II. Global environmental impacts: criteria and indicators

Land use at the forest margins has an impact on two global environmental concerns: the net emissions of greenhouse gasses (carbon dioxide, methane and nitrous oxide) which are believed to have an impact on global climate change, and the conservation of biodiversity.

The criterion for effects of land use change on net greenhouse gas emissions can be explained by reference to the effects on natural forests. When considered over large enough scales (in space and/or time) the net carbon exchange between vegetation and atmosphere shows a small flux, equal to the export of organic compounds in soil and water into non-terrestrial ecosystems. The current C stocks in forest systems are large relative to these fluxes and the main issue is in the fate of this stock during land cover change. The two other greenhouse gasses of main global interest (methane and nitrous oxide) can show net emissions or absorption, depending on local soil conditions. Wetland sites (swamp forests as well as rice paddies) generally emit methane, while upland forest soils can absorb and oxidize methane. Nitrous oxide is emitted from all soils where mineral nitrogen is present under relatively wet and warm conditions (so including natural forests), but there may be absorption into green vegetation under certain circumstances. Effects of land use change on greenhouse gas emissions can be measured and expressed in units that allow comparison with industrial emissions, and in the end an economic comparison can be made between the costs of reducing emissions in various sectors of society. Hence, it is important to quantify the effect of land use and land use change on these gasses as fluxes (amount of gas molecules per unit land surface area and unit time).

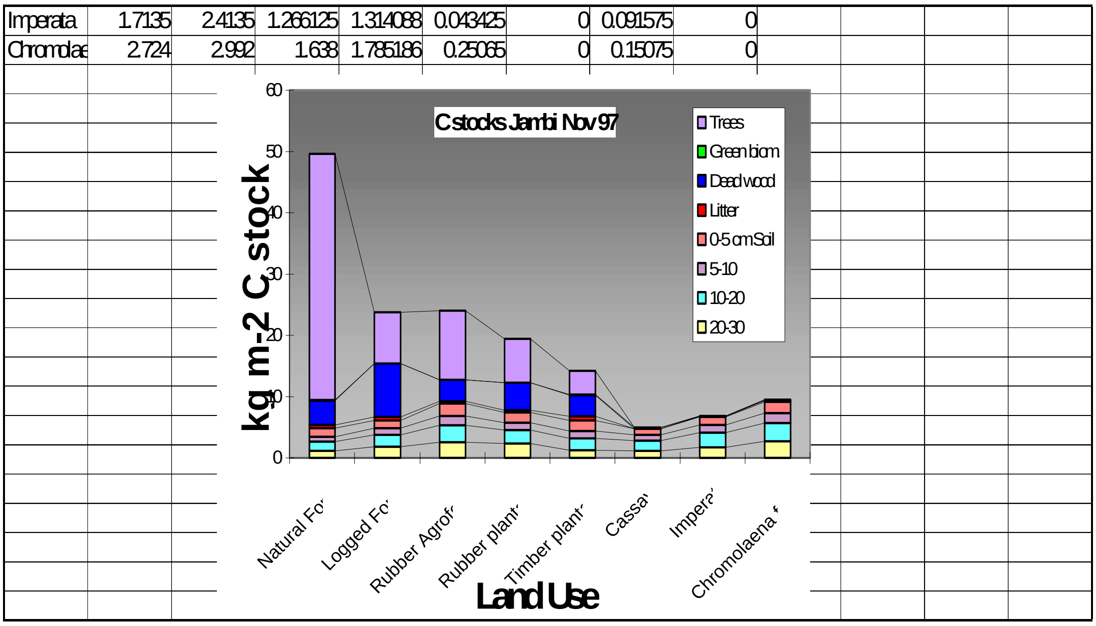
For biodiversity the criterion is the maintenance of global diversity and the role a particular area plays in that respect, but there is no currency equivalent to the one for greenhouse gases -- diversity measures can be expressed per unit area and per unit time, but can not be converted easily to other units of area or extrapolated in time. For example, if two areas both contain 100 different species, the combined area can contain anywhere between 100 and 200 species, depending on the species overlap. The contribution of a particular site to global biodiversity conservation depends largely on the number of unique flora and fauna elements it contains. Although survey data can show what plants and animals are currently present in a given sampling area, the really important question of how many of these species (or other taxonomic units or genes which are taken as the basis of comparison) would survive over a time frame of X years, can not be directly assessed (Rosenzweig, 1995). Dynamics of local extinction and recolonization depend on the landscape mosaic in which land use systems occur, as well as on the means of dispersal of the organisms concerned. As a very first step into such a dynamic analysis, local species richness is often used as an indicator, largely for lack of better measures. Local species richness can not be compared across ecosystems or even between continents, however, and the best we can do is express local species richness for various land use types *relative* to that of natural forest. We have to realize, however, that these ratio's can not be added or subtracted, and that their value probably depends on the scale at which measurements were made. For example, previous comparisons of plant diversity in rubber agroforests showed a local species richness of at least half that of a natural forest, for a 40 m line transect. This does not mean, however, that 1 ha of rubber agroforests will contain (let alone conserve) half the species of 1 ha of natural forest; comparisons at the level of Jambi province are even more uncertain, as it may well be that the 50% forest species in the jungle rubber are generalists, occurring throughout the province and the species not present in the jungle rubber are local specialists, with a different diversity/scale relationship. Despite all these caveats, we will present data here comparing biodiversity indices based on higher plants, which indicate the similarity between sample sites in forest and non-forest, based on a new technique of 'plant functional attributes' (Gillison 1998).

