyclical form, was designed to maximize the following:

- Productivity (by introducing new technology in the form of rubber clones, which give higher yields per tree and require less labor for tapping)
- Biodiversity (by keeping the spontaneous secondary forest component of the jungle rubber system -- this yields local benefits to the farmer in terms of potentially harvestable products (Figure 5.1), and global benefits if agroforests function as a reservoir in areas where primary forest has been lost)
- Affordability and adoptability (by keeping management and input levels to a minimum, and so within the reach of smallholder farmers)

The system comprises rows of clonal rubber trees, planted with a spacing of 3 m within the rows, and an interrow area, 6-m wide, where secondary forest species are allowed to regenerate (Penot et al., 1994). It falls under the cyclical classification and is established at the level of an entire field, after the slashing and burning of secondary forest or old jungle rubber vegetation.

This system (RAS 1) is currently being tested within a network of on-farm trials set up by the ICRAF/CIRAD/GAPKINDO Smallholder Rubber Agroforestry Project (SRAP) in two provinces in Indonesia (Penot, 1995). Results from the establishment phase of one trial, in Jambi province, highlighted many issues relevant to the introduction of high-value planting material into complex agroforestry systems.

The objective of the experiment reported here was to test a range of low-input management practices that were designed to ensure survival and growth of the clones in a highly competitive multispecies environment. Interactions between the effects of secondary forest species and farmer management practices on the establishment of clonal rubber were studied in order to do the following:

- Assess the effect of four weeding treatments on the growth of clonal rubber
- Identify and quantify constraints to, and factors affecting, clonal rubber growth under on-farm conditions

The trial involved clonal rubber trees grown by farmers in a total of 20 plots, in five replicate experimental blocks, spread across four farms (Williams et al., 2001). The amount of labor invested in strip weeding the rubber tree rows was significantly ($p < 0.001$) and positively correlated with rubber growth (Figure 5.8). However, unexpectedly, breakage of rubber tree stems by vertebrate pests (banded leaf monkeys, *Presbytis melalophos nobilis,* and wild pigs, *Sus scrofa*) was the most important influence on establishment. Pest damage was significantly ($p < 0.001$) but negatively correlated with rubber tree size, explaining almost 70% of the variation in rubber growth in the trial (Figure 5.8). In three farms, none of the trees escaped damage. These results were confirmed in a multiple linear regression analysis, where weeding effort and pest damage in combination explained 80% of the variation in tree diameter in the experiment (Williams, 2000).

In one trial, farmers generally decided to completely cut back the diverse vegetation between rows of rubber trees, including potentially valuable trees, rather than weeding within the rows and selectively pruning trees in the interrow. Farmers
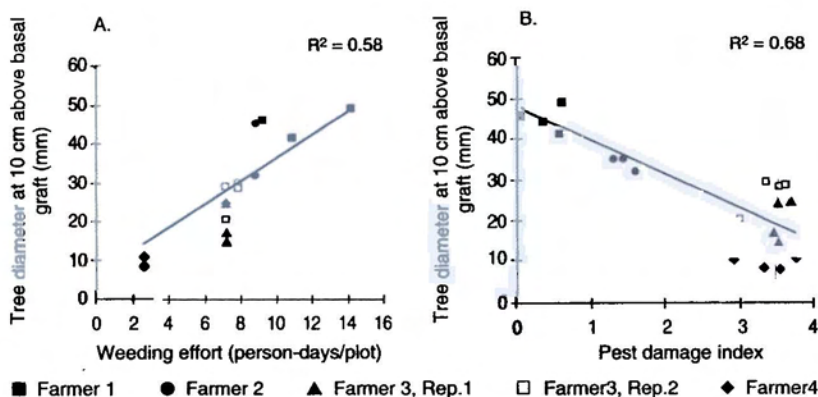
Figure 5.8   Linear regression between (A) mean rubber tree diameter per plot (21 months after planting) and weeding effort (person-days/plot), and (B) mean rubber tree diameter per plot and pest damage index*, for 20 plot means in an agroforestry trial in Jambi province, Indonesia. *The number of stem breaks sustained over 21 months for each tree, totalled for all trees in the plot, then divided by the total number of trees. (From Williams et al., 2001.)

thought that the interrow vegetation would harbor vertebrate pests and compete with the clonal rubber, and they had access to fruits, firewood, and other nontimber forest products on other land. Thus, contrary to expectations, when offered clonal germ plasm, farmers opted to use plantation methods to protect what they considered a valuable asset suited to monoculture, rather than maintain the traditional multispecies strategy they use with local germ plasm.

In other trials based on this system (RAS 1) in the province of Kalimantan, however, farmers from a different ethnic group were happy to keep the diverse secondary vegetation in the interrow area (Penot, pers. comm.). In this area there was no pressure from pests, so there was less of a risk of the trees failing to become established. Thus, different outcomes of the intensification trials were observed in different circumstances; and in the forest margins in Jambi, the major constraint to establishment of clonal rubber was not, in fact, competition from secondary forest species, but vertebrate pest damage.

