5. Highlights of Phase 1 Research

5.1 Land use categories in relation to remote sensing

For the ASB project a comparison is being made between the BIOTROP vegetation map of Sumatra made in 1983-1986 and recent satellite images (Landsat TM). Figure 30 gives the vegetation/land use types which can be distinguished on satellite images (Rosalina-Wasrin et al., 1995). Table 18 gives operational definitions of several of the land cover types, which can be used for assessing remote sensing data.

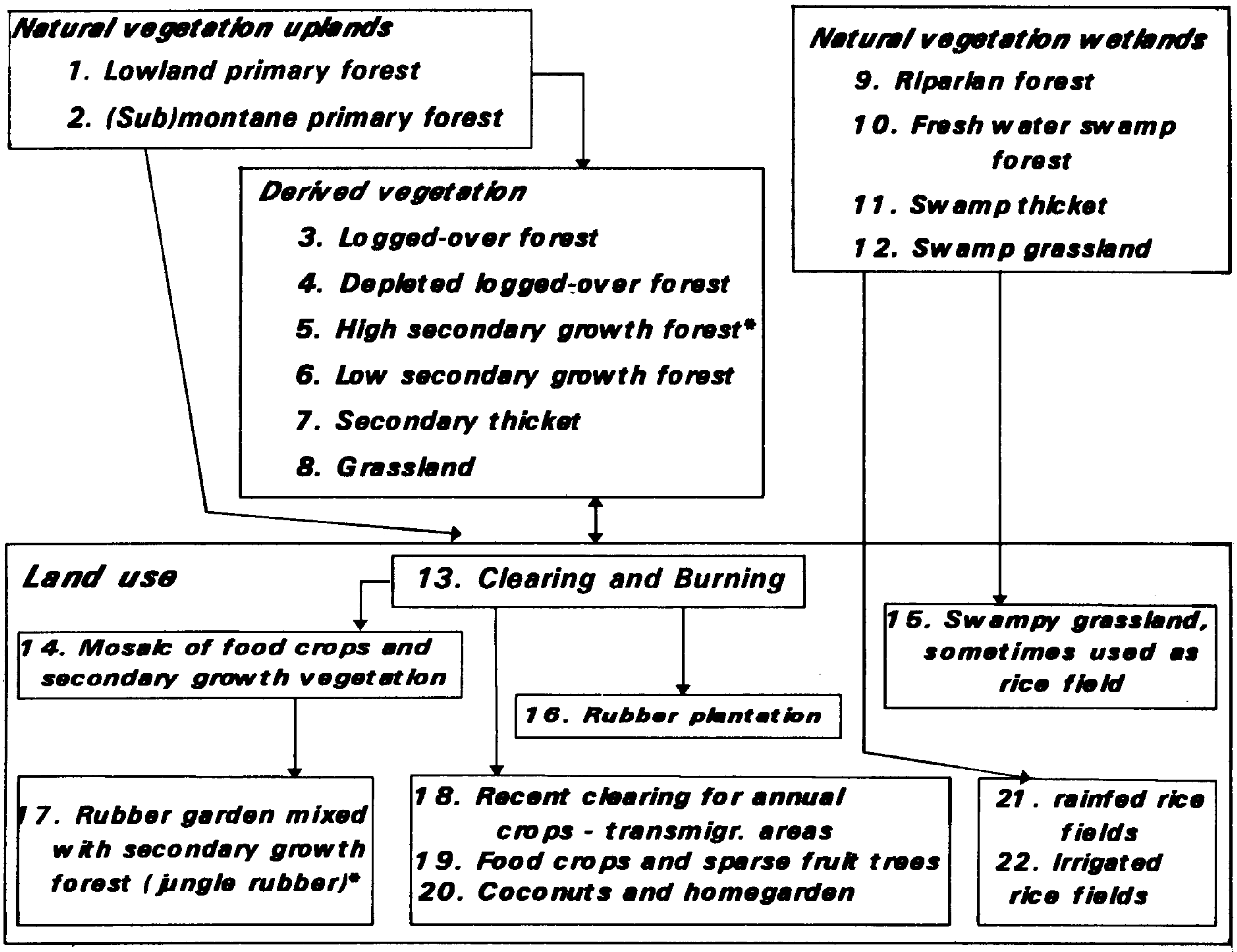


Figure 30. Vegetation and land use types which can be distinguished from satellite imagery. No distinction can be made between 5 (secondary forest) and 17 (jungle rubber) in this analysis, but it is hoped this will be possible in future work (see Table 18).

Table 18. Examples of definitions of land use systems/land cover types in Sumatra

LAND USE/ Land cover	Operational definition	Remote sensing comments
LOWLAND FOREST		
primary	Either: never logged (although may have had extensive harvesting of NTFPs) or: logged more than 100 years ago. Structure: 4 canopy layers. Diameter of some trees greater than 2 m. Height of emergent trees: 45-50 m. Dense stands of trees. Forest ground layer clean. Continuous canopy (except for "chablis" and "volis"). Epiphytes abundant.	Very good identification with remote sensing data. Highest absorption among vegetation types.
logged over	Structure: 2-3 canopy layers. Mosaic of patches results in non-continuous canopy layer. Canopy projection approaches 60%. No big emergent trees. Max. tree diameter < 1m. Max. tree height < 40 m.	Good identification in remote sensing data. Logging roads present.
secondary - tall /old	Height: 15-30 m. Homogeneous and continuous canopy layer. Projection of canopy can exceed primary forest, but biomass is less. Pioneers/fast growing species dominant.	Can be differentiated from rubber agroforest using color/tone and texture. Texture is smoother and radiometries higher than in rubber agroforest. (Cannot distinguish damar and durian agroforests.)
secondary - young regrowth	Height: 5-15 m with highest canopy projection 40%. One continuous canopy layer. Pioneers/ fast growing species dominant.	As a general rule, radiometric values are much higher in bands 1 (visible) and 2 (near infra red) and similar in band 3 (infra red). (Cannot distinguished from young agroforests.)
AGRO-FORESTRY	Perennial-crop based smallholder systems; often in mosaics that include secondary forest, belukar (bush fallow, shrub thickets 2-5 m), semak (shrubs and grass < 2 m), and/or ladang (upland fields)	See below. Agroforests have higher spectral values than logged-over forest.
Rubber agroforest	mature: greater than 10 years old; mosaic with other vegetation immature: 5-9 years old; mosaic with rubber predominant	Radiometries similar to logged-over forest, especially when structure already has 3 layers. Differentiation based on density and biomass is possible in the infra red wavelength.
Other perennial crops	mosaic w/other perennials dominant, e.g., cassiavera, coffee, or fruit trees.	
Young perennials	mosaic with unidentified perennial crops dominant (less than 5 years old)	
Perennial crops + wet rice fields	mosaic w/ any type of perennial crop dominant adjacent to wet rice land	
Home gardens	mosaic of crops, fruit trees, and dwellings	

Table 18. Examples of definitions of land use systems/land cover types in Sumatra -- (continued) --

LAND USE/ Land cover	Operational definition	Remote sensing comments
MONO-CULTURE PERENNIALS	Contiguous blocks of 20 ha or more. includes large-scale plantations, smallholder block planting projects, and smallholders associated with large-scale plantations in nucleus estate schemes. Continuous canopy layering, no structure, homogeneous, dense, and rectangular forms (blocks).	Homogeneous aspect in the visible and near infra red, usually clearly distinguishable by geometric road pattern. Maturity can be distinguished from above ground biomass and canopy projection.
rubber	mature: over seven years old	
oil palm	mature: over five years old	
timber (HTI)	stage: to be specified	
sugarcane		
SHIFTING CULTIVATION		
Mosaic of ladang and fallows	Upland foodcrop plots (ladang) possibly in association with fallows, but without assocation with perennial crops	
Bush fallow (semak, belukar)	Thickets/schrubs height 2-5 m. Mainly *Glochidion, Melastoma, Sapium* spp., *Peltophorum dasyrrhachys, Schima wallichii*	Distinction possible based on characteristic texture of clannish plants.
Grass fallow (semak, rumput)	Height less than 2 m. Always in mosaic of *Chromolaena, Eupatorium, Imperata* or others.	Slight differences detectable only in infra red band, since this wavelength is sensitive to above ground biomass.
GRASSLANDS		
Sheet *Imperata* (rumput alang-alang)	*Imperata cylindrica* sheet more than 1 ha contiguous.	Can be detected if in large areas, especially from radiometric values.
WET RICE FIELDS (sawah)	level land, may be technical, semi-technical, village or rainfed irrigated systems (also includes fish ponds)	

5.2 Effects of land use on soil carbon content on Sumatra

In the 1980's a coherent set of 1: 250 000 soil maps of Sumatra was prepared by the Centre of Soil and Agroclimate Research (CSAR-AARD, Bogor), in the context of the LREP (Land

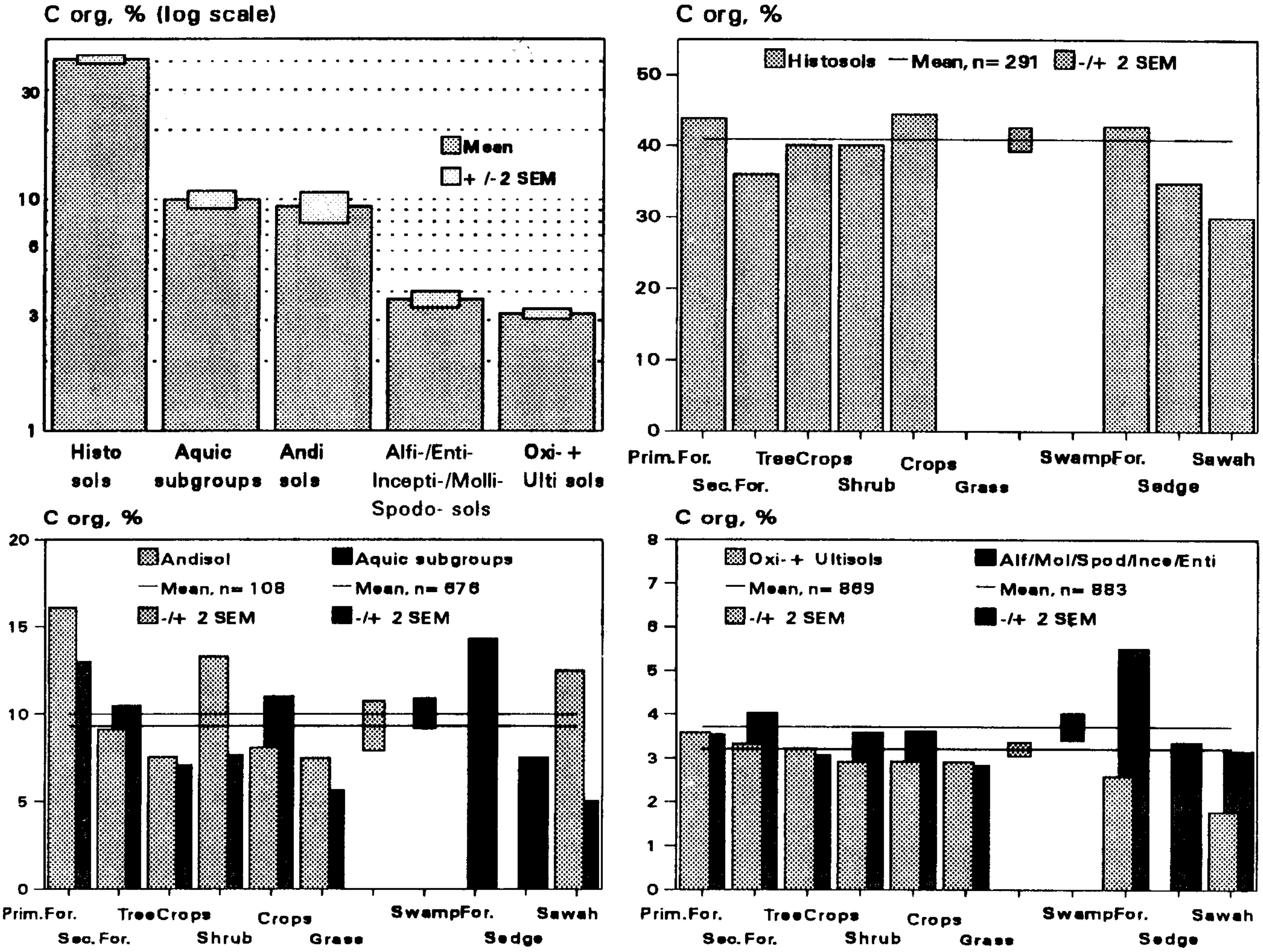


Figure 31. Average soil carbon content per soil type and land use, according to the LREP data set for Sumatra

Resources Evaluation and Planning Project) project (see section 3.2). The data are stored in a soil database and were recently analyzed for their soil organic matter content, as influencedby soil type and land use (Van Noordwijk et al, *submitted*). The soil data were grouped to make five classes: Histosols (peat), all wetland soils (classified as aquic subgroups of various soil orders; previously classified as Gley soils), Andisols (recent volcanic soils), a group of fairly fertile soils (Alfisols, Entisols, Inceptisols, Mollisols and Spodosols; this group (very) roughly corresponds with the 'Alluvial' soils of earlier soil maps and partly overlaps with the Latosols mentioned before) and a group of acid soils of low fertility (Oxi- and Ultisols, including most of the previous 'Red Yellow Podzolics').