We also collected data on belowground biodiversity, as this is an aspect on which little data exist. Parts of the belowground biodiversity may be directly relevant to the farmer, as they effect 'ecological service functions' (mineralization, soil structure maintenance, symbionts, soil-borne diseases and their control).

II.1 Carbon stocks

Lowland tropical rain forests have the highest standing biomass and aboveground carbon stocks of any vegetation in the world, and total C stocks of rain forests are only equaled by the deepest peat soils. Measurements in Jambi (Fig. II.1) indicate that the total carbon stock of natural forests on the peneplain (above a soil depth of 30 cm) can be up to 50 kg m^{-2} or 500 Mg ha^{-1}, with roughly 80% in live trees, 10% in dead wood and 10% in the soil. In logged forests (about 10 years after the logging event), live tree biomass is substantially reduced, but there is more C in dead wood and at least as much in the soil. In cassava fields total C stock can be reduced to about 10% of that in the forest, but soil stocks are still similar to those in the forest. (These data have not been corrected for differences in soil texture, however; compare the Corg/Cref ratio's described in chapter III).

Conversion of rain forest to other land uses, regardless of the technique used for conversion, is thus bound to reduce the amount of C stored in terrestrial ecosystems. As the total net release rate of carbon dioxide (CO_2) into the atmosphere from land use change and fossil fuel emissions exceeds the rate at which the ocean surfaces can absorb additional CO_2, atmospheric CO_2 concentrations increase.



Imperata	1.7135	2.4135	1.266125	1.314088	0.043425	0	0.091575	0
Chromolae	2.724	2.992	1.638	1.785186	0.25065	0	0.15075	0

Figure II.1 Carbon stocks in a range of land uses in Jambi

In combination with other greenhouse gases, CO_2 is held responsible for increasing the ‘greenhouse effect’ of reflecting radiation from the earth, leading to changes in circulation patterns affecting local climate, as well as causing an overall warming of the planet and an ensuing rise in sea levels. Apart from accepting and adjusting to these climate changes, the main mitigation options are to reduce fossil fuel use and slow down or reverse the trend of declining C stocks in terrestrial ecosystems. In all terrestrial ecosystems C sequestration (fixation) and C dissipation (release) are approximately in equilibrium, with the vast majority of carbon dioxide (CO_2) molecules captured by photosynthesis in leaves during the day being respired at night or during decomposition of litter. Only during phases of build-up of biomass (aboveground or in roots) does the C stock of an ecosystem increase. But in all natural ecosystems, phases of decline and rejuvenation follow phases of growth. And in managed ecosystems, harvest procedures arrest accumulation and usually lead to a period of rejuvenation. In evaluating the C stock of land use systems we have to choose a time frame: following CO_2 molecules at a day or seasonal scale is not necessary, as long as annual increments over the typical life span of a system can be predicted.

Averaging the C stock over the life span of a system gives a simple measure of its role in the global C balance, as long as different stages of the system may be expected to occur in roughly proportional areas at any point in time. If we can assign a typical ‘time-averaged Carbon stock (Mg ha^{-1})' to each land use type, we can directly evaluate how 'land use change' will lead to net C release or net C sequestration, depending on the sign of the difference of 'Cstock(after) – Cstock(before)'.This means that an evaluation of the C stock of a land use depends on the context and the types of comparisons made: compared to natural forest all other land use types lead to net C release to the atmosphere, compared to continuous annual crops, all other land uses lead to C sequestration.

