Economic performance of common agroforestry systems in Southern Sumatra: implications for carbon sequestration services[1]

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ABSTRACT

This paper presents an analysis of the performance of four agroforestry systems common in the southern part of Sumatra (Jambi and Lampung). The systems analysed are rubber agroforestry, cinnamon multicropping, oil palm monoculture and damar agroforests.These systems span the range from monoculture to complex agroforest and hence provide a useful overview of potential benefits and costs. Using a combination of modelling and data from various sources the paper shows that all four agroforestry systems can be financially and economically attractive. The relative performance of each system in terms of social and environmental benefits is discussed at a general level, as well as their potential as tools for carbon sequestration.

Keywords: Agroforestry, Carbon Sequestration, Sumatra, Indonesia, Economic Analysis

INTRODUCTION

Indonesia is home to about 10 percent of remaining tropical forests in the world, these forests are concentrated in the outer islands, including Sumatra, Kalimantan and West Papua. The rate of deforestation in Sumatra has historically been the highest in the nation (Suyanto et al, 2001). Deforestation has been driven largely by population pressure in the form of forest conversion by shifting cultivators and large private estates that employ transmigrants. The traditional shifting cultivation methods used in Sumatra are no longer sustainable, because, as available land has become scarce the fallow periods have become too short (Suyanto et al, 2001). Tree-based farming systems, particularly agroforestry, offer a sustainable alternative. ICRAF (1992, p.2) defines agroforestry as

> "a collective name for land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same land management unit. The integration can be in spatial mixture or in temporal sequence. There are normally both ecological and economic interactions between the woody and the non-woody components in agroforestry".

Agroforestry can assist in a variety of short, medium and long term goals of forest conservation, which have benefits both for local farmers and government agencies. Watkins (1993) points out that agroforestry is a sustainable management system for forest and conservation that increases production and ecological stability. The major roles of agroforestry can be summarised as (Simon and Wiersum, 1982):

(a) to take the pressure off existing forest resources and improve distribution of labour;
(b) to increase total production and meet the timber supply deficit;

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[1] Working paper CC03. ACIAR project ASEM 1999/093, http://www.une.edu.au/febl/Econ/carbon/.

(c) to rehabilitate watersheds, control erosion and reduce direct radiation;
(d) to provide socio-economic benefits for local communities and increase income opportunities;
(e) to implement greenhouse gas (GHG) abatement activities;
(f) to increase sustainability and improve soil fertility.

The establishment of agroforestry systems, however, is expensive in terms of labour and capital inputs, which may discourage their widespread adoption. Recent concerns over global warming and the possibility of earning credits for sequestering carbon may offer an avenue to alleviate establishment constraints.

Assessments by the Intergovernmental Panel on Climate Change (IPCC) report that initiatives to slow deforestation, promote natural forest regeneration and global reforestation in farm forestry and estates have the potential to offset between 12 and 15 per cent of global CO_2 emission expected between 1995 and 2050. More than two thirds of such opportunities exist in the tropics. Stuart and Costa (1998) argue that the combination of climatic conditions favourable for tree growth, land availability and abundance of labour will favour the development of forestry schemes in tropical countries.

The recent IPCC report on mitigation identifies analyses of regionally-specific mitigation options and barriers, especially in developing countries, as an important research priority (IPCC, 2001, p. 13). This paper addresses this issue by analysing the scope and potential of agroforestry systems in Jambi in particular, and the southern part of Sumatra in general, paying particular attention to the economic performance of some common systems. Using a combination of modelling, allometric equations and data from various sources, rough estimates of potential carbon sequestration are presented. Finally, a comparative assessment of the economic, environmental and social benefits of the various agroforestry systems is presented.

FEATURES OF THE STUDY AREA

The diversity of agroecological zones in the southern part of Sumatra is reflected on its agroforestry and land-use systems. The Western area of the study area includes highlands, a buffer zone and piedmont, covering the Kerinci district and the upper regions of Sarolangun and Bungotebo districts in the province of Jambi. The middle part of the province consists of a peneplain and the eastern part includes coastal areas covering swamp and mangrove forests. To the south is the Lampung province, where Krui on the west coast across the mountains of the Bukit Barisan range, is known for its complex agroforests. Important agroforestry systems in the highland, buffer zone and piedmont area include damar agroforestry and multicropping, involving complex multistrata agroforestry systems such as cinnamon plantations with potatoes or coffee as secondary crops. Major land-use systems in the peneplains include rubber agroforestry with food crops such as upland rice, and simple tree crop systems, including large-scale timber plantations, oil palm monoculture and industrial timber monoculture.

The major systems for plantation operations include industrial timber plantations (*HTI-Hutan Tanaman Industry*), and non-industrial forest plantations such as community forest development, reforestation/forest rehabilitation, and greening.

Plantations can be implemented in all forms of land, including inside forest jurisdiction and grasslands. Plantations may be established by the government or through cooperation with local communities, as is the case in agroforestry. Based on scale and species planted, the system can be divided into large scale and smallholder plots. All plantation systems usually involve monoculture of species with high growth potential, such as sengon (*Paraserianthes falcataria)*, or agathis (*Acacia mangium)*, depending on local conditions.

Timber plantations (HTI) may specialise in pulp or wood-based products. Some HTI operations are closely linked to transmigration programs, with transmigrants being employed in the establishment and maintenance of timber estates. Based on their funding, HTI operations are divided into "self-funding", where all costs for timber estate development are incurred by the company, and "shared funds", where the cost is shared between the company and government. In HTI operations species with higher yield and survival rates, as well as with faster growth, are most preferred. Figure 1 shows the area of timber estates established per year between 1994 and 2000.

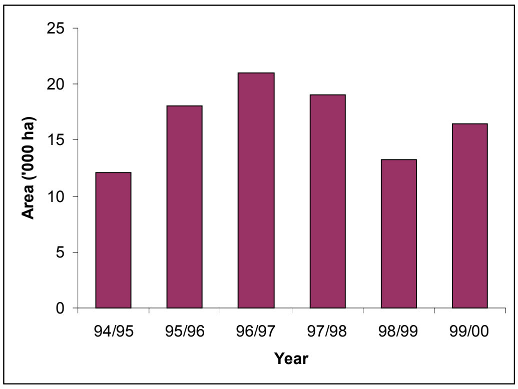

Figure 1. Area of timber estate establishment in Jambi (MoF, 2000)

One of the most common non-industrial timber plantations is called Community Based Forestry (CBF) or *hutan rakyat*. CBF operations can be established by the government or by private individuals, the latter are usually established in community or private lands. The aims of this activity are to obtain additional income, fulfil the needs of local people for wood (including fuelwood), and to provide environmental and ecological benefits. As forests involve a long-term investment, farmers usually adopt multi cropping species or alley cropping systems to obtain immediate income to support the family. Therefore the system provides a wide range of species consisting of main trees, perennials and fruit trees, and food crops. The main trees include rubber (*Hevea braziliensis*), damar (*Shorea javanica*), and kayu ulin (*Eusideroxylon zwagery*). While the most common fruit trees include durian (*Durio zibethinus*), duku (*Lansium domesticum*), and petai (*Parkia speciosa*).