The Histosols, which cover 10% of Sumatra, probably contain more than 90% of all C stored in Sumatran soils. The Andisols and the wetland soils both contain about 10% of C_{org}. On the Andisols C is intimately bound to clay complexes, while in wetland soils, the C is partially protected from decomposition by anaerobic conditions. On the relatively fertile upland soils (Inceptisols) and the Oxisols + Ultisols, the C_{org} content is 3.8 and 3.2%, respectively. The differences between all groups were statistically significant in a t-test.

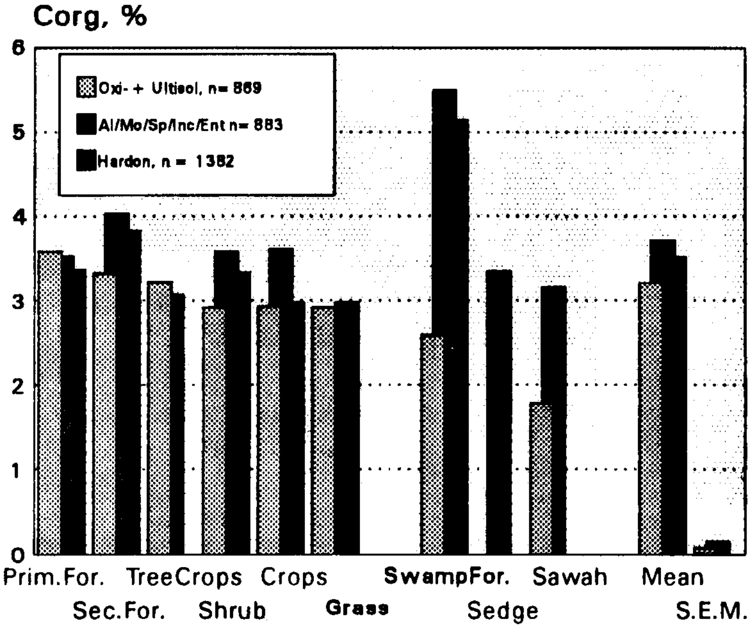


Figure 32. Comparison of average C-org content of topsoil for upland soils in the early '80's with data of Hardon (1936) for Lampung

Within the groups presented, no statistically significant differences between soil types were observed.

The wetland soils include human-made wet rice fields. The C_{org} content of these managed wetlands was below that of their natural counterparts in the sedge swamps. The widespread practice of burning rice straw at the end of the cropping cycle and the relatively young age of these wetlands may limit the accumulation of soil organic matter compared to natural wetland vegetation.

In general, the C_{org} content decreases from primary forest, to secondary forest to areas used for tree crops and the slash-and-burn series. On the major upland soils, the difference in C_{org} content between land use types is about 0.5% C. At an average bulk density of 1.25 g cm^{-3}, this represents 10 Mg ha^{-1} for a 15 cm top soil layer. Changes in deeper layers may be expected to be less, and the total change is probably less than twice the change estimated from the top layer only. On the Andisols and the wetland soils, larger differences in C_{org} content are observed between land use types, but the smaller number of observations makes comparisons less certain. Potentially, land use effects on C_{org} may be more pronounced on these soils as management reduces the protection of C_{org} when Andisols are tilled and wetland soils drained. The clearest example of interactions between land use and soil type is the relatively low C_{org} content of perennial tree crops on Entisols; this is largely based on coconut plantations on sandy soils at low elevation.

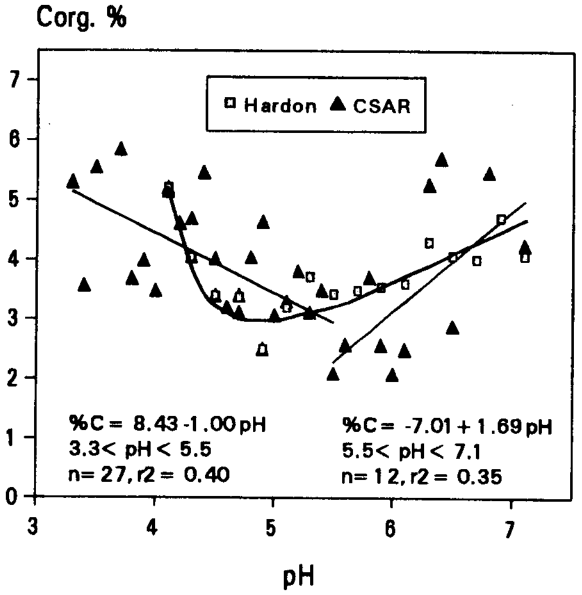


Figure 33. Relation between soil pH and C-org for forest soils in Sumatra; the squares refer to data of Hardon (1936), the triangles to recent data

A comparison can be made with an analysis made in the 1930's of a large data set obtained by Hardon (1936) from Lampung on the southernmost corner of the island. Lampung was then under transformation from forest to agricultural land, a change which today has been virtually completed. For nearly all land use categories, Hardon's data fell within the more recent data for the Incepti+sols and the Oxi- plus Ultisols. Hardon's average topsoil content over all land uses (3.53 %) is close to the present average of 3.46% for these soil groups. We conclude that the average C_{org} content of the topsoil in Lampung/S. Sumatra in the early 1930's was similar to the average for the whole of lowland Sumatra, excluding volcanic, wetland and peat soils in the late 1980's. There is no indication of any change in soil C storage under forests in the 50 year time span during which atmospheric CO_2 concentration increased by 20% in this period, from 0.29 to 0.35%. The data set for the 1980's confirms a relation between soil pH and C_{org} established in the 1930's by Hardon (1936). The combined data show that the lowest C_{org} content can be expected in the pH range 5.0-6.0. Below a pH of 5.0 reduced biological activity may slow down the breakdown of organic matter. Interestingly, most agricultural research recommends lime applications to the range *5.0 - 6.0; this* may *stimulate breakdown* of organic matter and thus contribute to crop nutrition, but possibly at the costs of maintaining the soil organic matter content. By selecting acid soil tolerant germplasm, adequate crop production can be obtained in the pH range 4.5 - 5.0, with higher C_{org} levels (this statement needs further corroboration).

The multiple regression analysis included soil pH, texture, altitude, slope, land use and soil type (Table 19). All these factors were entered stepwise into the equation. The quantitative factors: pH, clay and silt, had a slope which differs significantly ($p < 0.001$) from zero. The relative weighing factors for clay and silt are 1.4 and 1.0, respectively. The regression coefficient for altitude ($p < 0.01$) and for slope ($p < 0.05$) were also significantly different from zero. In this regression, the effects of altitude are studied separately from the different attitudinal distribution of soil groups. They indicate a positive effect on C_{org} of lower temperatures. The effect of slope suggests that a low rate of erosion also is an *(in situ)* protection mechanism for soil organic matter. The regression equation leads, for example, for an Inceptisol with pH 4.0, 25% Clay + 25% Silt, altitude 200 m a.s.l., slope 10% and under alang-alang:

$$C_{org} = \exp(+1.333 -0.0245 -0.624 +0.424 +0.085 -0.026 +0.011) = e^{1.179} = 3.25\%.$$

Table 19. Multiple linear regression of $\log(C_{org})$ for Sumatra soil database; Histosols were excluded from the analysis

$\mathrm{Log}(C_{org})$ = 1.333 + 0 (if soil is Oxi- or Ultisol) +
0.011^{NS} (if soil is Incepti+sol) +
0.834^{**} (if soil is Andisol) +
0.363^{**} (if soil is FluvAqsuborder) +
0.00994^{***} * Clay% + 0.00699^{**} * Silt% +
-0.156^{**} * pH +
0.000427^{**} * Altitude +
-0.00264^{*} * Slope +
\+ 0 (if LU is Swamp forest) +
-0.077^{NS} (,, Primary forest) +
-0.082^{NS} (,, Secondary forest) +
-0.169^{NS} (,, Upl_crops) +
-0.245^{*} (,, Alang-alang) +
-0.267^{*} (,, Perennial crops) +
-0.288^{*} (,, Shrub) +
-0.335^{*} (,, Sedge) +
-0.433^{*} (,, Sawah)

Compared to the average contents per soil type and land use, the C_{org} content will decrease 15% per unit increase in pH, increase 1% and 0.7% per percent increase in clay and silt content, respectively, increase by 4% per 100 m increase in altitude and decrease by 0.3% per percent increase in slope. No indication was obtained that tree-based production systems in plantations differ in C_{org} content from land used for annual crops. For research concerned with the global C budgets and the effects of land use change on C emissions, priority should be given to the peat and wetland soils; drainage of a few percent of the Histosols may release more CO_2 into the atmosphere from current soil sources than transformation of all remaining forest into *Imperata* grasslands.