Of particular relevance here may be the C stock of shifting cultivation systems. Fig. II.2 shows how the 'time-averaged C stock' depends on the length of fallow and the rate of C sequestration per year during the fallow. For very low land use intensities the time-averaged C stock of shifting cultivation may approach that of a natural forest, as the maximum C stock may be the same and the short episode of slash-and-burn and production of food crops may resemble what happens after a mature tree dies, falls and creates a gap. During intensification of shifting cultivation systems, the time-averaged C stock will decrease rapidly (note the logarithmic scale used for the Y axis in the graph). This analysis emphasizes the systems context of forest clearing: if it is done in the context of long-fallow rotations it will decrease the C stock much less than when it is done for (supposedly) permanent food-crop cultivation.

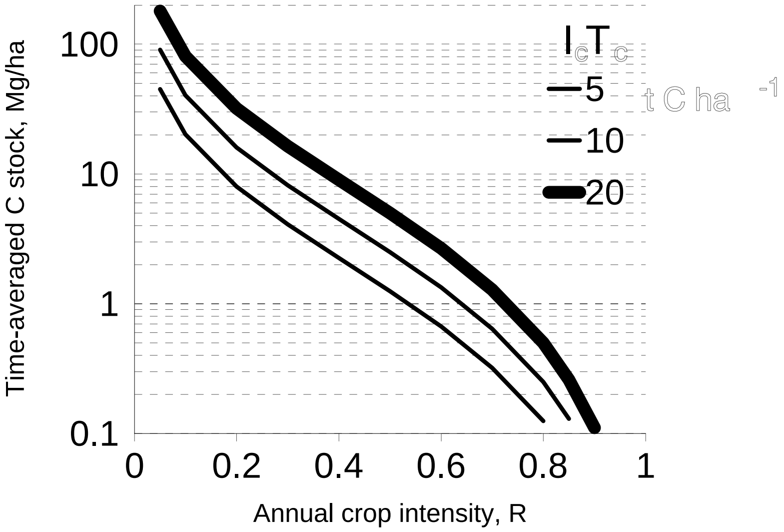


Figure II.2 *Time-averaged Carbon stock of shifting cultivation and fallow rotation systems, as a function of the land use intensity R = Tc/(Tc + Tf) where Tc is length of cropping period (yr), Tf = length of fallow regrowth period (yr) and Ic = annual C accumulation rate during fallow regrowth (Mg ha^{-1} yr^{-1})*

To estimate the time-averaged C stock of the range of land use systems evaluated as 'alternatives to slash and burn', we need the following information:

- Is it a rotational system where periodically whole fields are cleared of vegetation to start a new cycle, or is it managed under permanent vegetation cover?
- What is the length of a single rotation cycle?

- What is the rate of C sequestration per year during the various stages of the cycle (e.g. during periods where annual food crops are grown and during periods of fallow regrowth)?
- Does the C stock reach a maximum at which annual C sequestration levels off?

The land use systems chosen for evaluation all are rotational in nature, except for the community managed forest with extraction of non-timber forest products. Commercial logging (officially) consists of logging episodes and periods where the forest can recover. All other land use systems involve field clearing at the start of a new cycle, mostly using slash-and-burn techniques of land clearing. Some of the rubber agroforests may evolve into a stage of gap-level rejuvenation instead of field level clearing, but the form chosen for evaluation of profitability (chapter IV) is a rotational form. (We will come back to the issue of rotational versus permanent agroforests in chapter IV).

The main remaining uncertainty is the annual rate of C sequestration. The measurements of standing C stock in a range of land uses at different ages since land clearing by slash-and-burn can be used to estimate an average rate of C sequestration (Fig. II.3). In the figure three groups of land use are distinguished:

- logged-over forests; we have to make a rather arbitrary decision on the effective age of the natural forest and the line connecting the points of logged forest with natural forest may overestimate C sequestration if logging has done near-permanent damage to part of the system (such a logging ramps and trails, see chapter III),
- natural fallows (secondary forests), agroforests and more intensive tree-crop production systems, which apparently accumulate at a rate of about 2.5 Mg C
  ha-1 yr-1
- cassava/*Imperata* systems where there is a negligible rate of C accumulation with age, presumably because annual fires prevent the build up of C stocks in vegetation.

On the basis of these results time-averaged C stocks were assigned to the land use types chosen for evaluation (Table II.1).