CBF can also be established on land outside forest jurisdiction, through government sponsored programs, e.g., *penghijauan* (afforestation). This program typically takes place on critical land or community land. The main goal is to conserve soil and water, and sustain environmental functions. In many cases the establishment of afforestation programs reflects direct environmental interventions by the government, especially local government. This sort of project consists of undertaking a "crash-program" aimed at conserving eroded land and other marginal lands. However, there is evidence that the degree of community participation may represent the difference between success and failure of these schemes (Ginoga, 1999). Poor soil conditions and severe environmental problems provide the rationale for the establishment of these programs.

The realisation of government-sponsored CBF development in Jambi, for example, has been unsatisfactory, as shown in Table 1. In general, implementation of CBF has fallen below the level planned.

Table 1. Community Based Forests (CBF) established in Jambi, between 1995 and 1999. Source MoF (2000)

	Planned	Realised	
Year	(ha)	(ha)	(%)
1995/1996	2450	1475	60.2
1996/1997	1450	1450	100.0
1997/1998	2204	1704	77.3
1998/1999	950	922	97.1

Reforestation refers to establishing the same forest or stand on critical land inside forest jurisdiction. Jambi has about 40 per cent critical area (CSAR, 1989). The causes for the poor performance of the reforestation program are many, including socio-economic and biophysical aspects, such as inappropriate plantation techniques, fires and encroachment by local farmers. Therefore, incentives to local farmers to become involved in reforestation projects need to be developed.

Reforestation is mainly undertaken by the government or forest concession holders. The funding sources are the government reforestation fund *(Dana Reboisasi, DR*), presidential instruction (*Instruksi Presiden, INPRES*) and the OECF fund. Most of the species planted in this program are fast growing and with high survival rates.

The focus of this study is not on large-scale reforestation programs, but rather on the potential contribution of a selection of agroforestry systems common in the study area. The four agroforestry system analysed in this study are described in the following section.

THE AGROFORESTRY SYSTEMS STUDIED

This section describes four agroforestry systems that are common in southern Sumatra. The analysis follows the guidelines established by the Alternatives to Slash and Burn program (ICRAF 1998). Labour inputs are measured in terms of person days per hectare (pd/ha).

Rubber Agroforests

Rubber agroforestry refers to land use involving rubber as a main tree and other crops, such as rice, as a secondary crop. It represents the most common smallholder system in the peneplain of Sumatra. Rubber plantations in Sumatra and Indonesia cover about 2,579,528 ha and 3,662,472 ha, respectively. Hence, about 70 % of Indonesian rubber is grown in Sumatra (Ministry of Agriculture, 1999). This production system is usually operated by smallholders on areas of between 1 and 5 hectares. The type of planting material used includes cloned and traditional unselected seedlings (ICRAF, 1998).

Rubber agroforests usually replace "old jungle rubber" or secondary forest. The data in which our analysis is based was collected by ICRAF, as part of an on-going project in Jambi. The project is located in the Rantau Pandan and Bungo Tebo districts. Old rubber jungle was cleared in year zero and produced a negligible amount of saleable wood (Budidarsono, per.comm). The project experienced some problems with the supply of clone planting materials, resulting in a much lower planting density as compared to the traditional systems. Hence, in this paper, rubber agroforests are evaluated based on modelling. The BEAM model (Grist, et al, 1998) was calibrated to conditions in Jambi based on data from ICRAF (1998, p. 25) and other sources.

Inputs used for modelling rubber agroforestry are presented in Table 2. Local rubber seedlings were used for the traditional system and GT1 clones were used for the clone system. Planting density was 816 seedlings/ha (with trees spaced at 3.5 m). Only the clone system received fertiliser at the time of planting, which accounts for more intensive establishment labour use.

Table 2. Inputs and outputs in rubber agroforestry modelling

Inputs	Traditional	Clone
Establishment inputs:		
Seedlings (trees/ha)	816	816
Rice seed (kg/ha)	30	30
Fertiliser (kg/ha)	0	465
Materials (Rp/ha)[a]	204,000	204,000
Labour (pd/ha)	72.4	75.4
Recurrent inputs:		
Weeding labour (pd/ha)[b]	15.0	15.0
Tapping labour (pd/ha/d)	1.8	1.8
Outputs:		
Latex (kg/ha/yr)	988	1,255
Rice (kg/ha), year 1	621	544
Rice (kg/ha), year 2	322	167

[a] Includes fencing materials and pig traps

[b] Weeding takes place in years 1-7

[c] Includes latex cup and spout, slab moulder and formic acid

Modelling results show an average annual rubber production of 988 kg/ha in the traditional system, over a period of 21 years, and 1,255 kg/ha in the clone system, over a period of 24 years (Table 2). Rice farming was undertaken during the first two years, with yields of 621 kg/ha and 544 kg/ha for the traditional and clone systems respectively. The latter system produced lower yields because of the faster growth of rubber-tree clones, which results in more shading. Rice yields in year 2 were considerably lower than in year 1 because of increased shading by trees.

Although the systems simulated are a form of agroforestry because rice is planted during the first two years, these systems become a rubber monoculture after year 3 and differ from the traditional agroforestry systems that contain a diversity of other trees that produce fruit and timber. According to ICRAF (1998) smallholder rubber monoculture is rare in Sumatra other than in government projects.

Latex is produced from year 10 to year 30 in the traditional case, and from year 7 to year 30 in the clone system (Figure 2). Total latex production in the clone system is 45 percent higher than in the traditional system.