5.3 C,N,P in young 'jungle rubber' in Sitiung

Large areas of secondary/logged-over forest in Minangkabau village land (Hak Ulayat/Suku or Hak Milik) are being converted into rubber gardens. A land use transect in Tarawang

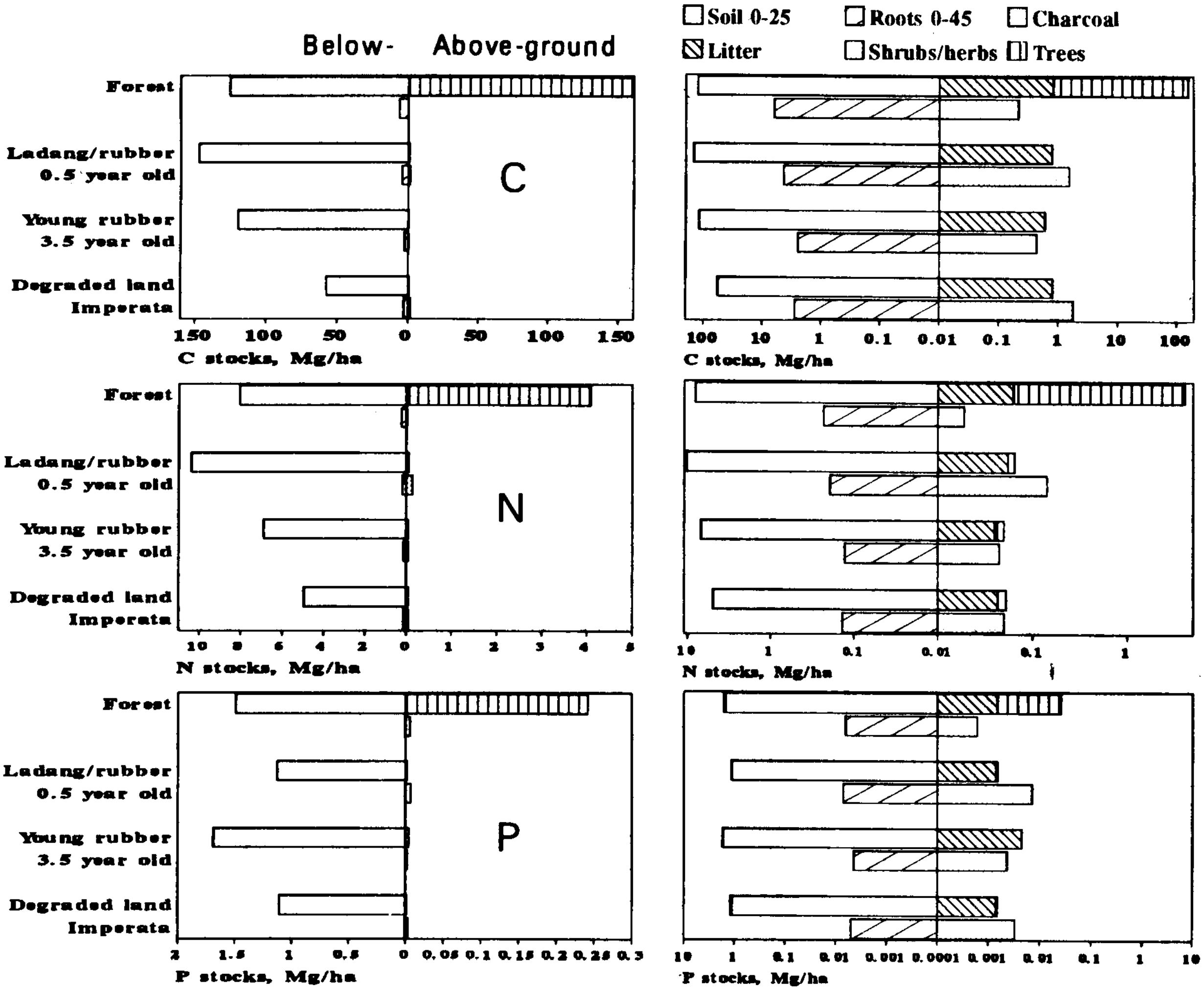


Figure 34. C,N and P balance for three stages in the transformation of secondary forest to young jungle rubber in Sitiung and a nearby *Imperata* field

Panjung was selected to describe such a transition on land belonging to farmers from Ampang kuranji (about 8 km by bicycle/foot path) (Zaini and Suhartatik, 1995). The site can be reached from the Trans Sumatra highway, by branching N.E. after Kotabaru on a stone (former tarmac) road. A small track to the right, in between mature rubber gardens after about 3 km, then about 1 km by foot. Location of the Tarawang Panjung transect: 1° 09'.781- .843; E. 101° 42'.047 - 086. Elevation: circa 150 m a.s.l.; Land class: A2at: 2-15% slope, > 90 cm effective soil depth, well drained, no signs of erosion.

Forest land is cleared and burnt in the dry season (August-September-October). A first year rice crop (padi gogo) is planted, but hardly any weeding is done. After the rice harvest, heavy bush vegetation remains plus various trees regrowing from stumps. Rice yields only about 0.5 t ha^{-1}. For a neighbouring plot a farmer mentioned: first year 750kg/ha, second year 125 kg ha^{-1}. Rubber is planted in the rice crop.

In the second year, the shrub vegetation is slashed and a second rice crop can be grown. The vegetation changes, as many of the shrubs (especially *Trema*) do not regrow. In the third year, a grass/climber vegetation (*Mikania*) starts to dominate; no food crops are grown and the rubber will gradually dominate the vegetation. The study site is close to a 'rubber project', and farmers are using 'clones' (we could not identify the type), planting at 3x4 m. Around a temporary house, nangka, banana, mango, sugarcane and kunyit (a ginger) were planted.

Above-ground biomass. Tree diameters were measured within two 50 x 2 m sampling strips. In the plots after forest conversion, the diameters of felled trees were measured as well. Felled trees in the sampling strip were recorded by diameter and length. For each sampling strip, ten regularly spaced 1 m^2 samples were taken for shrub/herb layer biomass. Freshweights were recorded in the field, subsamples were taken for drying and chemical analysis.

Litter, charcoal, soil. Inside each of these strips all plant litter and surface charcoal was collected from a 0.5 x 0.5 m^2 subsample. Soil was collected from the layer 0-25 cm, and twice per sampling strip soil colour at 25 cm depth was determined (Munssell soil colour chart). A composite soil sample was made per sampling strip for lab analysis and SOM fractionation.

Roots. Per sampling strip, two pinboard (40x60x10 cm) samples were taken, washed in a small stream in the forest and cut per 10 cm layer. The samples were cleaned further in the lab, dried and weighed.

Figure 34 gives the C, N and P balance for four stages of the transformation of secondary forest into young rubber plantations; on the left hand side a logarithmic scale is used, on the right hand side a linear scale. Apparently, this transition can be made without substantial depletion of soil reserves, and the major effects on the C balance are on above-ground stocks. The fact that little weeding is done helps to maintain an effective soil cover. At the same time it definitely reduces the yields of the upland rice crop.

5.4 Greenhouse gas emission and sequestration

Preliminary measurements in Muara Tebo site, Jambi were carried out to establish a research protocol, to be shared with the other ASB sites and to determine both the ambient concentration and the flux rate of methane (sink/source strength) of forest and converted forest soils (Murdiyarso and Husin, 1995).

5.4.1 Methane (CH_4)

We tested the effectiveness of using low-cost syringes, followed by transportation both by air and over land before the samples were analyzed. Ambient concentrations of methane were sampled by means of canisters (special gas tight containers) followed by sub sampling using syringes. Samples taken using canisters were assumed to be kept more secure than using syringes. Measurements were carried out in various land use types such as logged-over forest, crop land, abandoned land, and during burning events. Results of ambient concentration obtained during the field work from various land uses using various techniques are shown in Table 20.

The canister samples were considered to be the best sampling device. They are too expensive to be used in large numbers for a replicated sampling scheme. Samples analyzed from the sub-samples in the syringes seem to suffer from diffusion or leakage. Relatively high values are reduced and low values (below the "standard" ambient concentration of 1700 ppbv) are increased. The leakage may be caused by changes in air pressure and insufficient seals. It is also obvious that in general the samples which were transported by land, although it took longer, suffered less from leakage than those transported by air. The evidence so far suggests that sampling by syringes may be permitted if the time between sampling and analysis of the samples is not too long, say 3 days, and samples are not exposed to changes in air pressure (that means transported by land, not by airplane).

Another solution to overcome leakage and transporting time may be the use of vacutainers, a medical accessory (bottles with rubber stoppers normally used for taking blood samples). Subsequent tests with these gave positive results. They can be used for safe (and cheap) sample storage during transport. Based on the experience from the Muara Tebo site, sampling at various sites in West Sumatra was carried out using vacutainers.

Although the data on ambient methane concentration in table 20 from all sources were not replicated and can only serve as a first indication, samples from canisters show some interesting trends. The current ambient methane concentration is believed to fall around 1700 ppbv. It is shown that the ambient methane concentration during burning events (smouldering fires) was enormous. Meanwhile, the forest environment shows a low concentration of methane which indicates that no emission is occurring and dry forest soil may act as sink for methane. In agricultural lands the methane concentration is slightly higher, especially near a rice field and the basecamp (next to the river). At the basecamp the morning concentration was higher than the daytime value. This might be associated with atmospheric conditions from nightly inversion that persists in the morning.

Methane flux was measured in various land uses using the closed-chamber method. Samples were taken at consecutive measurements with 10-minute intervals. Nine land use types were represented and located in Muara Tebo, Sitiung (II, IV, V) and Air Dingin.

Table 20. Ambient methane concentration at Muara Tebo (August 1994)

Type of land use	Methane concentration (ppbv)		
	canister	syringe-1	syringe-2
Smouldering fire	25,769	18,754	13,519
Basecamp (7 am)	2,131	1,930	1,561
Pond, rice field	1,879	1,956	-
Newly burnt forest	1,739	1,983	1,760
Mixed crop field	1,722	1,731	-
Basecamp (12.45 pm)	1,630	1,762	-
Logged-over forest	1,604	1,788	1,681

Note: Syringe-1 transported by air (analyzed 3 days after sampling)
Syringe-2 transported by land (analyzed 10 days after sampling)

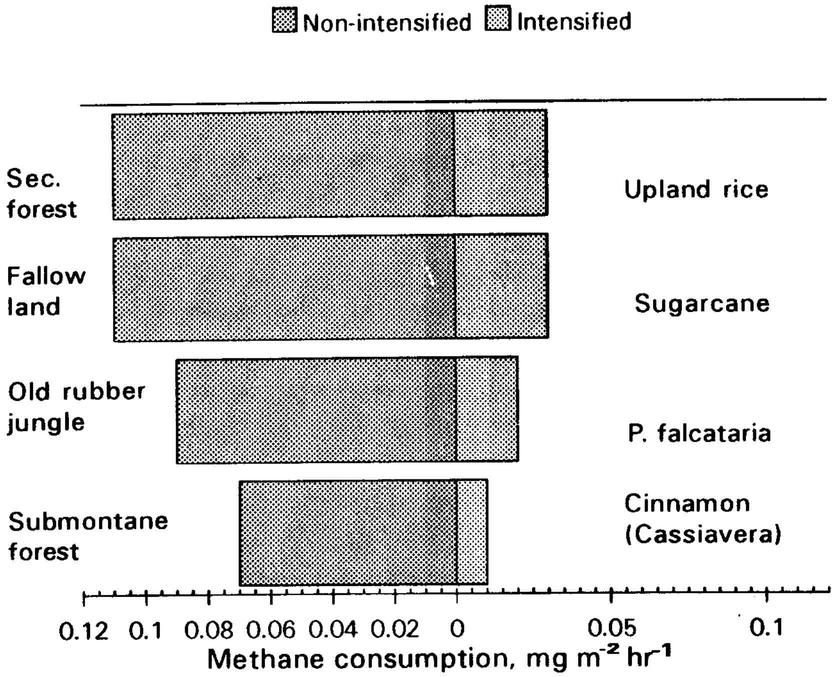


Figure 35. Methane consumption by topsoil of (semi)natural vegetation (left) and their intensively used c.q. degraded counterparts (right)

Estimates of CH_4 emissions from rice fields in Indonesia which are dominated by gleysols and latosols ranging from 1.1 to 6 Tg/yr (Husin, 1994) and 0.4 to 4.2 Tg/yr (Murdiyarso et al) respectively. There was an interesting result during the Characterization Phase that upland and forest soils consumed methane with a rate depending on the intensification of land use, hence population pressure. This may considerably offset the emission from rice fields.

The figures indicate that, at least in the dry season, secondary and logged-over forest and rubber agroforests act as sinks for methane. A much lower sink strength was shown by newly burnt forest soil, which might be caused by less active methanotrophe bacteria due to higher soil temperature or as a direct effect of the burning. If the methane consumption rates found here for forest soils are extrapolated to 24 hours per day on a yearly basis and to all forested upland soils of Indonesia (this is thus a very wild speculation...), methane consumption might off-set a substantial (30%??) part of methane production by rice fields. This calculation merely shows that the methane consumption rates found have potential relevance to the effects of land use on greenhouse gas emissions and, therefore, merit further research.

5.4.2 N_2O emission

Initial data on N_2O emission are shown in table 21. The trend here may be opposite to the effect on methane, with the biologically more active forest soils emitting more N_2O than the more depleted rice and alang-alang soils. Evidently, a further analysis and further replication is needed.