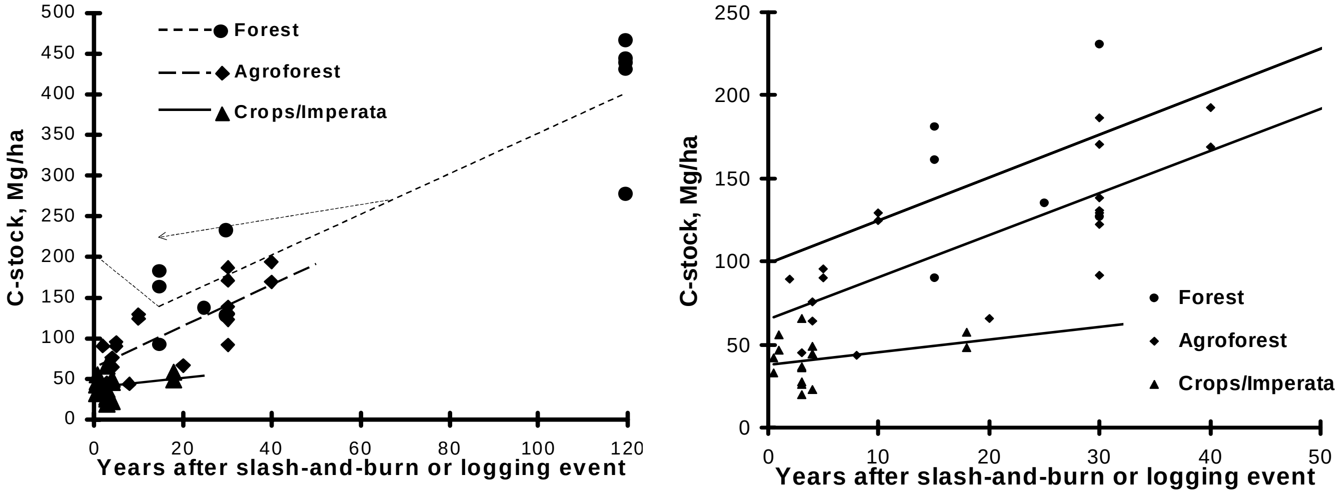


Fig. II.3 *Carbon stock in aboveground biomass, surface litter and top 30 cm of the soil, as a function of time since forest clearing (slash-and-burn) or logging (left: whole data set, right: excluding the natural forest plots)*

Table II.1 *Time-averaged carbon stocks for land uses of the lowland peneplain; three regression lines were used for the calculations (1 for forest, 2 for agroforest and tree-crop plantations, 3 for cassava-imperata)*

Land use system	Line	Maximum age (yr)	Time averaged C stock Mg ha^{-1}
Natural forest	1	120	254
Community-based fores management	1	60	176
Commercial logging	1	40	150
Rubber agroforests	2	40	116
Rubber agroforests with selected planting material	2	30	103
Rubber monoculture	2	25	97
Oil palm monoculture	2	20	91
Upland rice/ bush fallow rotation	2	7	74
Cassava/*Imperata* rotation	3	3	39

The values given here contain many assumptions. As part of the ASB-Phase 2 activities in Indonesia, efforts were made to use the Century model (Parton *et al*., 1987, 1994) for typical transitions from forest into other land use patterns. As the best data on such a time series were collected in the Lampung benchmark area for a forest-to-sugarcane conversion series (where isotope discrimination allows us to follow the fate of 'forest' versus 'cane' organic inputs, Hairiah *et al*., 1995), model efforts focussed on this series for model validation (Sitompul *et al*., 1996). Modifications were made to the core routines of the Century model to represent fractions similar to the measurable size-density fractions

(LUDOX method, Hairiah *et al.*, 1995). The results (Fig. II.4) show that good agreement between measured data and modelled estimates could indeed be obtained.

When the same model was used, however, for data of the KILLSOM/ADDSOM experiment at the BMSF station in the Lampung benchmark area, agreement between measured and modeled was less convincing (Fig. II.5); the experimental data contain a substantial scatter, indicating micro-variability not accounted for in the model. Simulations for *Peltophorum* inputs deviated more from measured points, possibly due to the effect of polyphenolic substances not yet accounted for in the Century model. Overall this experiment shows that none of the organic input treatments is able to maintain the soil organic matter level as it was at the start of the experiment, despite total inputs from litter of at least 8 Mg ha^{-1}. The main reason for this effect may be a lack of soil macrofauna incorporating litter into the soil -- nearly all inputs decompose at the soil surface and probably contribute little to soil C pools. The century model can be modified to include such effects of soil fauna, and this appears to be a priority area if a better prediction of land use effects on soil carbon pools is needed. Better predictions of soil carbon fractions, however, appear to be more relevant for 'sustainability' issues than they are for the total C balance. Changes in total carbon stocks are clearly dominated by changes in aboveground biomass and a better prediction of vegetation development is key to improved modeling of land use effects.