Because we now understand that the resource-poor smallholders prefer *sisipan*-style management rather than cyclical rubber agroforestry, new experiments were started to test the option of grafting clonal buds directly onto *in situ* local rubber seedlings. Initial results are variable but encouraging. Further work is being carried out to explore and adapt the technology through farmer-led experimentation, combined with researcher-led on-farm trials.

CONCLUSIONS AND DIRECTIONS FOR RESEARCH

The property of combining biodiversity conservation and economic profitability is a strength of jungle rubber, but it is also a weakness because the balance between

the two is easily disrupted. Jungle rubber is not a forest type, it is a plantation, even though it does not look like one. It is owned and managed by a farmer who makes rational decisions based on socioeconomic circumstances and information available. Jungle rubber is a low-input, medium-output system that depends on relatively large areas of available land to make a living for a family, even though its returns to labor are attractive when compared to other types of labor available in Indonesia.

Conversion of natural forests leads to a lack of habitat for natural populations that are probably needed to maintain the present biodiversity levels in jungle rubber (Beukema, in prep.). The extent to which current diversity levels in agroforests are a transient phenomenon, based on influx of seed and animals from surrounding forests in the past, and the extent to which they form a habitat ensuring effective reproduction and maintenance of populations, are as yet unresolved questions.

As the scaling results for ferns indicate, much of the richness of agroforests as a category is related to the diversity between plots and farms. Landscape-level diversity of rubber agroforestry systems probably depends on the diversity in management intensity. This, again, may be a transient phenomenon reflecting a past in which there was room for expansion into forest lands. Over time, a gradual process of intensification on the existing rubber land may reduce the between-farm diversity, possibly accelerated by the impact of extension of specific rubber-based technologies. On the other hand, diversification of the economic basis of rubber agroforests, with value accruing from rubberwood and other timber trees (some of them high-value but relatively slow-growing species) and fruits (with improved road access to urban markets, which would make fruits like *duku* [*Lansium domesticum*] from Jambi marketable in Jakarta), could provide an incentive for maintaining diversity in farming styles.

Overall sustainability (i.e., probability for persistence as well as continued scope for adaptation) of complex agroforestry systems should be the focus of further research to develop alternatives to mainstream intensification of tropical agroecosystems, based on the interaction of ecology and economy.

It had been assumed that jungle rubber agroforestry systems are essentially cyclical and old stands are rejuvenated through slash-and-burn methods at the start (or end) of each cycle. Research and extension activities have been designed and implemented accordingly. The significance of the farmer-developed *sisipan* or enrichment planting method is much higher than initially perceived. An increasing proportion of smallholder rubber cultivators are actively adopting the *sisipan* method, primarily due to prevailing financial constraints and decreasing new land availability. This also has a positive impact on the environment and on biodiversity and carbon stocks. Preliminary economic analysis of a pilot study indicated that the *sisipan* method is perhaps more rewarding than the slash-and-burn approach due to low capital investment at a household level, although this is likely to be different when returns are calculated per unit area of land.

Ongoing work on local knowledge indicates that farmers have a fairly good understanding of the ecology in the *sisipan* method. Because little is known in the scientific community about this approach, farmers' knowledge can play a significant role in the direction and type of research and development program. Local ecological knowledge can partly fill in the large gaps that still exist in the professional understanding about

the jungle rubber system, at least within the foreseeable future. Preliminary analysis of local ecological knowledge also reveals gaps and constraints, as well as windows for improvements.

Another improvement strategy investigated through rubber agroforestry research under the SRAP project revealed the technical possibility for establishing rubber plantations under less-intensive management. However, farmers' behavior of intolerance of any weeds and other vegetation when clonal germ plasm is used reflects a constraint in their knowledge system. Studies of gap manipulation, pest management, incorporating planting material with higher latex productivity, and the economic and environmental consequences of cultivating nonrubber species could substantially increase our understanding of this promising method.

The *sisipan* method offers much potential, but much more still remains to be researched and understood despite substantial qualitative ecological knowledge among farmers. Introduced less than a century ago, rubber is relatively new, and rubber production systems, including jungle rubber agroforests, are constantly being modified as economic factors, forest and land factors, as well as social environments change. The short-term financial gain and farmers' current perception of a need for intensive management for high production may act against this potential method of *sisipan*. Although we use the term "permanent" to describe the system, the history of rubber is too short to actually evaluate the permanence of the system. Again, the continued dynamism of jungle rubber system would mean that any suggestion of permanence would remain very much in doubt.

Although very promising, the *sisipan* technique largely remains invisible to most rubber research and development professionals, and many do not believe that *sisipan* is a possible alternative to monocropping as a viable economic activity despite its widespread existence. Nonetheless, farmers practicing *sisipan* do not speak highly of this, perhaps a reflection of the predominance of monocropping technology in extension messages. Research on appropriate mixtures of rubber and nonrubber for optimum productivity and biodiversity while maintaining farmers' affordability and inherent flexibility needs to be initiated soon in order to enhance the knowledge base and confidence in the *sisipan* strategy. Enhancing the productivity of rubber production systems through *sisipan* without compromising environmental and other socioeconomic advantages remains a challenge to the research community.

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