Table 21. Preliminary N_2O emission data (mg m^{-2} hr^{-1}) for Jambi ASB benchmark sites

Converted forest	0.033
Submontane forest	0.032
Abandoned land	0.025
Primary forest	0.023
Secondary forest	0.023
Upland rice	0.004
Alang-alang	0

5.4.3 C-balance

Table 22 estimates the net C emission or sink strength for the three main benchmark areas on the basis of recorded land use change and the difference in estimated total C stock of each vegetation type. The method followed is further explained by Murdiyarso and Wasrin (1995).

Table 23 summarizes the results and shows that the Rantau Pandan benchmark site may have been a net C sink, as the rubber agroforests matured. The North Lampung and Bungo-Tebo benchmark areas emitted considerable amounts of C as forest was converted to vegetation types with lower C stocks.

The peneplain area of Jambi is dominated by lowland dipterocarps forests. They cover more than 2 million ha out of 4.5 million ha of forested land in Jambi (FAO/McKinnon, 1982). This type of forest is characterized by its large biomass, hence carbon stock. Therefore, tropical forest ecosystems store most of their carbon (60%) above the ground, the rest is either stored in the soil or on the forest floor (Brown and Logo, 1982).

The biomass of the lowland Jambi forest is comparable to that of its neighboring forest in Pasoh ranging from 475 to 664 ton/ha. Meanwhile, the growth or biomass increment was estimated to be as much as 7 ton/ha/yr, out of net primary production, which ranged between 25 and 50 ton ha^{-1} yr^{-1} (Kato *et al.*, 1978).

Table 22. Carbon loss and gain from land use change in Bungo Tebo, Rantau Pandan and North Lampung

Muara-Tebo	Logged-over	Secondary forest	Plantation	Perennial crops	Annual crops
Logged-over	-	3,798 (-55)	6,415 (-200)	7,845 (-250)	12,456 (-295)
Secondary forest	-	-	8,394 (-145)	10,468 (-195)	6,212 (-240)
Perennial crops	-	15,792 (195)	-	-	1,528 (-45)
Annual crop	-	2,731 (240)	362 (95)	2,016 (45)	-

Rantau Pandan	Highland forest	Lowland forest	Logged-over	Second. forest	Perenn. crops	Annual crops
Highland forest	-	-	-	-	-	-
Lowland forest	-	-	7,234 (-139)	168 (-55)	472 (-146)	-
Logged-over	-	-	-	5,805 (-55)	2,911 (-250)	-
Secondary forest	-	-	-	-	574 (-195)	110 (-240)
Perennial crops	-	-	-	9,555 (195)	-	619 (-45)
Annual crops	-	-	-	12,720 (95)	8,505 (95)	-

North Lampung	Logged-over forest	Second. forest	Plantation	Perenn. crops	Annual crops	Alang-alang
Logged-over	-	4,073 (-55)	5,616 (-200)	-	2,359 (-295)	-
Second. forest	-	-	17,137 (-145)	7,331 (-195)	27,380 (-240)	-
Perenn. crops	-	1,852 (195)	101 (50)	-	17,011 (-45)	432 (-30)
Annual crops	-	8,786 (240)	3,376 (95)	865 (45)	-	578 (15)
Alang-alang	-	-	3,642 (80)	-	-	-

Notes: The first numbers indicates the area (ha), the numbers in brackets indicate the amount of carbon changed (ton); negative sign indicates the system looses carbon

Table 23. Estimated total C balance of three benchmark areas for 1986 - 1994 (8 years)

	Area (ha)	Total C-loss (t)	Total C-gain (t)	Net C-loss (t)	t C ha^{-1} yr^{-1}
Rantau Pandan	63,819	2,296,888	3,879,660	-1,582,712	-3.1
Muara Tebo	148,571	11,945,690	3,928,750	8,016,940	6.8
North Lampung	141,332	13,315,855	3,125,83	10,190,020	9.0

5.5 Soil Organic Matter Dynamics in North Lampung ASB Benchmark Area

5.5.1 Introduction

Declining food crop production after converting forests into agricultural use (either temporary or permanently) is widely seen as due to declining soil organic matter (SOM) content. Understanding roles of soil organic matter (SOM) in soil fertility and changes in soil physical processes is important for improved soil management strategy (Hairah, 1995).

In the context of the ASB project, three aspects of soil organic matter are to be considered:

* SOM is important for the **sustainability** of food crop production in slash and burn practices via its role in: (a) N and P mineralisation, (b) Al detoxification, (c) maintaining good soil structure,

* SOM is relevant to **greenhouse emissions** and sinks, based on total C stocks in the soil and possibly via a link with CH_4 and N_2O sinks and sources,

* SOM is related to soil **biodiversity**, via functional groups of soil organisms such as mycorrhizae, rhizobia, methanothrope bacteria etc.

Measurement of total soil-C is adequate for evaluating C-stocks in the soil, but not for studying soil-C dynamics over the short term, as only a small part of the total C is responding rapidly. Development and testing of improved soil management practices would be easier if more sensitive indicators were available. A size density fractionation method for soil organic matter has been developed by Meijboom *et al.* (1995), based on a silica suspension LUDOX (produced by Du Pont) which can be used as a good tool for studying soil-C dynamics. Spatial variation in clay content is more likely to affect total C_{org} than the Ludox fractions, so a more sensitive tool can be obtained.

Aims of this study were:

(1) To quantify the soil organic matter status with emphasis on the light fraction (labile) SOM after converting forest to agricultural land,

(2) Initiate measurement of soil-carbon dynamics under controlled conditions in a long term experiment with known inputs (above- as well as below-ground).

5.5.2 Effect of burning on soil-nutrient status

Burning increases soil temperatures temporarily and produces large quantities of ash. The ash layer is mainly in the top 0-3 cm and partially in 3-5 cm, where the mean ash weight respectively is about 75 and 80 % on dry weight basis, and it consists of burned plant material, fine charcoal as well as true ash. Table 1 shows soil chemical properties of forest before burning (BMSF project data) and after burning. Burning increased soil pH from about 6 to 8. This is due to accumulation of base cations from burnt above-ground biomass.

Table 24. Chemical properties of forest soil before and after burning in N. Lampung.

	pH		C-org %	P-Olsen mg kg^{-1}	Ash/dw %
	H_2O	KCl			
Before burn:					
0 - 5 cm	6.2	4.7	2.44	5.0	
5 - 10 cm	5.6	4.6	2.12	2.0	
After burn:					
0 - 3 cm	8.1	7.5	7.55	51.4	75
3 - 5 cm	8.3	7.2	4.28	25.6	80
5 - 10 cm	7.2	6.0	1.94	6.7	
Ash				384	

	K	Ca	Mg
	--------	cmol$_c$ kg^{-1}	------
Before burn:			
0 - 5 cm	0.20	1.44	0.62
5 - 10 cm	0.20	1.85	0.52
After burn:			
0 - 3 cm	5.37	25.5	4.47
3 - 5 cm	2.02	14.8	3.46
5 - 10 cm	0.29	3.12	0.63
Ash	176	23.6	17.6

5.5.3 Effect of burning on C-stocks

Carbon stocks were estimated by measuring tree biomass and soil around the site of the Biological Management of Soil Fertility (BMSF) Project in N. Lampung. A forest fire reduced total C from tree biomass by about 50% and about 97% if unburnt tree trunks are removed from the plot (Figure 36); changes in soil C were small.

5.5.4 Soil organic matter distribution under different land use systems

Forest clearing and cultivation leads to changes in soil organic matter status. Based on the Ludox fractions, we may distinguish three situations in N. Lampung (Figure 37):

a. Forest (remnants of logged-over primary and various types of secondary forest)
b. SOM-maintaining practices: woodlots (initial KILLSOM/ADDSOM measurement), forest plantation, home garden and unburnt *Imperata*.

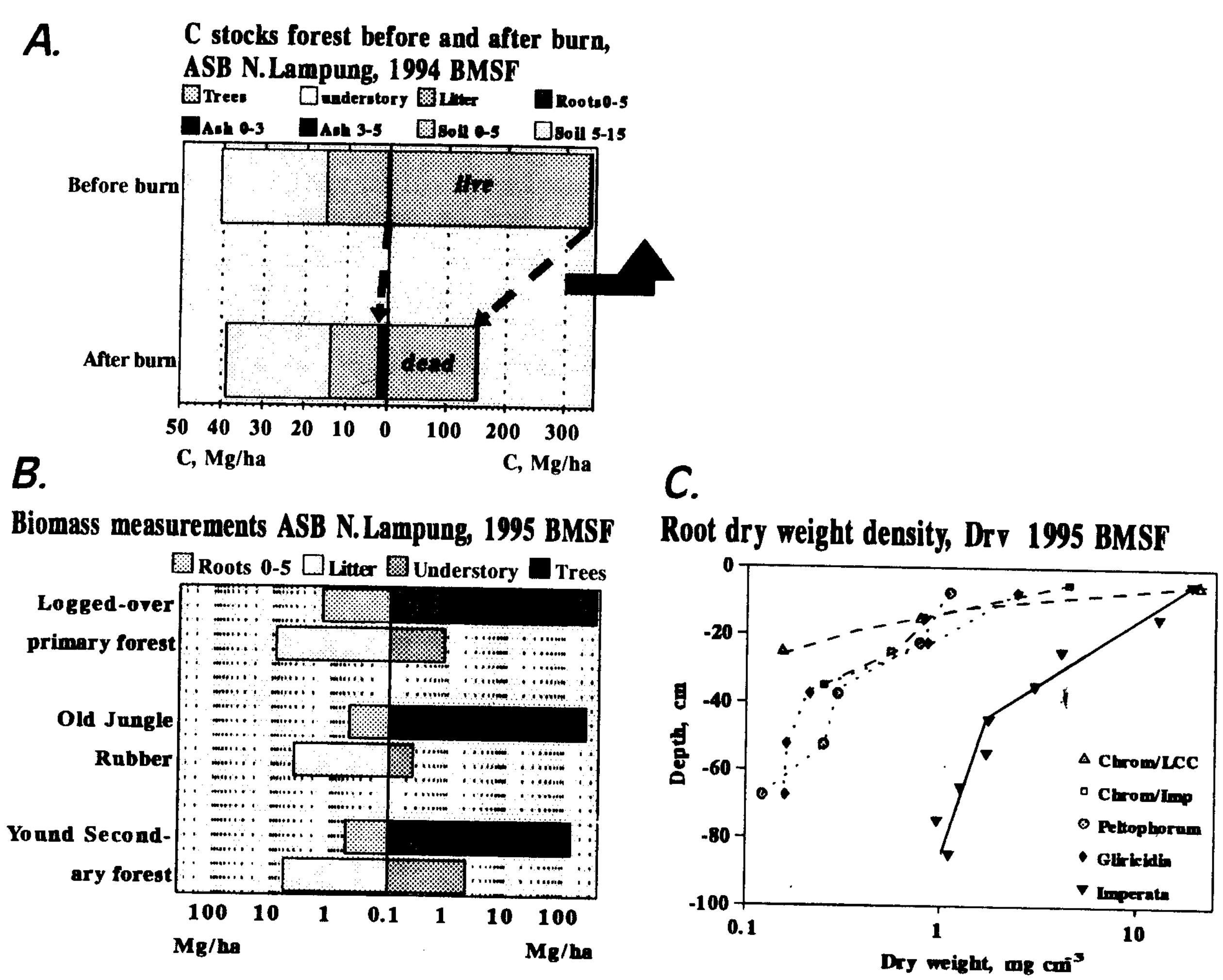


Figure 36. A. Effects of forest burning on above- and below-ground C stocks in N. Lampung; B. Biomass in three forest types; C. Root dry weight distribution with depth

c. Degrading land: burnt *Imperata*, sugar cane plantation with burning practices, and forest plantation with bulldozer land clearing.