II.2 Greenhouse gas emissions

Measurements of the net flux of methane and nitrous oxide were made in a wide range of land use systems. Scaling up from point measurements to typical fluxes over the life span of a land use system (similar to the time-averaged C stock) is not yet possible, however. Day/night as well as seasonal rhythms have to be considered to derive annual flux data, which should be combined for the year of forest clearance and slash-and-burn, early re-growth etc.

Table II.2 summarizes the flux data obtained in the wet and dry season for the land uses of our current evaluation. Methane oxidation rates were higher in the dry than in the wet season. The low level of NH_4 and NO_3 in *Imperata* and cassava might have caused the low N_2O emission from those land-use systems. Data on N-mineralisation, therefore, have to be analyzed to explain the difference with nitrification or denitrification pathways. For the current analysis we explored the relationship between net methane flux and soil bulk density, and between nitrous oxide emission and soil mineral N concentration, both modified by water-filled pore space at the time of observation. Both relationships were weak, and may not form sufficient basis for extrapolation between measuring points. A further process-level analysis of causal factors is probably needed before GHG emissions can be linked to models such as the Century model.

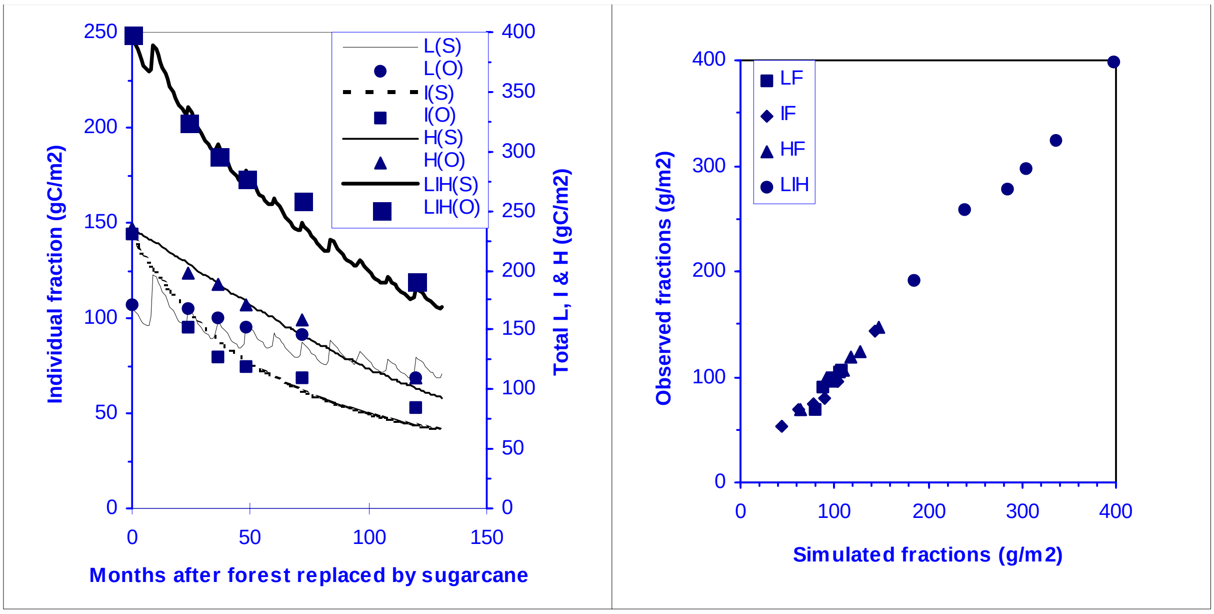


Figure II.4 *The dynamics of simulated (lines, S) and observed (points, O) for light (L), intermediate (I), heavy (H) and total macro-organic matter (LIH = L + I + H) fractions when lowland rainforest is converted to sugarcane (A), and the relationship between observed and simulated L, I, H & LIH fractions (B) within 0-20 cm depth under sugarcane. LIH = L + I + H*