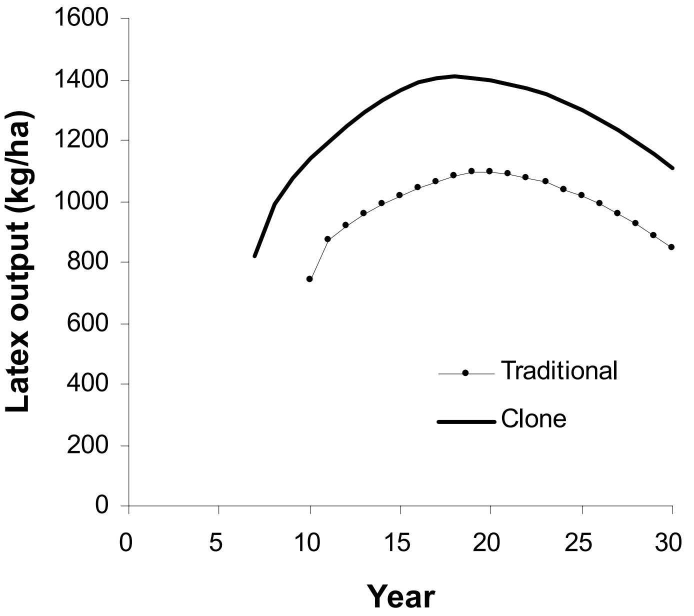

Figure 2. Latex production results of simulated rubber agroforestry projects in Jambi

The BEAM model estimates the growth of trees based on tree girth, and provides annual values of this variable. Girth values were converted to diameter, and biomass carbon stocks were estimated using the allometric equation of Ketterings et al. (2001):

$$W = 0.11 \cdot \rho \cdot D^{2.62} \tag{1}$$

Where W is tree biomass (kg/tree), D is diameter at breast height and ρ is wood density, assumed to be 0.53 t/m^3 for rubber trees (Brown 1997). A carbon content of 50 percent of biomass was assumed. Biomass accumulates faster in the clone system and reaches 83 t C/ha by year 30, as compared with only 39 t C/ha in the traditional system (Figure 3). Although these estimates do not include carbon in soil and litter, and hence underestimate actual carbon stocks, they indicate that a rubber system based on GT1 clones would have sequestered twice as much carbon by the end of the project life than a traditional system.

The difference in estimated carbon content between the two systems is caused by differences in tree diameter (16.9 cm for the traditional system and 22.5 cm for the clone system in year 30) and these values have a critical influence through the assumed allometric equation. The figures above assume that both tree types have the same wood density (0.53 t/m^3), which may not be the case if faster tree growth is associated with lower wood density.

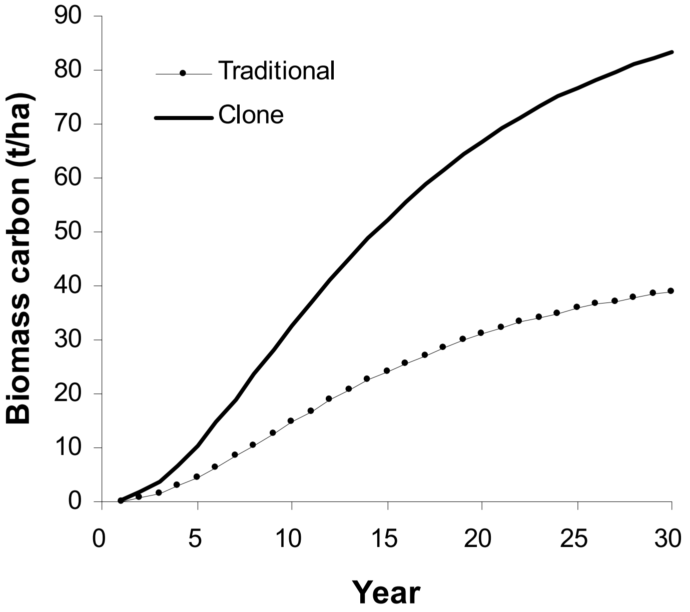

Figure 3. Simulated carbon content in above-ground biomass in the rubber agroforestry systems

Cinnamon Multicropping

The area of cinnamon plantations in Indonesia is about 119,905 ha, around 116,761 ha (97 percent) are located in Sumatra, and about 49 per cent of these are located in Jambi. In the upper region of Kerinci the most common farming system found is multicropping involving cinnamon (*Cinnamomum burmanni*) and annual crops (Wibowo, 1999). Potato is the most popular annual crop, with a relatively small amount of scallion and maize. In the lower region of Kerinci a similar multicropping system is common, but the most common secondary crops are coffee and chilli, with a small amount of maize.

Cinnamon trees are usually planted in rows about 4 metres apart, and spaced about 1-2 metres apart along each row (Wibowo, 1999). Multicropping is practised until cinnamon trees reach an age of about 6 years, after which the system becomes a monoculture of cinnamon, with negligible amounts of annual crops or bananas grown on the edge.

For simplicity, it was assumed that agriculture commences in the year following clearing. It was also assumed that cinnamon is harvested in year 12 and that coffee is planted under an eight-year cycle, with production assumed to begin in the second half of year 3. In Kerinci, coffee can be harvested throughout the year, with annual peaks reached quarterly. In year 3, however, the plantation usually has no annual peaks. Coffee production then increases and reaches a maximum in year 6 or 7. Due to increased shading, coffee production is assumed to decline by a half in year 8 and ceases completely in year 9, as the plantation becomes a monoculture of cinnamon. The annual crops (potato and chilli) are assumed to be cultivated from year 1 to 6. In the upper region farmers plant potato twice a year, while in the lower region chilli is planted once a year. Chilli production starts from the fourth or fifth month and lasts until the end of the planting year. Because of shading, both potato and chilli production end in year 7.

Inputs and outputs used in these systems are presented in Table 3. Multicropping of cinnamon and chili produced the highest amount of wet bark (20,224 kg), while multicropping with potato produced the lowest (16,593 kg).

Table 3. Inputs and outputs for a hectare of cinnamon multicropping in Jambi. Figures indicate total amount used/produced over the years indicated

	Cinnamon/potato		Cinnamon/coffee		Cinnamon/chilli	
	amount	years	amount	years	amount	years
Cinnamon (seedling/ha)	2,054	1-2	1,816	1-2	1,941	1-2
Potato seed (kg/ha)	9,614	1-6				
Coffee seed (kg/ha)			2	1		
Chilli seed (kg/ha)					11	1-6
Fertiliser (kg/ha)	8,481	1-6	2,486	1-8	1,832	1-6
Pesticides/insecticides (appl./ha)	627	1-6	32	1-8	99	1-6
Labour:						
Family (pd/ha)	2,403	1-12	1,595	1-12	1,531	1-12
Hired (pd/ha)	682	1-6	292	3-8	880	1-6
Outputs						
Cinnamon, wet bark (kg/ha)	16,593	4-12	18,926	4-12	20,224	4-12
Potatoes (kg)						
Large	82,940	1-6				
Medium	17,534	1-6				
Small	5,148	1-6				
Coffee, dry beans (kg)			6,096	3-8		
Chilli (kg)					25,240	1-6

Source: Wibowo (1999).

The amount of carbon sequestered in cinnamon plantations was estimated by assuming a wood density of 0.43 kg/m^3 and a carbon content of 50 percent of biomass. Tree biomass was estimated using the allometric equation of Brown (1995):

$$W = 0.049 \cdot \rho \cdot D^2 H \qquad (2)$$

Were H is tree height (m), and the remaining variables have been previously defined. Tree height and diameter were obtained from Wibowo (1999). These estimates (Figure 4) exclude carbon in soil and litter, and hence underestimate actual carbon stocks. Also, the carbon content of crops and coffee plants was ignored. It is expected that the carbon stock in the cinnamon-coffee system will be higher, at least during the first 6 to 7 years, hence these figures should be taken only as rough approximations.