Under SOM maintaining practices (without burning or removing of plant residues from the plot) the sum of the Ludox fraction (g kg^{-1}) in the top 5 cm of soil may still decrease by about 20-30 % from the forest level, even when the light fraction increased by about 40 %. Under degrading situations, the data suggested that 8-10 years after opening the forest, the sum of the Ludox fraction decreased by 70-80 %. In the 5-15 cm depth layer, however, the converted forest sites exceeded the forest. Total content of the Ludox fractions (in g/kg of soil) for this second layer is only 20-50% of that in the top 5 cm. In the 5-15 cm soil layer the heavy fraction is dominant over the light and intermediate fraction in dry weight and probably also in C content (data forthcoming).

5.5.5 *Conclusion*

The Ludox fractionation method gives a much more sensitive indicator for studying carbon

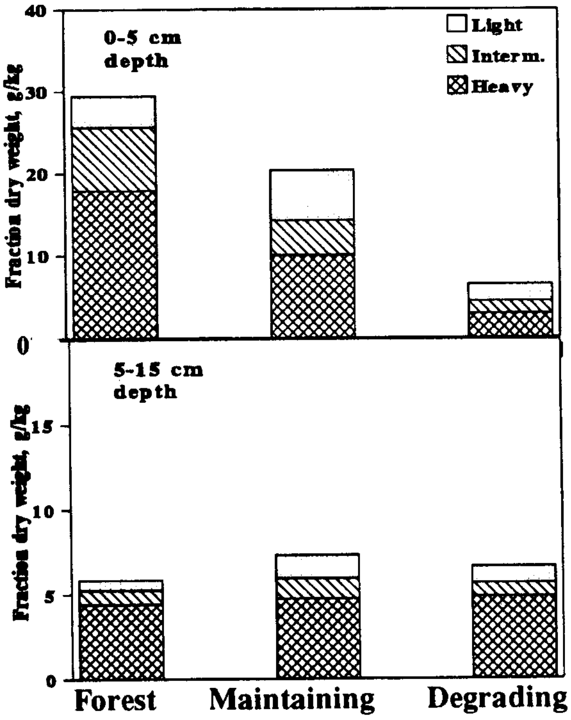


Figure 37. Soil organic matter fractions, based on LUDOX size/density fractionation for three groups of management practices and two soil layers

dynamics than total soil C, especially when the 0-5 cm depth is studied. Direct measurement of functional roles of these fractions is desirable.

Further research may concentrate on the following topics:

a. Functional interpretation of soil fractions as obtained with the Ludox method for their role in N and P mineralization, Al detoxification and soil physical properties.
b. Dynamics of the Ludox fractions in controlled experiments with known organic inputs from above-ground litter and root turnover (Killsom/Addsom).
c. Integration of the soil organic matter fractionation results with a dynamic model of SOM such as Century, to evaluate a large number of possible land use practices for their long-term effects.
d. Investigating a possible linkage between Ludox fractions and the soil's ability to act as a sink for methane.

5.6 *Eupatorium inulifolium* (kirinju) as a preferred fallow species in Air Dingin

During an initial study to characterize farming systems at the boundary/buffer zone of Kerinci Seblat National Park, around Air Dingin, the dominant role of a certain multipurpose shrub species was noted in the fallow vegetation (Cairns, 1995). The national park boundary contributes to a further intensification of land use, and fallow rotation systems have long since replaced classical 'shifting cultivation' agriculture in the area.

Eupatorium inulifolium H.B.K. (synonyms: *E. pallescens* DC and *E. javanicum* Boerl.; locally known as *kirinju*) has been introduced to Indonesia from tropical America in the second half of the 19'th century through the botanical garden in Bogor as a green manure. It's spread in W. Sumatra since the turn of the century was documented by Stoutjesdijk (1935). It rapidly found recognition as an 'improved fallow' species and was actively spread by farmers for that purpose. It's wind dispersed seeds caused rapid further expansion. At that time conflicts between farmers and forestry officials were reduced as short-duration *Eupatorium* fallows allowed more intensive land use, reducing fallow length by half and so reducing the requests for opening new forest lands. It forms dense thickets of 3-4 m high, shedding large amounts of leaf litter. *Eupatorium* also gained a reputation as an invader and destroyer of *Imperata* grasslands. Although liked by farmers, the species got a reputation of being an obnoxious weed as it invaded pastures and forest land. It is not palatable by cattle, is aggressive towards young trees and in the dry season is susceptible to fire, which spreads rapidly and is very hot in *Eupatorium* stands.

Eupatorium inulifolium with an attitudinal range of 200-1800 m a.s.l. plays a role similar to *Chromolaena odorata* at lower elevation, and can be seen either as an obnoxious weed or as useful multipurpose shrub. During a survey of farming systems in the Air Dingin area, special attention was paid to farmer's knowledge and evaluation of this plant in the context of fallow rotation systems. During a 6 week period, 75 farmers were interviewed on the subject in three sub-villages. They gave an overwhelmingly positive evaluation of the species. It is much preferred over *Imperata* and fern fallows. As major benefit they mentioned its role as fertility indicator: under *Eupatorium* thickets the soil has good tilth and is easy to cultivate, due to the litter layer (surface mulch). Fertilizer requirements are less than half that after *Imperata* fallows. The plant has a limited direct use, but dry stems can be used as firewood and some specific effects such as insecticide were mentioned. Reclamation is normally done by slash-and-burn, but variants such as slash-and-mulch or slash-and-bury (for young stands) occur as well. Mulch transfer from *Eupatorium* thickets to crop land was also mentioned. As disadvantages farmer's mentioned that the plant is a weed during the cropping period and dense stands may increase humidity at crop level and enhance fungal diseases.

As reasons for fallowing the land, lack of capital (for fertilizer, etc.), lack of labour and lack of time were mentioned (by 23, 10 and 7% of respondents, respectively), as well as the need for soil fertility restoration (20%). Fallow duration is usually short: 46% 1 year (or less), 30% 1-2 years and only 24% more than 2 years. Fallow duration is further reduced because of increased pressure on the land (increasing population density, limited access to new land because of the proximity to the national park border) and there is a trend towards permanent cultivation, especially for vegetable crops for the nearby city markets. On the other hand, the fact that most of the irrigated rice fields are now double-cropped, reduced the pressure on the uplands to some extent.

From the farmer's responses, which are similar to the situation for *Chromolaena*, it is not clear whether the plant actually improves the soil (and if so, by which mechanism) or only acts as an indicator. As a first step to address that issue, fallows with three types of vegetation (*Eupatorium, Imperata* and ferns) of different fallow age were sampled. The data (Table 25) first of all showed that the ferns occurred on acid andisols (soils of volcanic origin), with their typically high soil carbon content, linked to the mineralogy. Both *Imperata* and *Eupatorium* were found on red-yellow ultisols, but the pH of the *Eupatorium* fallows was higher than that of *Imperata* land. No major differences were found in available P or

Table 25. Average soil chemical condition of topsoil (0-15 cm) under three types of fallow vegetation in the Air Dingin area (Cairns, 1995)

	Ferns	*Imperata cylindrica*	*Eupatorium inulifolium*
No. of samples	5	5	6
Soil type	Andisol	Ultisol	Ultisol
pH(H_2O)	4.8	4.9	5.5
pH(1*M* KCl)	3.8	3.8	4.5
C_{org} %	11.2	2.8	2.4
N_{tot} %	0.65	0.25	0.24
P_{Bray} mg kg^{-1}	0.4	0.9	2.0
Exchangeable cations:			
K $cmol_e$ kg^{-1}	0.22	0.32	0.53
Ca $cmol_e$ kg^{-1}	1.04	6.85	10.26
Mg $cmol_e$ kg^{-1}	0.48	2.01	2.96
Na $cmol_e$ kg^{-1}	0.31	0.29	0.34
Al $cmol_e$ kg^{-1}	2.91	2.19	3.87
H $cmol_e$ kg^{-1}	0.29	0.25	0.23
ECEC $cmol_e$ kg^{-1}	5.26	11.47	14.81
Al/ECEC, %	55	19	26

exchangeable cation content. Soil C content was higher under *Imperata*, which is in line with it's more acid conditions. The soil data confirm a certain indicator value of the vegetation. No direct evidence was obtained for any improvement in indicators of chemical soil fertility for the top 15 cm; the data showed no significant regression or trend of soil parameters on fallow duration within a 2 year period. Although this may be partly due to the limited size of the data set, it may also reflect the insensitivity of classical soil fertility parameters to changes that are relevant for crop growth and/or the importance of soil physical and soil biological factors, rather than soil chemical factors in the improved crop growth after a fallow. A further possibility is that the main improvement occurs upon reclamation of the fallow vegetation. Phosphorus accumulation in the above-ground biomass over time is shown in Figure 38 for *Eupatorium* fallows. After 2 years the above-ground biomass contains about 20 kg ha^{-1} of P and the litter layer about 10 kg ha^{-1}. For *Imperata* and the fern vegetation the above-ground biomass P content was 6.3 and 3.4 kg ha^{-1}, respectively, without an appreciable litter layer. These amounts of organic P inputs may have an appreciable effect on the first rice crop after opening the fallow. Another fallow experiment with the different fallow species growing on the same initial soil conditions is needed to further clarify the direct role of the various fallow species, apart from their indicator value. Such an experiment has now been started with *Chromolaena* in the Lampung benchmark area.

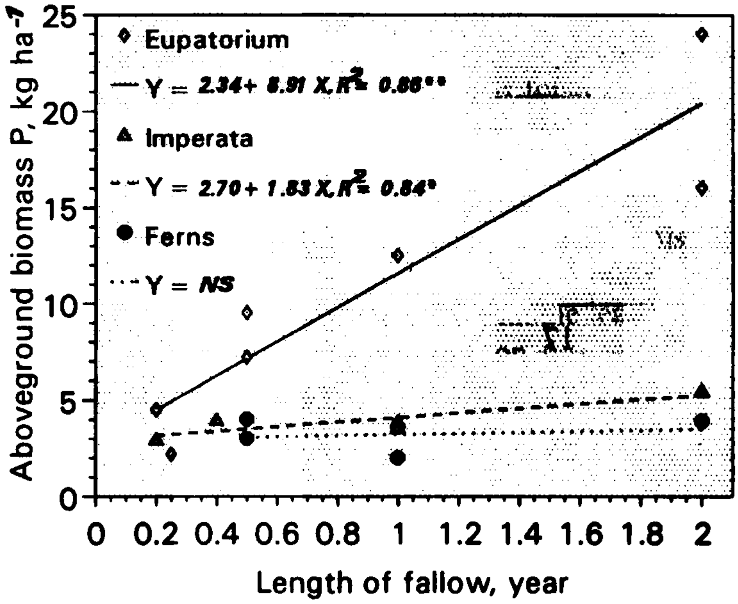


Figure 38. Phosphorus in aboveground biomass as a function of fallow age for *Eupatorium*, *Imperata* and fern fallows in Air Dingin

The recent study thus confirmed the description of Stoutjesdijk (1935) that a newly introduced improved fallow species can reduce fallow duration and thus diminish conflicts with forest conservation, but fallow systems are rapidly replaced by more intensive permanent cropping systems in the study area. The relevance of fallow systems may be higher in more remote areas, with less road access.

5.7 Root distribution of multipurpose trees for acid soils

Combinations of trees can lead to 'multipurpose tree stands', in as far as the tree combination yields a variety of products. In the agroforestry literature a lot of mention is made of 'multipurpose trees'. Emphasis on the multi-functionality of individual trees is clearly relevant where only few trees exist, as in the semi-arid tropics. In the humid tropics the required multifunctionality may come from the stand rather than from the tree. The compatibility of trees to grow in mixed stands depends on biological interactions (complementary use of above- and below-ground resources, synergistic relations with other biotic components) as well as social, agronomic and economic ones (complementarily of labour demand, phased economic productivity, independence or even negative correlations of price fluctuations). For the resource use interactions, the below-ground ones are the most difficult to observe, and yet they may be the most important ones overall, especially on infertile soils.