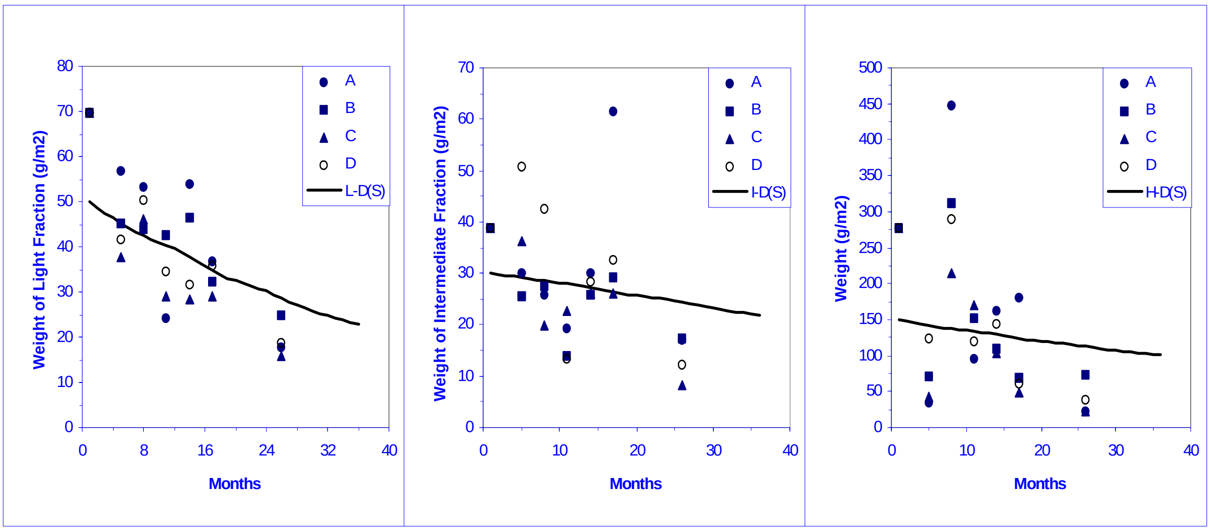


Figure II.5 *Modeled and measured fate of soil macro-organic matter fractions as part of a KILLSOM/ADDSOM experiment in Lampung (Hairiah et al., 1996), where Gliricidia litterfall is the main source of inputs; the overall decline is still a consequence of past conversion from forests and a lack of incorporation of organic inputs into the soil*

Data for methane oxidation and nitrous oxide emission can be compared on the basis of their 'net radiative forcing' (NRF) CO_2 equivalent values (26 and 206, respectively). It is obvious that removing above-ground carbon stock from forested land or tree-based system will have a greater effect on global warming than that caused by soil emissions. For the natural forest and rubber monoculture plots studied the overall effect on net radiative forcing is negative (this means less global warming, as more methane is oxidised than nitrous oxide emitted in NRF equivalents). For the other land uses nitrous oxide emissions will have a bigger impact on the greenhouse properties of the atmosphere than the methane oxidation.

The last two columns in Table II.2 make a tentative comparsion between the greenhouse gas fluxes of land uses per se, with the effects of land use conversions based on change in time-averaged carbon stock. When the difference in C stock is allocated to a 25 year time period, and the data are converted to units of mol C m^{-2} yr^{-1}, it becomes clear that changes in C stock will be one to two orders of magnitude larger than the emissions in the land uses on a stable basis. Obviously, the net climate effect for any land use when derived from lowland rainforest is strongly negative (for the first 25 years), while all land uses would have a substantial mitigating effect on climate change if they replace the *Imperata*/cassava cycle.

II.3 Belowground biodiversity

Data on belowground biodiversity indicators are summarized in Table II.3. For most parameters the differences between data collected in Jambi and those in Lampung were larger than those between different land uses within each of these benchmark areas. This is reflected in the probability values for the two 'main effects' (province and land use) in table II.3; for a number of parameters land use effects in Lampung differed from those in Jambi, reflected in a statistically significant interaction.

Table II.2 *Summary of net greenhouse gas emission effects from current land use (methane and nitrous oxide) and land use change (carbon, allocated to a 25 year period)*

Land use system	Time averaged C stock, Mg ha^{-1}	Mean seasonal net methane absorption, mg m^{-2} h^{-1}		Mean seasonal net N_2O emission, µg m^{-2} h^{-1}		Net radiative forcing (C equivalents) mol m^{-2} yr^{-1}		
		Wet	Dry	Wet	Dry	soil emissions	LU conversion (25 years) from forest	from *Imperata*
Natural forest	254	0.036	0.046	12.9	1.80	-0.03	0	n.a.
Community-based forest management	176	*	*	*	*	*	26	n.a.
Commercial logging	150	0.044	0.050	17.8	3.60	0.06	35	n.a.
Rubber agroforests	116	0.035	*	34.6	2.97	0.71	46	-26
Rubber agroforests with clonal material	103	*	0.029	*	3.06	0.61	50	-22
Rubber monoculture	97	0.009	0.060	6.1	0.43	-0.06	52	-20
Oil palm monoculture	91	*	*	*	*	*	54	-18
Upland rice/ bush fallow rotation	74	*	*	*	*	*	60	-12
Cassava/*Imperata* rotation	39	0.001	0.018	9.4	*	0.24	72	0

n.a.= not applicable
**= no data*

At first sight the effects of land use on belowground biodiversity appear to be much smaller than expected. Estimates of total population size for most microbial or soil macrofauna groups are remarkably similar, although there are indications of shifts between groups. For example, the *Imperata* grasslands have the highest densities of earthworms and mycorrhizal spores, while the forests have more ants and spiders in litter and soil samples (but not in the pitfall traps). The total number of soil macrofauna groups present in litter+soil samples was reduced in the Cassava+ *Imperata* samples, but for pitfall samples no difference was found and for mycorrhizal spore diversity the highest values were found for this land use type.