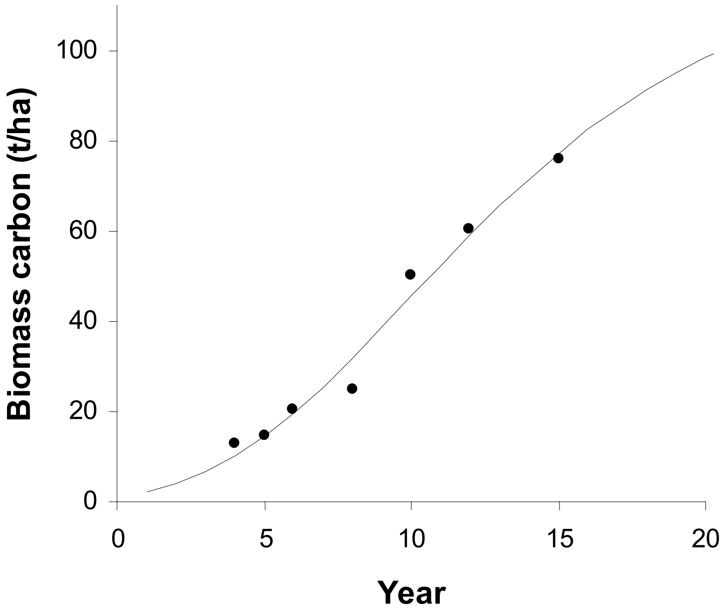

Figure 4. Estimated carbon stocked in above-ground biomass in cinnamon trees. The solid line represents a Gompertz function fitted to the data (see text for details)

The estimated carbon data was fitted to a Gompertz function to interpolate carbon stocks for further analysis (Figure 4). Biomass carbon in year 12, when the final cinnamon harvest occurs, was estimated at 60.3 t C/ha. This estimate was obtained by the equation:

$$C = \beta \left(\frac{\alpha}{\beta} \right)^{\exp(-\gamma \cdot t)} \tag{3}$$

Where C is carbon content (t/ha), *t* is time in years and the estimated parameters are: $\alpha = 1.92$, $\beta = 120.91$ and $\gamma = 0.1554$.

Oil Palm Plantations

Strictly speaking, based on the definition presented in the introduction, oil palm plantations would not be considered an agroforestry system. However, this system was included in the analysis because of its economic importance to Indonesia and because it provides a means of studying a range of systems from complex agroforests to monocultures. About eight per cent, or 222,096 ha, of oil palm plantations in Indonesia are located in Jambi (Ministry of Agriculture, 1999). The average production between 1990 and 1998 was about 142,864 tons. Oil palm plantations are usually operated by large-scale companies or state companies, with a large area of coverage. Only about 23 per cent of oil palm plantations are operated by smallholders.

ICRAF has established oil palm plantation and industrial timber estate projects in Jambi and Lampung, but none has reached maturity. Therefore the project identified in this paper is located in the nearby province of Riau, where plantations were established earlier and have reached maturity. The sample plantation consists of 10,700 ha established over a period of 10 years (Figure 5A). The first fruit crop is harvested in year four and maximum production is reached in year 21 (Figure 5B).

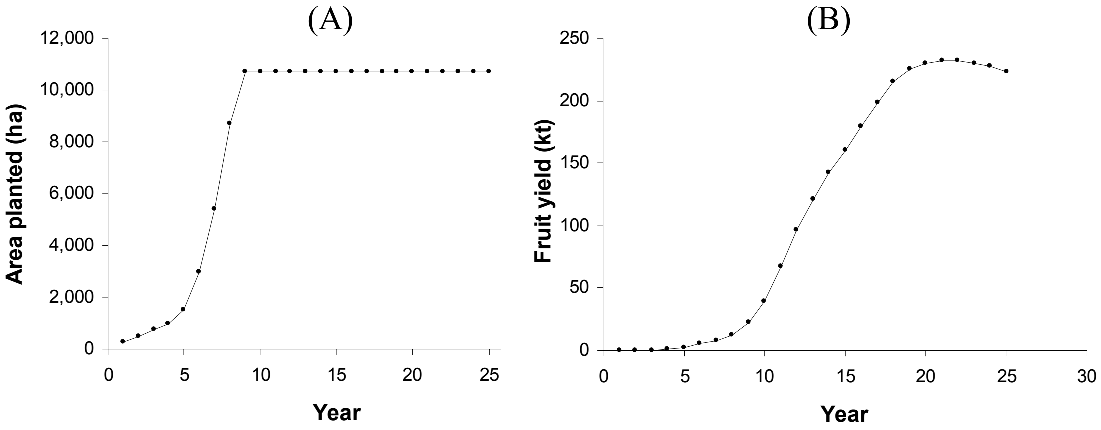

Figure 5. Establishment path (A) and fruit yields (B) of large scale (10,700 ha) oil-palm plantation.

Estimating the carbon sequestration rates of the oil-palm plantation was difficult, because no time series of volume, height or diameter was available. Also, as pointed out by Brown (1996), it is often difficult to estimate biomass content of palms because "[w]ood density of palms varies considerably by species and within the stem of the same species, and it can range from about 0.25 to almost 1.0 t/m^3" (Brown 1996). Also, biomass of the leaves has to be included and this may range between 10% and 65% of the stem biomass. We resorted to using a Richards-Chapman function adjusted by the information that a 25 year-old plantation has a volume of 250 m^3/ha and a frond biomass of 10 t/ha (Lubis et al. 1994), assuming a density of 0.4 t/m^3 results in a total biomass of 110 t/ha, or 55 t C/ha, by year 25. We used the equation:

$$C = \alpha(1 - \exp(-\beta \cdot t))^{\gamma} \tag{4}$$

With the parameter values $\alpha = 72.0$, $\beta = 0.08$ and $\gamma = 1.9$. This is just a rough approximation and should be used with caution.

Damar Agroforests

The damar agroforest (*repong* damar) reviewed here is located in Krui, Sumatra. It is a traditional system following forest or bush clearing and was developed by local people since 1927 (De Foresta, et al. 2000). There are approximately 55,000 ha of damar agroforests in Krui, and about 80 percent of Indonesian damar resin is produced here.

Damar agroforests follow a multicropping scheme, in which the main trees are planted along with other crops, including food crops, fruit trees, and other perennials, including trees for fuel wood. The main tree species is damar (*Shorea javanica*), while duku, durian, pepper and coffee are planted as the secondary perennials. The most common food crops grown are rice and a negligible amount of vegetables.

Based on farming inputs used there are two types of dammar agroforestry: traditional and semi-intensive. The latter includes application of chemical fertilisers and insecticides to perennial crops, such as coffee and pepper, to lengthen their harvestable life (Budidarsono, et al., 2000a). Table 4 presents data on both traditional and semi-intensive damar agroforestry systems.