Table 26. Root patterns of multipurpose trees on acid soil, N. Lampung; preliminary survey of 5-7 year old trees (mostly in homegardens)

Species	Percent taproot of $\Sigma Root_{pox}$ diameter A	Shoot/ $\Sigma Root_{pox}$ diameter ratio, B	$\Sigma Shallow\ Root_{pox}$/ Stem diameter ratio (100-A)/(100B)
Leucaena leucocephala	17	0.39	2.13
Parkia speciosa	23	0.46	1.67
Annona muricata	28	0.44	1.64
Perunema canescens	4	0.78	1.23
Psidium guajava	11	0.74	1.20
Nephelium lappaceum	15	0.77	1.10
Pithecellobium jiringa	10	1.00	0.90
Gliricidia sepium	18	0.94	0.87
Paraserianthes falcataria	17	0.86	0.97
Eugenia aquea	17	1.43	0.58
Ceiba pentandra	45	0.95	0.58
Gnetum gnemon	15	1.53	0.56
Anacardium occidentale	45	1.20	0.46
Calliandra calothyrsus	75	0.64	0.39
Peltophorum dasyrrachis	74	0.69	0.38
Artocarpus heterophyllus	69	0.89	0.35
Durio zibethinus	75	1.14	0.22
Artocarpus integer	84	0.86	0.19
Mangifera indica	85	1.04	0.14

Van Noordwijk *et al.* (1995) developed a protocol for root research based on the diameter and orientation of tree roots close to the stem ('proximal roots') and tested the method in a preliminary survey of the root system of eighteen multipurpose trees in N. Lampung, on an acid ultisol. Most of the trees were part of a home garden and were about six years old. The assumptions of 'fractal' or 'self-similar' characteristics underlying the new method were shown to be acceptable, at least as a first approximation. Between the root systems of the various trees considerable differences were found, however, in the average value of the branching parameter. Much less variation was found in the stem branching patterns of the same trees, and root patterns can not be predicted from the stem branching.

The percentage of vertically-oriented roots of the sum of proximal root diameter squared ranges from 11-85% (Table 26). A clear relationship was found between the sum of squared root diameters and the square of the stem diameter at breast height. The sum of proximal root diameters squared is 50 - 200% of the stem diameter at breast height. We can thus use the stem diameter to obtain an index of 'shallow rootedness' or 'root competitiveness' by dividing the basal area of all shallow roots by the stem basal area. This index will be (nearly) independent of tree size. In our survey, its value ranged from 0.14 - 2.13 (Table 26). Mango, Jackfruit (Nangka) and Durian were the trees with the least shallow roots. Leucaena and Parkia (Petai) have the shallowest root systems on this acid soil and may be most competitive to other trees, as well as to associated crops.

5.8 Tree-Soil-Crop interactions in hedgerow intercropping

Continuous crop production is not feasible on most of the acid soils of the peneplain, unless high fertilizer + lime inputs and an intensive cropping system (mechanical tillage, herbicides) prevent *Imperata* infestation. Maintaining soil organic matter levels appears to be one of the keys to success, especially if no or only moderate amounts of lime are to be used. The organic inputs can either come from cover crops or from trees. In the past decade there have been a number of attempts to use the hedgerow intercropping concept in three of the benchmark areas (Sitiung, Kuaman Kuning and N. Lampung). Farmer acceptance has been low so far. Biophysically mixed results have been obtained and a further analysis of both the successes and failures seems needed before any further attempts at extension. Tree-soil-crop interactions can be separated into positive and negative ones.

In cooperation between Brawijaya University and ICRAF tree-soil-crop interactions are studied in a long term hedgerow intercropping experiment near the benchmark area in N. Lampung. The experiments have shown consistent yield advantages (compared to a no-tree control) for a local tree *Peltophorum dasyrrachis* (previously wrongly identified as *P. pterocarpum*), but not for more conventional tree species. The current experiment aims to separate positive and negative terms of the interaction equation for a number of hedgerow tree species (Fig. 39).

Results for the first growing season, with consistent rainfall surplus, showed a strongly positive residual effect on soil fertility when hedgerow trees were removed after 8 years of alley cropping. For *Calliandra* and *Leucaena* crop yields in these plots were higher than those obtained with the highest N fertilizer rate tested (135 kg ha^{-1}). In the normal alley cropping system, however, only *Peltophorum* outyielded the controls, as before. The difference is largely due to above-ground interactions (shade), as the effects of fresh mulch application and below-ground interaction (measured by the effects of root trenches), were small.

In the second cropping season, which was much drier than normal, a very poor crop yield was obtained on all plots (Fig. 39B, note Y axis scale). Crop response to N fertilizer application was negative under these circumstances, but the residual effect of alleycropping was still positive. The relative size of the shade, root and fresh mulch components was

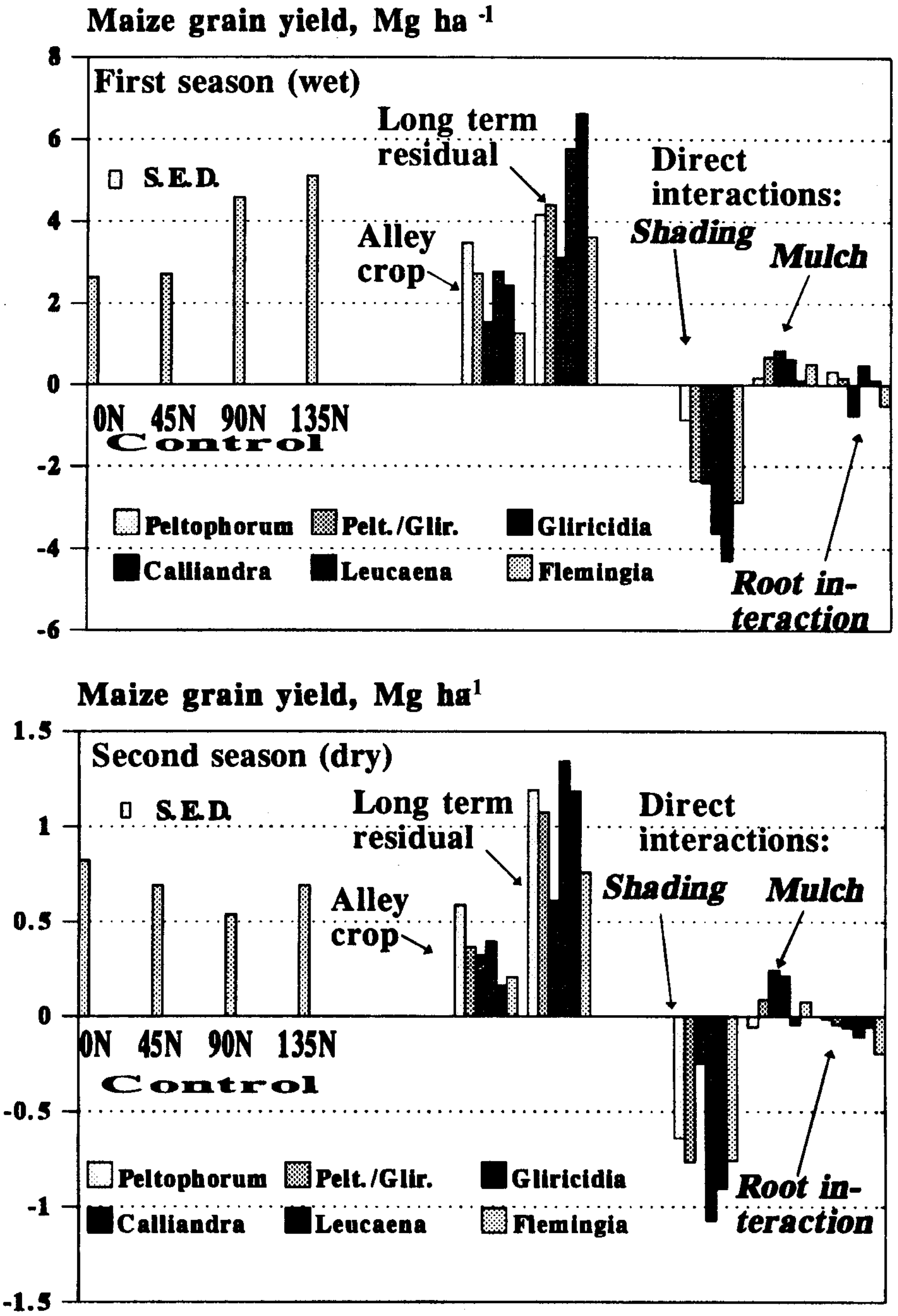


Figure 39. Positive and negative tree-crop interactions (long term soil improvement, shading, effects of fresh mulch and root interactions) in hedgerow intercropping of maize with 5 tree species; a N response on control plots is shown

similar to that in the first season, but tree roots had started to creep underneath the root barriers, so the separation of below- and above-ground interactions was not complete.

The same experiment contains mulch transfer treatments. In the second season positive mulch effects were obtained for both single and double mulch rates, clearly outyielding the N response curves. As all treatments obtained a moderate basal P fertilizer dressing, the mulch effect is largely attributed to positive effects on the water balance.

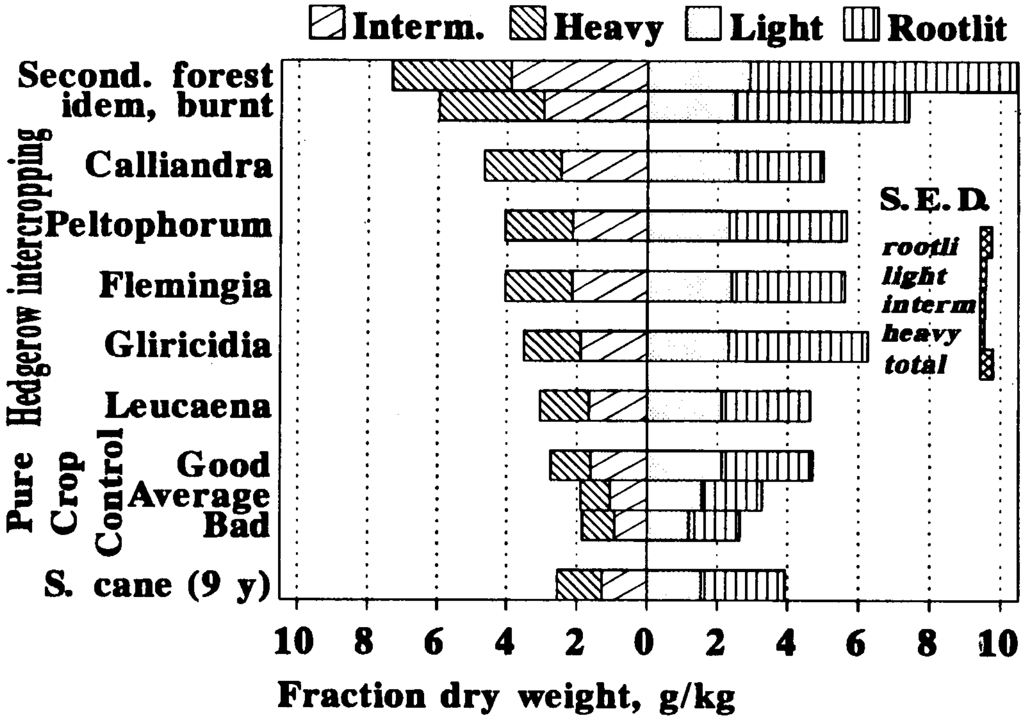


Figure 40. Organic matter fractions obtained by size (sieving) and density (LUDOX) fractionation of soil from forest, 9-years of hedgerow intercropping and control plots in N. Lampung

Overall the experiment shows the considerable positive soil fertility effects which can be obtained with tree mulches on these acid soils, but also points to the strong competition that occurs in alley cropping. In the humid tropics, with overcast weather, shading has directly negative effects on crops such as maize. The relative success of the local tree, *Peltophorum dasyrrachis*, is not due to pronounced positive effects (these are just average), but to small negative effects. The tree is less competitive than the others, partly because of a deeper root system (that is why it was first selected), but especially because of a dense canopy shape, giving a high mulch/shade ratio.