Table II.3 *Results of the surveys of indicators belowground biodiversity in five land uses of the lowland peneplain of Sumatra; the statistical model tested for differences between the two provinces (Lampung versus Jambi, confounded with a different sampling date (September versus November)), five land use categories (Forest, Agroforest, Rehabilitation (young tree-based systems), Cassava and Imperata, respectively) and their interaction. For data on soil fauna the model included a term for depth effects (surface litter and three soil layers), which is not reported here*

	Prob of F > value found			Means for land use types						
	Pro-vince	Land use	P * L	P	all	F	A	R	C	I
Total bacterial count (CFU g^{-1} of soil, log)	.0001	.057	.0003	L	3.34	3.48	3.41	4.03	2.49	3.32
				J	4.03	4.00	3.84	3.81	4.21	4.50
				J+L		3.80	3.65	3.94	3.18	3.71
Fungi (CFU g^{-1} of soil, log)	.0001	.0008	.0001	L	3.21	3.46	3.39	3.41	2.26	3.44
				J	4.28	3.31	4.10	5.05	5.40	5.11
				J+L		3.37	3.78	4.07	3.52	4.00
Respiration (mg CO2-C kg^{-1} day^{-1}, log)	.0001	.0001	.38	L	1.90	2.04	1.95	2.13	1.48	1.89
				J	2.65	2.83	2.70	2.56	2.33	2.54
				J+L		2.53	2.36	2.30	1.82	2.10
P-solubilizers (CFU, g^{-1} of soil, log)	.0001	.0323	.038	L	-1.49	-1.10	-1.80	-0.47	-1.46	-2.38
				J	.376	-.063	0.779	0.897	-.446	0.464
				J+L		-.528	-.510	0.076	-1.21	-1.43
Azotobacter (CFU, g^{-1} of soil, log)	.0001	.45	.0004	L	-.167	0.183	0.075	-.243	-1.060	0.036
				J	2.13	1.77	1.72	2.79	2.79	2.50
				J+L		1.17	0.98	1.28	0.59	0.91
Azospirillum (CFU, g^{-1} of soil, log)	.0001	.070	.33	L	0.70	1.19	0.417	0.819	0.645	0.416
				J	3.37	3.58	3.14	4.22	4.42	2.11
				J+L		2.22	2.18	1.67	2.53	1.02
Spores of mycorrhizal fungi (g^{-1} of soil, log)	.0001	.0001	.0001	L	5.15	4.97	4.80	5.18	5.89	4.96
				J	4.33	3.82	3.80	4.16	5.68	5.60
				J+L		4.25	4.24	4.80	5.81	5.17
Number of mycorrhizal fungal species	.0001	.0001	.0001	L	5.68	5.19	5.89	5.93	6.09	5.39
				J	4.72	4.07	4.08	4.39	5.93	6.89
				L+J		4.49	4.85	5.34	6.04	5.80
Active Soil Carbon indicator 1 (Microb population/C_{org})	.28	.59	.41	L	17	11	16	30	12	17
				J	21	15	24	18	29	26
				J+L		14	20	25	19	20
Active Soil Carbon indicator 2 (Microb population * C_{ref} / C_{org})	.15	.73	.33	L	43	27	41	82	27	41
				J	61	47	65	43	85	79
				J+L		39	55	66	50	54

PITFALL trappings of active surface fauna (number of individuals per pitfall during 2 days)