Table 4. Inputs and outputs of semi-intensive and traditional damar agroforest. Figures represent the total amounts used or produced over the period of time indicated

	Traditional		Semi-intensive	
	Quantity	**Years**	**Quantity**	**Years**
Fertilizers (kg/ha)	0		234	3,4
Chemicals (l/ha)	0		135	3-15
Planting materials				
Paddy gogo, *Oriza sativa*, (kg/ha)	70	1,2	70	1,2
Robusta coffee (kg/ha)	3	3	3	1
Dadap, *Erythrina fusca,* (stumps/ha)	1,500	1	1,500	1
Lada, black pepper, (vines/ha)	1,250	2	1,500	2
Duku, *Lansium domesticum*, (seedlings/ha)	25	1	15	1
Durian, *Durio zibethinus*, (seedlings/ha)	25	1	25	1
Damar, *Shorea javanica*, (seedlings/ha)	146	1-4	146	1,2
Pete, *Parkia speciosa*, (seedlings/ha)	8	1	8	1
Labour (pd/ha)	3,535	1-25	4,744	1-25
Outputs				
Paddy rice (kg/ha)	3,000	1,2	3,000	1,2
Coffee (kg/ha)	5,301	3-10	10,202	3-15
Lada (kg/ha)	5,329	4-11	8,126	4-16
Pete (bunches/ha)	21,600	10-25	21,600	8-25
Duku (kg/ha)	5,925	10-25	5,925	10-25
durian (unit/ha)	5,325	20-25	5,325	10-25
Damar resin (kg/ha)	4,500	8-25	4,500	20-25
Fuel wood (pods/ha)	1,056	4-25	1,056	4-25

Source: ICRAF data

During the first two years about 1500 kg/ha of rice is produced per year. For the traditional system, in the third to tenth year of operation, about 663 kg of coffee are produced per year, totalling to 5,301 kg, half of the semi intensive system production. Black pepper is produced during the fourth to eleventh year. While *Parkia speciosa* starts to produce in year eight. *Lansium domesticum* and *Durio zibethinus* start to produce in year ten. No roundwood was obtained from the plot, because damar wood has no economic value (Budidarsono et al., 2000a).

As compared with rubber agroforestry and cinnamon, damar is not a fast-growing species (Wahyono and Rostiwati, 2001), trees may reach a diameter of 35cm in 45 years. However, the presence of other tree species contributes to carbon stocks in damar agroforestry systems. The amount of carbon sequestered by above-ground biomass in damar systems was based on information presented by Vincent and deForesta (1998) and Vincent et al. (2001). The Richards-Chapman equation (4) was adjusted with the parameter values $\alpha = 200$, $\beta = 0.04$ and $\gamma = 2.0$. This is a rough estimate that should be refined before attempting its use in a real project. However, it provides a first approximation for the preliminary analysis undertaken later in the paper.

SYSTEM PERFORMANCE

In this section, the performance of the agroforestry systems reviewed above is examined in financial and economic terms. The analysis undertaken follows the guidelines established by the Alternatives to Slash and Burn (ASB) program (ICRAF, 1998; Budidarsono et al., 2001b). The private discount rate is set at 20% and the social rate at 15%. The prices of the major inputs and outputs used in the analyses are presented in Table 5.

Table 5. Prices of major inputs and outputs used in financial and economic analyses

Item	Unit	Private Price	Social Price
Discount rate	%	20	15
INPUTS			
Urea	Rp/kg	290	290
TSP	Rp/kg	450	450
Family labour	Rp/pd	0	5,055
Hired labour	Rp/pd	5,055	5,055
Rubber seedling	Rp/seedling	150	150
Rubber-clone seedling	Rp/clone	1,200	1,200
Rice seed	Rp/kg	1,000	960
Cinnamon seedling	Rp/seedling	100	100
Coffee seed	Rp / kg	2,143	2,143
Potato seed	Rp / kg	670	670
Chilli seed	Rp / kg	3,000	3,000
Palm oil seedling	Rp/seedling	500	500
Damar seedling	Rp/seedling	500	500
OUTPUTS			
Cinnamon bark (wet)	Rp / kg	1,200	1,200
Coffee beans (dry)	Rp / kg	1,578	1,578
Potatoes	Rp / kg	370	370
Chilli	Rp / kg	643	643
Rice	Rp / kg	548	392
Latex	Rp / kg	1,840	1,840
Palm oil (fresh fruit)	Rp / kg	162	175
Damar resin	Rp / kg	886	916

Financial analysis is based on private prices, those prices actually experienced by producers. Economic analysis is based on social prices, where the actual prices are adjusted to eliminate distortions caused by market imperfections. Policies that may cause such distortions include input and output price subsidies, tariffs and quotas.

Financial analysis measures profit as the farmer experiences it. Family labour is not paid a wage and the value of forestland cleared is not charged to the farmer. Hence the net private returns (NPR) calculated in financial analysis represent the return to family labour, land, management and capital.

Economic analysis measures profit as it 'should be' in an ideal world with no price distortions. Family labour is paid the going market rate and the cost of cleared land is accounted for. Hence the net social returns (NSR) calculated in the economic analysis represent the returns to management and capital, in an ideal world where 'true' prices are paid for inputs and outputs.

Financial Analysis

In financial terms, a system is feasible if its net present value (NPV) is positive. For clarity of exposition, the financial NPV is hereafter referred to as net private return (NPR). The financial analysis is presented in Table 6.

The traditional rubber system yields a negative NPR (-Rp75,000/ha), so it is not feasible under the assumptions of this study. In contrast, the clone rubber system is feasible, with an NPR of Rp120,000/ha (Table 6). However, the latter system does not break even until year 22 when discounted cash flows become positive. This may be an important barrier to adoption.

Table 6. Financial analysis

Agroforestry system	NPR[1] (Rp '000/ ha)	Establishment cost (Rp '000/ ha)	Years to positive cash flow	Labour requirements Establishment (pd/ha)	Operation (pd/ha/yr)	Total (pd/ha/yr)
Rubber, traditional	-75	2,123	na	7,462	na	249
Rubber, clone	120	3,582	22	5,942	190	249
Cinnamon/Coffee	4,051	1,904	6	1,296	99	157
Cinnamon/Potato	16,061	946	1	0	257	237
Cinnamon /Chilli	7,349	1,087	1	414	201	217
Damar, traditional	7,403	5,382	5	903	132	141
Damar, semi-intensive	10,157	6,977	5	1,069	184	190
Oil palm	269	1,928	19	882	86	56

[1] NPR: net private return, estimated as the NPV with private prices.