As total soil organic matter content is a poor indicator of functional pools, attempts are made at fractionation. Figure 40 gives results for the LUDOX fractionation method. The fields with previous hedgerow intercropping can be distinguished from the control plot in the intermediate and heavy fraction; the trees with the highest polyphenolic content of the prunings (*Calliandra* and *Peltophorum*) have the largest heavy pool (indicating soil carbon closely linked with mineral particles). Further tests of the functional significance of these pools for N and P mineralization are underway.

Figure 46.

In the rubber jungle

5.9 Smallholder rubber agroforestry

5.9.1 Introduction

Indonesia is poised to take first place in the world in natural rubber production. Rising wages already have reduced the competitiveness of producers in Malaysia and Thailand. Malaysia's production levelled off as a consequence; even Thailand's output seems about to reach its peak. But production costs on Indonesian estates are almost as high as Malaysia's estates and Thailand's smallholders, while production costs for Indonesian smallholders are much lower than all of these (Barlow *et al.*, 1994). In fact, Indonesian smallholders probably are the lowest-cost natural rubber producers in the world. So, in the future, Indonesia's competitive advantage in natural rubber production will derive mainly from its smallholders.

Smallholders already produce over 70 percent of Indonesia's natural rubber. Most of this comes from over 2 million ha of rubber agroforests (sometimes called "jungle rubber") in Sumatra and Kalimantan (Gouyon *et al.*, 1993; Dove, 1993). These rubber agroforests are probably the most widespread complex agroforestry system in Indonesia. Besides being the key to Indonesia's future competitive advantage in natural rubber, a workable strategy to raise productivity of these rubber smallholders also could play an important role in poverty alleviation. Despite development in other sectors, increases in smallholder rubber productivity still can be an important engine of economic growth in regions of Sumatra and

Kalimantan. The supply of workers continues to grow in these rubber-producing regions, while new land is getting scarce. Under these conditions, farmers will be eager to raise productivity if they have profitable options.

Rubber agroforests maintain a forest-like environment that retains biodiversity. A variety of products tend to be harvested in addition to latex, including many types of fruits and timber.

5.9.2 History of smallholder rubber in Indonesia

> "The history of agriculture probably has not seen any other case where the introduction of a single crop had such a dramatic effect on the economic condition of smallholders in vast areas, as the introduction of *Hevea brasiliensis* in Indonesia." (Van Gelder, 1950).

In Sumatra's peneplains virtually all shifting cultivation has been transformed into rubber-based agroforestry. Although *Hevea* was introduced to Asia in the later decades of the 19th century, the first smallholder trees were probably planted around the turn of the century. Planting material spread through trade links that already existed for forest products such as damar, gutta percha, jelutung and rattan, as well as agricultural products such as copra and pepper. Introduction in Sumatra started in Jambi and expanded rapidly into the southern and western sections of the island.

Rubber prices boomed in 1909-1912, which led to rapid planting. With minor ups and downs, growth continued smoothly until about 1930. The colonial government had no idea about the rapid spread of rubber trees until the market was flooded with smallholder output. Recorded smallholder production increased from 150 tons in 1912 to 128 000 tons in 1925. By that time government policies attempted to discourage smallholder rubber production in order to support prices for estates.

European planters initially thought that rubber could only be grown under intensive management and clean weeding, that tapping required utmost care not to kill the trees, and that processing of the product needed special skills. The large-scale planters were wrong on all three points. Smallholders, however, quickly had learned that *Hevea* is very amenable to extensive management systems. Rubber trees fitted easily into the existing *ladang* (shifting cultivation/slash-and-burn) system. Smallholders simply planted some rubber trees in the first upland rice crop (often but not always followed by a second rice crop) and left them to grow with the fallow vegetation (*belukar*).

To the European planters smallholder rubber growing in *belukar* looked abandoned and mismanaged, compared to the clean-weeding system then used in the plantations. After some time, however, it became apparent that *Hevea* benefits from the intergrowth and that the intensive management on the plantations nearly killed the crop; cover crops eventually were introduced into the large estates. Rutgers (1925) concluded that "Intuitively the native had chosen the right way to handle the tree, which was only gradually followed by the European plantations, which started off with much too intensive management."

5.9.3. *A development opportunity ... that is being missed*

Rubber agroforestry systems are unique among rubber development options because they offer opportunities to provide a wide range of benefits to smallholders, processors, and the nation. This package includes greater income and employment for smallholders, expanded business opportunities for processors, a focal point for regional development, larger non-oil exports, and environmental benefits, including conservation of biodiversity.

But these important opportunities are being missed. Although smallholders are planting a lot of rubber on their own, most lack adequate access to improved planting material suited to their conditions. In the places where such planting material is available, farmers need more practical information on how to use it best.

Despite years of effort to provide smallholders full technical packages through development projects based on rubber monoculture, these have reached only about 13% of the farmers (Table 27). An additional 10-20% of the smallholders in the vicinity of these projects have had indirect benefits through technical information and improved planting material. But as the typology of rubber smallholders in Table 27 shows, some 75% of the farmers have not had access to improved systems and, as a result, continue to be locked into low yields averaging about 600 kg dry rubber/ha/year for mature trees.

Over time, these missed opportunities will threaten Indonesia's competitive advantage in natural rubber. Just as in Malaysia and Thailand, higher wages will come with Indonesia's successful economic development. If there is no increase in smallholder productivity to offset rising labor costs, the low-cost advantage of Indonesia's smallholders will evaporate and so will its natural rubber industry.

Table 27. Typology of smallholder rubber farmers In Indonesia

Class	Situation	%	System
1	Government projects	13	Estate-like monoculture
2	Non-project but good access to markets, credit	12	More intensive rubber agroforestry; tendency towards monoculture
3	Moderately isolated	50	Jungle rubber, some improved management
4	Isolated, no access to credit, extension	25	Jungle rubber

Source: Penot, 1995.

5.9.4 What can be done to support rubber agroforestry development?

Sustained success with agricultural exports requires a long-term commitment to invest in research and development in order to increase yields and reduce production costs. For example, when its share of the rubber market was threatened by synthetics in the 1950s, Malaysia acted to retain its competitive position. At that time, almost half the area of its estates and 2/3 of its smallholdings were planted with trees over 30 years old. An ambitious programme of research, replanting, and rural development transformed the situation (Barlow 1978). Malaysian natural rubber output grew more than 150% from 1955 to 1988, despite competition from synthetics abroad and rising wages at home. Thailand employed a very different rubber development strategy, suited to its smallholder sector and institutional capabilities, to overtake Malaysia. Now rubber agroforestry presents an opportunity--and challenge--for Indonesia to develop its own strategy suited to its unique conditions.

5.9.4.1 Smallholder development programmes. To date, Indonesia's smallholder rubber development efforts have met with little success. Block-planting projects of the 1970s and 1980s, including project management units (PMUs) like SRDP and PRPTE as well as nucleus estate schemes (NES/PIR), were intended to produce large increases in yields. Achievement of the high yields necessary to justify the costs of block planting depended on application of purchased inputs at levels better-suited to large estates than to smallholders. By the mid-1980s, it already was apparent that high-cost block-planting projects had proved difficult to implement in Indonesia and had benefited only a small fraction of rubber smallholders. Moreover, Indonesia's economic situation had changed because of declining oil prices, which forced cuts in the development budget. About the same time, agricultural development projects began to fall from favor as international donors shifted their attention to environmental concerns. As a result, rubber development programmes withered.

Indonesia's tight government budget constraints make it more important than ever to develop a feasible alternative to the costly block-planting strategy. Programmes aimed at gradual productivity growth in rubber agroforestry systems seem to hold potential for productivity gains at a small fraction of the cost of block planting. Furthermore, the environmental benefits of rubber agroforests make projects aimed at development of these systems attractive to international donors. In short, compared to block-planting, rubber agroforestry programmes should put less demand on the government budget while being more likely to attract substantial funding from international donors.

5.9.4.2 Marketing improved planting material. An unfortunate feature of the block planting strategy that Indonesia pursued in the 1970s and 1980s was that almost all of the limited supply of improved planting material available for smallholders was restricted to project participants. Improving the supply of higher-yielding planting material and providing farmers with practical information about its use should have key roles in any smallholder rubber development programme, including one aimed at rubber agroforests. Various approaches already have attempted to improve planting material supplies for smallholders on a pilot scale, including efforts by local authorities in Jambi Province. One of the main lessons from these pilot projects is that planting material programmes need to pay attention to demand as well as supply (Barlow *et al.*, 1993). Since such a large proportion of smallholder rubber

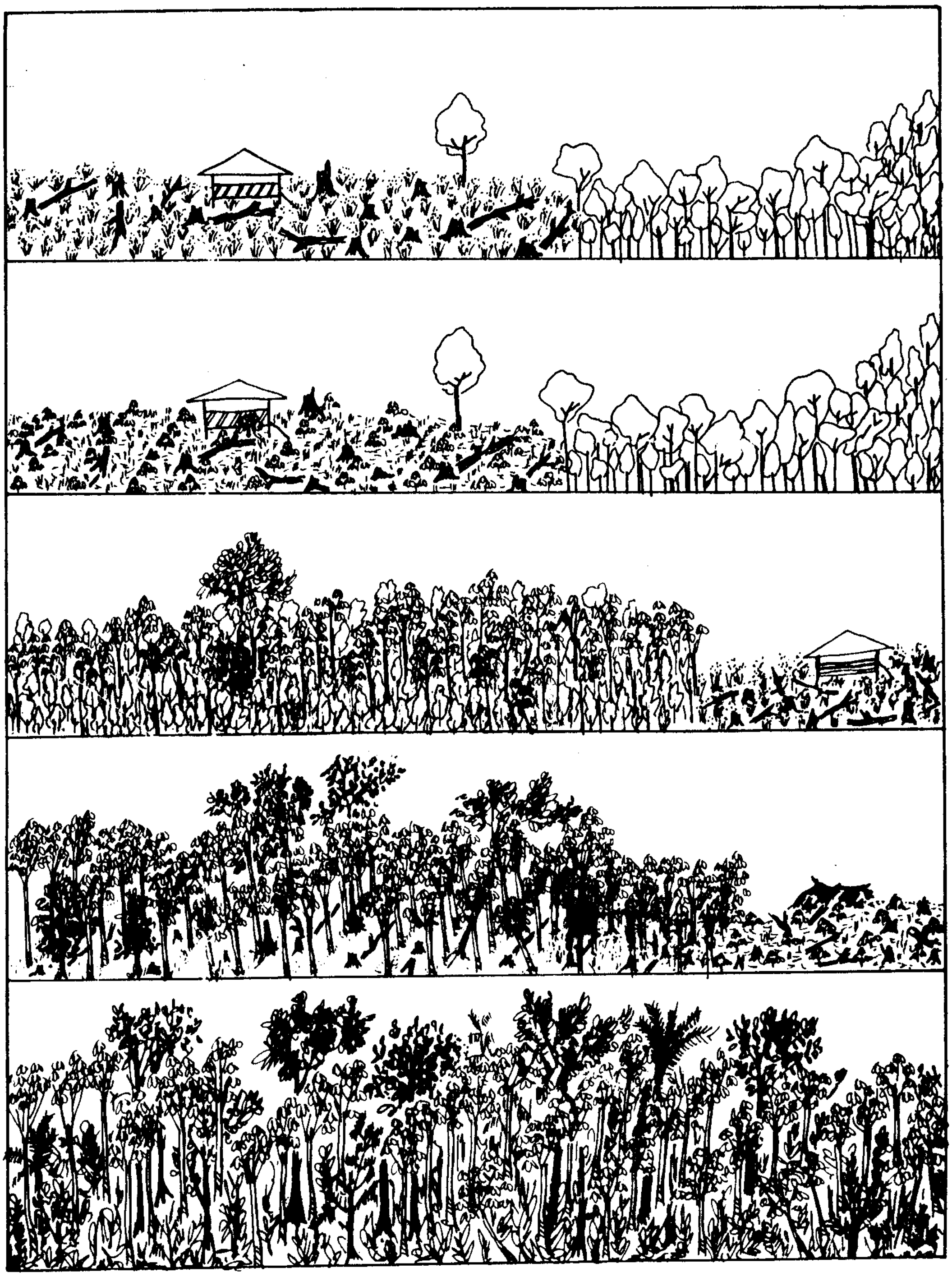


Figure 42. Development of jungle rubber systems over time

area is still under trees grown from unimproved seedlings, projects have taken for granted that there is a big potential demand for higher-yielding planting material. Indeed, some unassisted farmers have started replanting with improved materials. For instance, in parts of Sumatra it is common for farmers to buy improved rubber planting material, usually in small quantities obtained from small private nurseries. Elsewhere, however, smallholders' lack of awareness of these opportunities or lack of information on how to achieve the benefits of planting higher-yielding rubber may mean actual demand falls far short of apparent potential. Social marketing techniques may be a cost-effective means to address these problems by using mass media and other marketing channels to provide farmers with technical information they need to choose material that is appropriate to their economic circumstances and to help them to put it to its best use.