The remaining systems all have positive NPRs, so they are feasible. Of the cinnamon systems, multicropping with potato is the most attractive, with an NPR of over 16 million rupiah. The damar systems are also attractive, with NPRs of Rp 7.4M/ha and Rp 10.2M/ha for the traditional and semi-intensive systems respectively. Oil palm produces an acceptable NPR (Rp 269,000/ha), but it takes 19 years to reach a positive cash flow. This figure is consistent with that reported by Papenfus (2002) for large oil-palm estates (NPV at private prices of Rp 275,000/ha).

Establishment costs were estimated as the present value of costs until the system reaches a positive cash flow. The highest establishment costs accrue to the damar systems, both of which take five years to reach positive cash flows. The lowest establishment costs accrues to the cinnamon/potato system, which reaches positive cash flow during the first year of operation.

The labour requirement per hectare per year (last column of Table 6) provides a good indicator of potential for providing employment. In this regard, the rubber systems (with 240 pd/ha/yr) and the cinnamon potato system (with 237 pd/ha/yr) perform best. Whereas oil-palm system provides the least employment potential (56 pd/ha/yr); because this is a large-scale, capital-intensive system.

Economic Analysis

The economic NPV is referred to as net social return (NSR) to distinguish it from the private analysis. In economic terms, the traditional rubber system becomes profitable and the cinnamon/coffee system becomes unprofitable (Table 7). The profitability of the cinnamon/potato system decreases to half its financial value (with an NSR of about Rp 8M/ha compared to an NPR of Rp 16M/ha), but it remains quite attractive. The best economic performance is produced by the damar systems, with NSRs of Rp 10.6M/ha and Rp 14.5M/ha for the traditional and semi-intensive systems respectively. The oil-palm system produces an NSR of Rp 1.6M/ha, this figure is consistent with that reported by Papenfus (2002) for large oil-palm estates (NPV at social prices of Rp 1.5M/ha).

Table 7. Economic analysis

				Labour requirements		
Agroforestry system	NSR[1] (Rp '000/ ha)	Establishment cost (Rp '000/ ha)	Years to positive cash flow	Establishment (pd/ha)	Operation (pd/ha/yr)	Total (pd/ha/yr)
Rubber, traditional	678	2,334	17	5,238	171	249
Rubber, clone	1,728	3,780	14	4,842	164	249
Cinnamon/Coffee	-1,445	10,444	na	1,887	na	157
Cinnamon/Potato	7,991	16,393	3	1,070	202	237
Cinnamon /Chilli	1,990	13,644	12	2,411	43	189
Damar, traditional	10,644	5,774	5	903	132	141
Damar, semi-intensive	14,548	7,646	5	1,069	184	190
Oil palm	1,621	2,299	15	542	85	56

[1] NSR: net social return, estimated as the NPV with social prices.

In terms of employment potential, the rankings are the same as in the financial analysis. With rubber and cinnamon/potato systems providing the best prospects, and oil-palm providing the least employment (56 pd/ha/yr). The traditional and semi-intensive damar systems are intermediate, requiring 141 pd/ha/yr and 190 pd/ha/yr respectively.

In the case of oil palm both establishment labour (542 pd/ha) and operational labour (85 pd/ha) estimates are consistent with those of Papenfus (2002), who reports 532 pd/ha and 83 pd/ha/yr for establishment and operational labour, respectively, in large oil-palm estates. However, our figure for total employment potential (56 pd/ha/yr) is considerably lower than that estimated by Papenfus (2002) who reports 133 pd/ha/yr. This may be caused by a different method of calculating this figure. We took the total labour input over the life of the project (1,397 pd/ha) and divided it by 25 (years); this would be the demand for labour if a steady cycle were established in the region, with an equal proportion of plantation areas in each age group.

Although we do not present an analysis for smallholder oil-palm systems, it is worth noting that Papenfus (2000) reports a total labour requirement of 48 pd/ha/yr for independent smallholder oil-palm systems. This author points out that, in interviews with smallholders, the primary reason for wanting to grow oil palm was that the labour requirements were much lower than for rubber, which requires labour for tapping. Hence the 'social' objective of employment generation may not be consistent with smallholder objectives for production systems that require less labour.

The most striking difference between the financial and economic analysis occurs with the cinnamon/potato system. This is largely because, in social pricing, land price is set at the prevailing market price of Rp 4.63 M/ha. Despite the decline in profitability, the system remains capable of producing very high economic returns. This result reflects the fact that cinnamon systems have been traditionally established by clearing forested land. In the case of rubber and damar systems this fact was not considered, hence it is implicitly assumed that these systems were established in previously cleared land with low opportunity cost. This implicit assumption may need to be revised as more information becomes available. For example, land with low opportunity cost would tend to be less productive and incur higher establishment costs for fertilisation and rehabilitation, so our estimates may be too optimistic.

CARBON SEQUESTRATION SERVICES

To compare the carbon sequestration services that can be provided by different agroforestry systems it is appropriate to take a common time horizon. Vincent et al. (2001) measured established damar systems in Sumatra and the systems they sampled were around 70 years old. This was taken as an appropriate planning horizon in this study, as it provides an approximate measure of permanent carbon-emission reductions. Figure 6 presents the simulated carbon sequestration trajectories of the four agroforestry systems over a period of 70 years, based on the assumptions previously explained. These plots consider only aboveground biomass and assume a baseline of zero (i.e. they show carbon accumulation starting with bare ground).

The mean amount of carbon sequestered by each system can be calculated by dividing the area under the corresponding curves (Figure 6) by 70 years. This measure is equivalent to the time-averaged carbon measure used by ASB (ICRAF 1998), except that no soil, litter and belowground carbon pools are included in our figures.

Table 8. Carbon sequestration, costs and return to labour for selected systems

System	Average C sequestered t C/ha	Carbon Cost $US/tC	Return to labour Rp/pd
Rubber, traditional	19.8	11.76	6,481
Rubber clone	42.4	8.92	7,953
Cinnamon/potato	22.7	72.23	9,180
Damar traditional	102.7	5.62	11,706
Damar intensive	102.7	7.45	15,042
Oil palm	27.0	8.64	12,941

Note: an exchange rate of Rp10,000 per US$ was used.

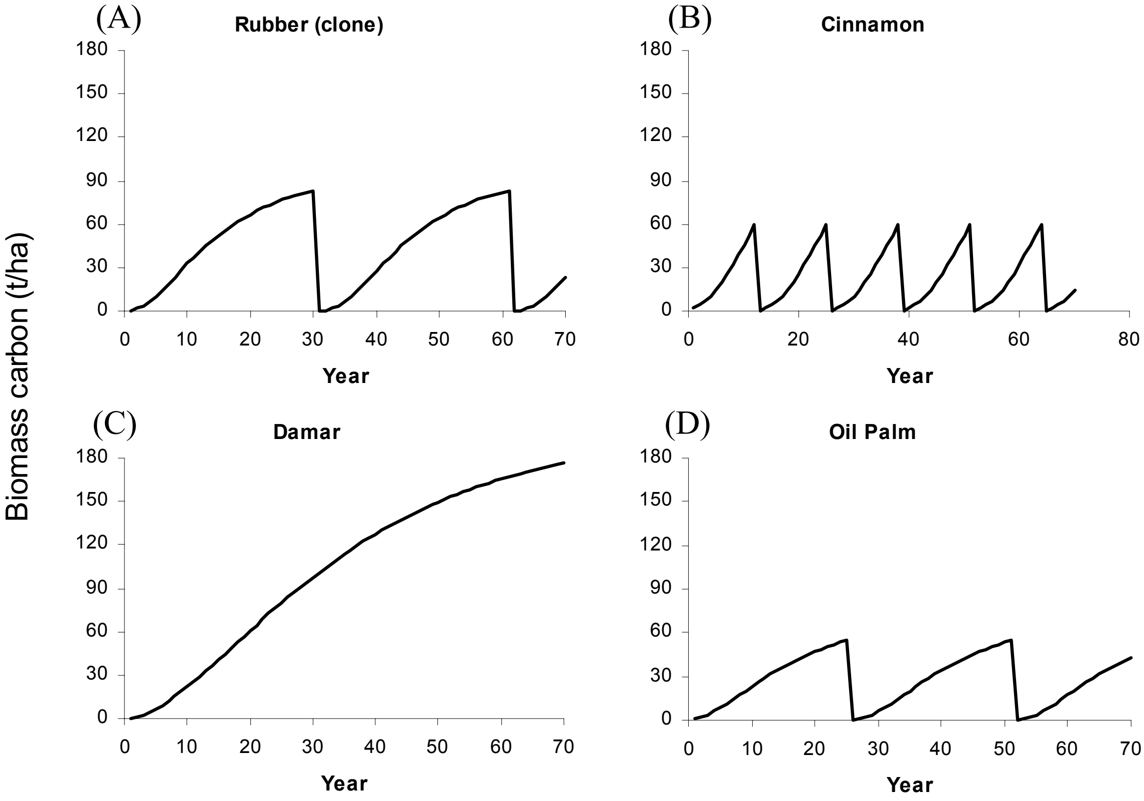

Figure 6. Simulated carbon sequestration in aboveground biomass in four agroforestry systems

Damar systems sequester the largest amount of carbon, with an average of 102.7 t C/ha (Table 8). The traditional rubber system sequesters only 19.8 t C/ha, whereas the clone system sequesters 42.4 t C/ha. The latter figure is about half of the time-averaged carbon content calculated by ASB for rubber monoculture (97 t C/ha). According to our figures oil palm sequesters 27 t C/ha (Table 8), this figure is about one third of the time-averaged carbon content calculated by ASB for oil palm monocultures (91 t C/ha).

As discussed earlier, the discrepancies between our figures and those of ASB are partly explained because we accounted only for aboveground biomass. But litter, soil and belowground biomass can be important pools of carbon. The simplest approach to estimating belowground biomass is to apply a constant root/shoot ratio (R/S ratio). Although the R/S ratio varies with site characteristics and stand age, a range of R/S ratios can be obtained from the scientific literature (Hamburg, 2000). A conservative approach recommended by MacDicken (1997) is to estimate root biomass at no less than 10% or 15% of above-ground biomass. Hamburg (2000) recommends a default R/S ratio for regrowing forests of 0.15 in temperate ecosystems and 0.1 in tropical ecosystems. Although ratios as high as 0.4 have been measured in temperate forests, the author recommends to err in the side of caution, to avoid the possibility of crediting non-existent carbon. If we applied this approach, our figures would increase by 10%, but the general conclusions would not be affected. The carbon content of soil humus in tropical soils is around 65 tC/ha (Tomich et al. 1997), and this magnitude would not change much under normal management, unless tillage or slash and burn occur.

An arbitrary measure of the cost of carbon sequestration was obtained by dividing establishment costs (at social prices) by the average carbon sequestered by each system. Although this may not be the true cost of providing an incentive for tree planting, it could be argued that a program that covers establishment costs would be attractive to smallholders. By this measure, the damar systems provide the lowest-cost per tonne of carbon sequestered (US$5.62/tC and US$7.45/tC for the traditional and semi-intensive systems respectively). Most estimates of the market price of carbon range between US$5 and US$25, and five of the six systems evaluated in Table 8 fall within this range, hence they could be attractive investments for carbon sequestration. The exception is the cinnamon/potato system, with a cost of US$ 72.23 t/C.

Another interesting comparison can be obtained by evaluating the performance of each system in terms of carbon sequestered and return to labour. Return to labour is calculated as the wage rate that makes the NPV equal to zero, so it provides a measure of how attractive the activity is relative to alternative employment opportunities for the farm family. All six systems evaluated in Table 8 provide a better return than the base wage rate of Rp 5,055/pd. In terms of providing both good returns to labour and carbon sequestration services the semi-intensive damar system is best (top right, Figure 7) and the traditional rubber system is worst (bottom left, Figure 7).

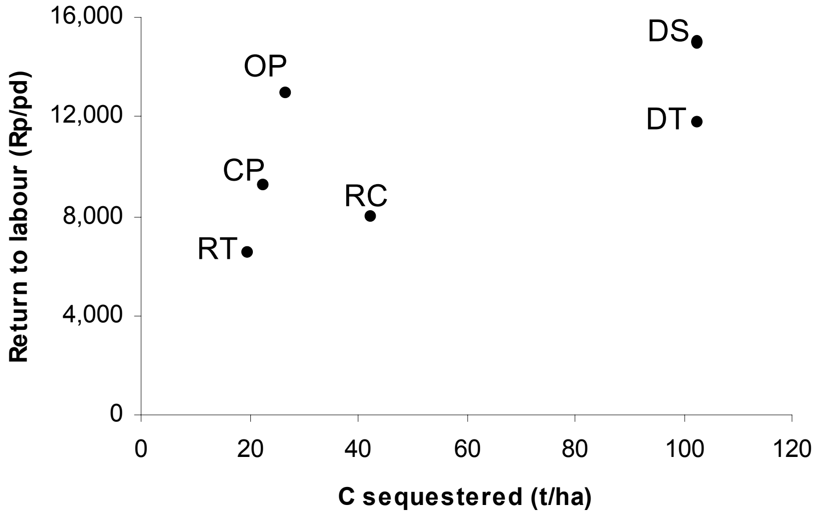

Figure 7. Return to labour and carbon sequestered by selected agroforestry systems. Legend: RT, rubber-traditional; RC, rubber clones; CP, cinnamon/potato; DT, damar traditional; DS, damar semi-intensive; OP, oil palm

The foregoing analysis provides good insights into the attractiveness of agroforestry systems in terms of profitability and carbon sequestration potential. However, two warnings are in order. First, the true cost of carbon sequestration is the opportunity cost of the given land use relative to the best alternative (or the current land use). That is, the cost of making landholders shift land-use practices. This cost would be specific to a given site and may differ from that based on establishment costs (Table 8). Second, in order to capture carbon payments, some transaction costs would be incurred, because activities such as monitoring and certification of carbon stocks are costly. If transaction costs are high enough, carbon-sequestration payments may not provide enough of an incentive to plant trees.