5.9.4.3 Research on rubber agroforestry systems. Since much of the funding for rubber research has come from plantations, important scientific questions regarding application of improved technology in smallholder settings have not received adequate attention (Tomich, 1991). Indeed, there is little scientific evidence on performance of improved rubber planting material under the conditions faced by roughly 75% of rubber smallholders in Indonesia. Filling this research gap is of crucial practical importance since productivity growth in rubber agroforests depends on adaptation of higher-yielding planting material to these complex agroforestry systems. There is reason to believe that rubber yields could be increased substantially by planting these materials with only minor increases in labor and inputs. Two broad classes of research questions deserve priority.

* For specific agroecological and socioeconomic conditions, which among the higher yielding rubber planting materials that are available produces the highest payoff for smallholders?

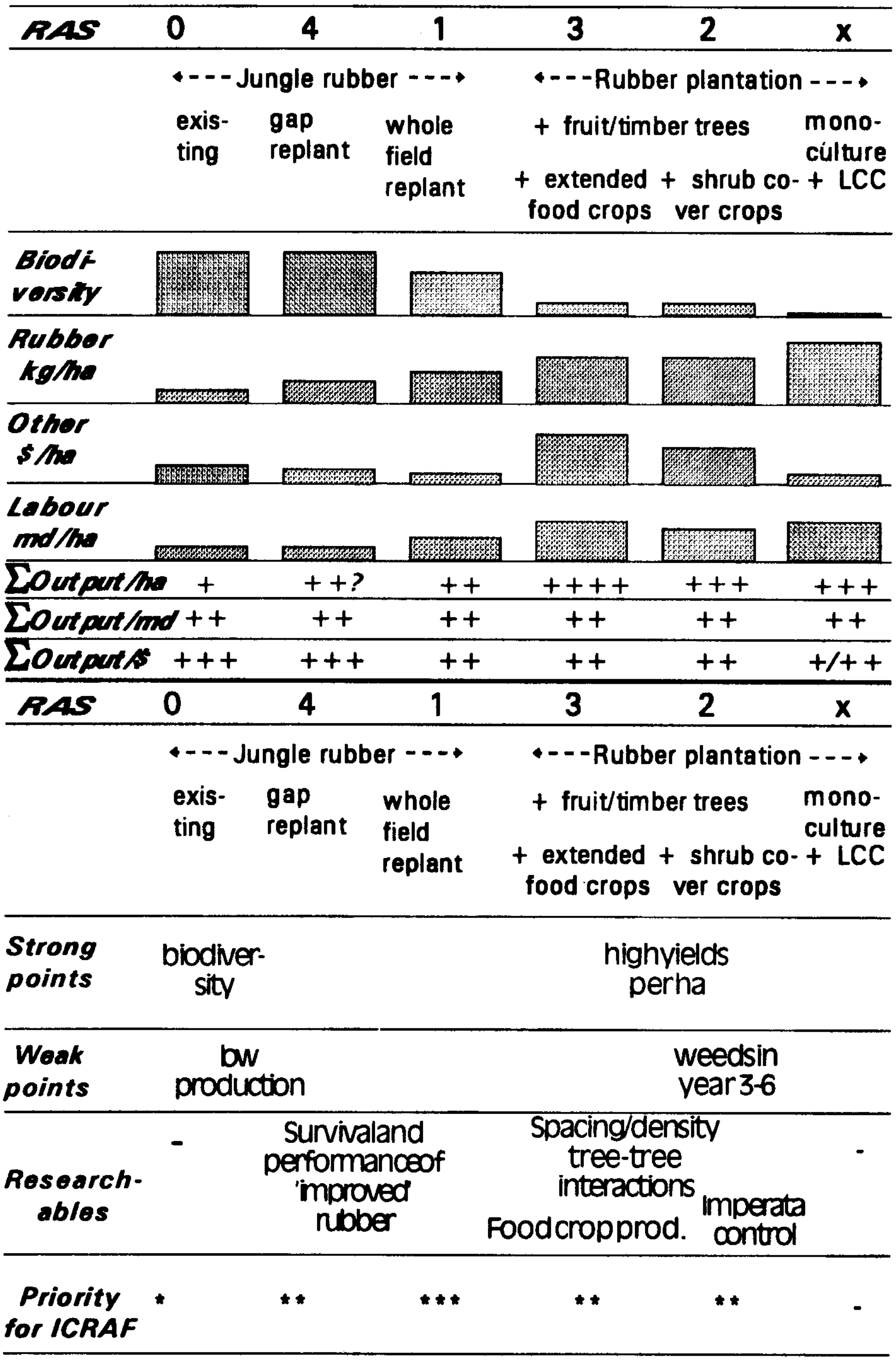
* What are the effects of productivity increases on biodiversity of rubber agroforests?

Agronomic trials and economic analysis concerning the first question can provide the foundation for new smallholder development programmes aimed, for the first time, at rubber agroforestry systems. The methods to design and conduct trials to identify improved planting material are well-understood as are the appropriate economic tools; the main barriers to research on the agronomic and economic aspects of rubber agroforestry are institutional. In particular, there is no clear mechanism for funding national research on smallholder rubber agroforestry in Indonesia. On the other hand, methods to predict the impact of productivity increases on biodiversity still must be developed.

In the context of the Alternatives to Slash-and-Burn Program, ICRAF has initiated a research project to test whether the productivity of rubber agroforestry systems can be improved without losing the benefits that both farmers and outsiders perceive regarding this biodiverse farming system. This work is undertaken in collaboration with CIRAD, the Rubber Research Institute of Indonesia, ORSTOM, and GAPKINDO, the Indonesian Rubber Processors Association. The recommendation domain is the class III farmers in Table 27: non-project farmers that want to improve the rubber productivity without being able to afford great increases in management intensity or capital investment.

The work will be carried out in three major smallholder rubber provinces: Jambi, West Sumatra, and West Kalimantan. In the current phase, a more detailed characterization of the smallholder rubber agroforestry systems is being conducted in the study areas and budwood gardens are being established locally to provide clonal materials for on-farm trials. Research on the biodiversity of rubber agroforests, which has been in progress for several years by ORSTOM, will be integrated with this project.

The trials will be targeted according to three rubber agroforestry systems (Penot, 1995). The first system (RAS 1) will address the performance of certain improved planting materials



RAS	0	4	1	3	2	x
	←---Jungle rubber---→			←---Rubber plantation---→		
	existing	gap replant	whole field replant	+ fruit/timber trees		monoculture
				+ extended food crops	+ shrub cover crops	+ LCC
ΣOutput/ha	+	++?	++	++++	+++	+++
ΣOutput/md	++	++	++	++	++	++
ΣOutput/$	+++	+++	++	++	++	+/++

RAS	0	4	1	3	2	x
	←---Jungle rubber---→			←---Rubber plantation---→		
	existing	gap replant	whole field replant	+ fruit/timber trees		monoculture
				+ extended food crops	+ shrub cover crops	+ LCC
Strong points	biodiversity			high yields per ha		
Weak points	low production				weeds in year 3-6	
Researchables	-	Survival and performance of 'improved' rubber		Spacing/density tree-tree interactions Food crop prod.	Imperata control	-
Priority for ICRAF	*	**	***	**	**	-

Figure 43. Terminology used for Rubber Agroforestry Systems (RAS) and their tentative characteristics

within the current jungle rubber management system with little outlay for purchased inputs. The second system (RAS 2) will investigate the direct establishment of complex agroforests through combinations of rubber and other perennials (fruit, nut, and timber species), in which the compatibility of the species combinations will be an issue. In the third system (RAS 3), the complex agroforestry framework of rubber and associated trees is that same but there will be no food intercropping. Instead, combinations of covercrops, shrubs, and fast-growing trees will be developed as a means of weed control. In terms of agroecological conditions, RAS-1 trials are targeted to forest margins where there is an adequate supply of natural species propagules to regenerate a secondary forest-like environment. RAS-2 and RAS-3 research is targeted toward the *Imperata* grasslands, where natural forest regeneration will not occur, and the species mix in the agroforestry system must contend with the highly-competitive grass.

5.10 Rubber wood: Environmental opportunity and policy barriers

Research questions about the use of rubber wood emerged from parallel work within ASB-Indonesia on measurement of greenhouse gas emissions, on land use systems and household economics, and on national policy (Suyanto, 1995). Even from the preliminary data on land use systems, it was clear that a significant share of slash-and-burn clearing in Sumatra involved smallholders' old rubber gardens instead of natural forest. Rubber accounts for roughly 60% of the standing trees in these so-called "jungle rubber" systems. Today, most of the rubber wood goes up in smoke when smallholders fell trees to clear old gardens for replanting, thereby contributing to greenhouse gas emissions.

5.10.1 Wood products as alternatives to burning rubber wood

Large-scale plantations also use slash-and-burn to clear land for replanting. However, a growing portion of the rubber wood from plantations now is being processed instead of burned. Some of this rubber wood is used in manufacture of fibre board while choice pieces can be sawed into high-value lumber that is a substitute for ramin, which is among the most valuable timbers. International prices for rubber wood increased in the late 1980s because of rapid depletion of stocks of ramin wood, which comes from natural forests in SE Asia.

More measurements of above-ground biomass for "jungle rubber" and other systems are needed to produce complete carbon accounts for the various land use systems and land clearing methods. Work so far suggests that there may be alternatives to burning rubber wood that would have environmental benefits. As a result of discussion among the members of the local team, a need was identified for complementary analysis of the economics of rubber wood produced by smallholders.

Smallholder rubber wood is not as uniform as rubber wood from large-scale plantations because most smallholders plant seedlings while plantations use clones. This gives plantations a technical advantage over smallholders as rubber wood suppliers, especially for processors of higher-value sawn wood. Better infrastructure and economies of scale may also make it more profitable for processors to focus on plantations for their rubber wood supplies. Despite these technical disadvantages, there may be viable marketing opportunities for smallholder rubber wood, especially as raw materials for medium density fibre board (MDF). Moreover, small-scale, mobile processing equipment now is available that could improve the economics of smallholder rubber wood, even for sawn wood. In the future, rubber wood could emerge as another important product (along with latex, fruit, and other non-timber tree products) of smallholder rubber agroforests.