OVERALL COMPARISON OF AGROFORESTRY SYSTEMS

Different agroforestry systems produce different social and environmental benefits. Social benefits may be measured by indicators such as food security, income generation and poverty alleviation. None of the systems considered provided food security directly in the long term; because staple foods, such as rice and potatoes, are produced only during the first few years. However, steady employment can contribute to both food security and poverty alleviation. Poverty alleviation is also concerned with how the agroforestry plot can provide sustainable income, food, fuel and shelter to farmers and their families.

In this section we summarise our results by selecting the best variant (in terms of NPV at social prices) of each agroforestry system and comparing it to the other systems. The comparison is undertaken in terms of profitability, employment potential and carbon sequestration services. The systems selected are: rubber clones, cinnamon/potato, damar semi-intensive and oil palm.

The damar system is the most attractive in terms of social NPV (Figure 8A), returns to labour (Figure 8C) and carbon sequestration (Figure 8D) and it ranks third in terms of employment potential (Figure 8B). The rubber system provides the best employment potential, but much lower NPV and returns to labour than either damar or cinnamon systems.

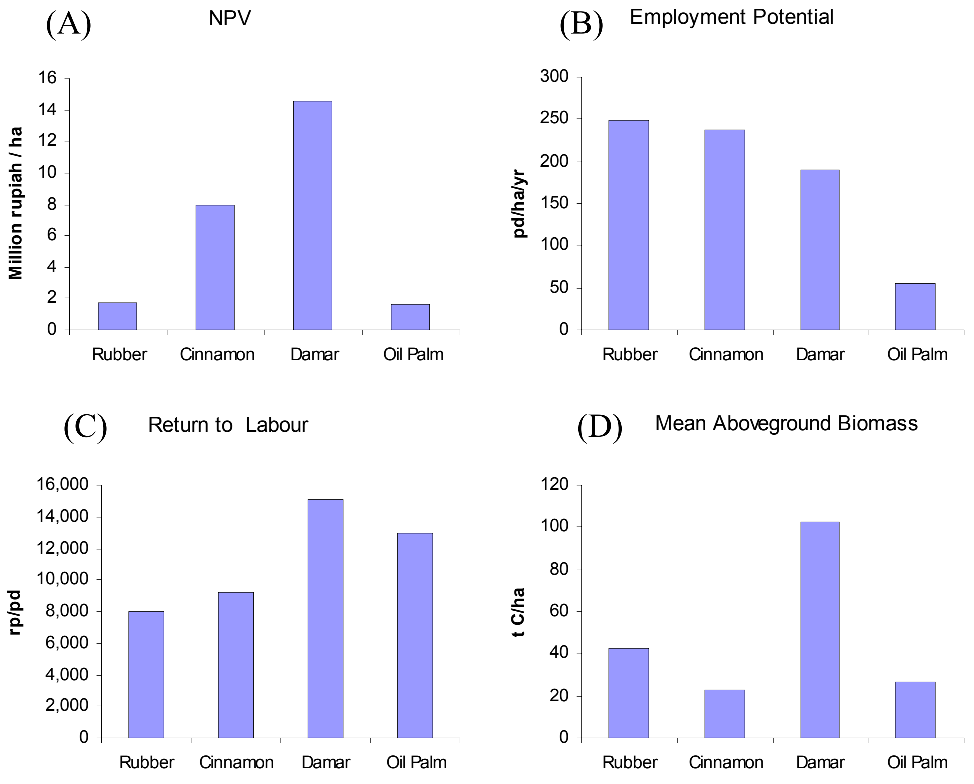

Figure 8. Comparison of agroforestry systems in terms of profitability, employment potential and carbon sequestration

For completeness, the analysis should also consider the long-term physical impact that agroforestry has on soil erosion, soil fertility, and hydrological balance, because these factors influence the plot's capacity to generate income in the future, as well as overall benefits to society. Such an assessment, however, is out of the scope of this paper. The only environmental benefit measured in this study is carbon sequestration. It must be pointed out that the foregoing analysis did not take account of the cost to society of the CO_2 released during forest clearance. Hence it could be argued that this is not a complete economic analysis, unless land prices reflect this cost, which is unlikely.

Ecological impacts are complex in nature and their evaluation is difficult. As Jansen (1994) points out, the majority of ecological problems involve a combination of short and long-term effects. Evaluating the ecological impacts of a project would require long term monitoring and associated ecological changes in order to have a full picture of how these variables are linked.

For a preliminary assessment, however, three major indicators can be used: (i) the length of the project, (ii) the land productivity, and (iii) use of fertiliser and chemicals. The length of the project refers to the periods during which trees provide environmental services. Using these indicators, damar agroforestry provides the longest project and hence more ecological benefits. While cinnamon is harvested in year 12 and hence gives the 'shortest' environmental benefits.

The land productivity, as measured by crop production, indicates how the agroforestry plot can be utilised for the purpose not only soil conservation but also for the output of valued products. This criterion takes into account the possible change in soil fertility associated with development of agroforestry. Land productivity is measured by types of output produced, i.e., food crop, perennials and main trees. Using this indicator, damar agroforestry gives the highest land productivity, in term of types of output produced and magnitudes of output.

Excessive use of fertiliser and chemicals will eventually have adverse effects on the land and humans, however, without fertiliser inputs land can be impoverished in the long term. Use of fertiliser and chemicals in oil-palm plantations is the highest, amounting to 17.25 t/ha over the life of the project. As compared to traditional rubber with no fertilisation. The damar system requires 234 kg/ha of fertiliser, while use of fertiliser in cinnamon systems varies depending on the associated crops. Coffee has the highest use of fertiliser in cinnamon systems.

Overall, it is likely that damar agroforestry provides the highest environmental benefits, as it is the closest system to a natural forest within the set studied here. Also, in terms of biodiversity, damar agroforests contain about 50% of the bird and plant life of primary forests, whereas oil-palm plantations contain less than 5% (ASB 2001).

SUMMARY AND CONCLUSIONS

This report provides a description of four important agroforestry systems in southern Sumatra, ranging from a complex agroforest to a large-scale monoculture of oil palm. In general, all the systems evaluated appear to be attractive from an economic standpoint, except the cinnamon/coffee system. The paper also demonstrates how economic analysis can be combined with simulation of carbon sequestration to evaluate the potential of agroforestry systems to provide profits and contribute to mitigation of global warming.

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