Ants (log)	.007	.15	.85	L	4.68	4.76	4.40	5.32	4.28	4.66
				J	5.48	5.56	4.71	6.35	5.41	6.06
				J+L		5.04	4.50	5.51	4.48	4.86
Spiders (log)	.002	.1793	.55	L	2.4	2.37	2.36	3.04	2.46	1.90
				J	3.05	3.02	2.56	3.61	3.26	3.31
				J+L		2.60	2.42	3.15	2.61	2.10
Beetles (log)	.0073	.0154	.77	L	2.54	3.64	1.87	2.98	2.14	2.20
				J	3.76	4.57	3.58	3.36	3.38	3.90
				J+L		3.97	3.39	3.05	3.36	2.30
Cockroaches (log)	.0023	.0021	.46	L	.35	-.03	-.33	.4	.97	.64
				J	.99	.73	.07	2.4	2.0	1.1
				J+L		.24	-.21	.76	1.16	.70
Crickets (log)	.0001	.0001	.57	L	1.93	1.02	.93	2.41	2.92	2.26
				J	3.16	2.71	2.24	3.36	4.47	4.63
				J+L		1.63	1.33	2.58	3.20	2.60
Number of groups per sample	.015	.313	.35	L	5.5	5.3	5.3	6.6	5.6	4.8
				J	6.7	6.6	7.0	6.0	8.0	5.5
				J+L		5.8	5.9	6.5	6.0	4.9

LITTER + SOIL macrofauna (the statistical model included a factor for depth not reported here), No. m^{-2}

Ants (log)	.73	.0020	.384	L	.26	.75	.39	.31	-.04	0
				J	.50	1.22	.20	.79	.31	-.24
				J+L		1.08	.26	.55	.16	-.12
Spiders (log)	.0001	.0025	.213	L	.25	.62	.79	.04	-.09	-.02
				J	-.32	-.14	-.33	-.29	-.51	-.44
				J+L		.09	.01	-.13	-.33	-.23
Earthworms (log)	.0023	.0064	.049	L	-.18	.15	-.36	-.26	-.55	.03
				J	.34	0	.23	.72	.33	.84
				J+L		.04	.06	.23	-.05	.44
Slugs (log)	.64	.176	.076	L	-.08	.17	.11	.17	0	0
				J	.14	.05	.07	.33	.42	0
				J+L		.08	.08	.25	.24	0
Other groups	.54	.040	.683	L	5.28	8.7	7.3	4.6	4.1	2.6
				J	4.01	5.7	4.8	5.4	1.3	1.3
				J+L		6.6	5.5	5.03	2.5	2.0
Number of groups per sample point	.0001	.0025	.223	L	3.33	4.3	4.0	3.3	2.4	2.9
				J	2.75	3.3	2.5	3.3	2.5	2.1
				J+L		3.5	3.0	3.3	***2.5***	***2.5***

In a further analysis of the data we only compared the *Imperata*/cassava land use (IC) with the three others (RAF). In that analysis we found a significant decrease in IC compared to RAF for respiration, P-solubilizers, woodlice (isopods) caught in pitfall traps and ats, spiders, cockroaches, crickets, 'other' and group diversity for the soil macrofauna. A statistically siginificant increase was found for mycorrhizal spore density and diversity and pitfall catches of cockroaches, slugs and crickets. For parameters such as earthworms an increase in *Imperata* was off-set by a decrease in cassava.

In the Lampung benchmark area detailed information was obtained on nematode genera (or families) in the five (ICRAF) land uses. Only for the plant-parasitic *Meloidogyne* nematodes did we find a significant ($p < .001$) effect of land use, with very high densities in the cassava fields, intermediate ones in the forested fields (RAF) and an absence in the *Imperata* fallow plots. For the other groups (*Rhabditida, Dorylaimida, Criconemoides, Tylenchus, Helicotylenchus, Rotylenchus, Monochus, Hoplolaimus, Scutelonema, Aphelenchus*) differences between replicate samples in the same land use were larger than those between land uses as a group, so the null-hypothesis of no land use effect was not rejected.

The number of rhizobia in the soil was estimated using a MPN method (Brockwell *et al.*, 1975) and three legumes *(Macroptilium atropurpureum, Pueraria phaseoloides* and *Glycine soja)* as host plants. Siratro-nodulating bacteria were found in only one location of forest, and mature agroforest, all three locations of young agroforest, two locations of cassava and two location of *Imperata* grasslands, while kudzu-nodulating bacteria were found in one location of forest, one location of mature agroforest, two locations of young agroforest, none of cassava and *Imperata* grasslands. There were no wild soybean-nodulating bacteria found in any locations in Lampung. In Jambi siratro-nodulating bacteria were found in two of the four locations of forest, one of the five locations of mature agroforest, one of the two locations of young agroforest, none of the two locations of cassava, and one of two locations of *Imperata* grassland. Kudzu-nodulating bacteria were found in two of the four locations of forest, more of the five locations of mature agroforest, one of the two locations of young agroforest, none in cassava and *Imperata* grasslands. Similarly, wild soybean-nodulating bacteria were not found in any locations in Jambi. The results thus indicate that in several locations land use systems are lacking suitable host legumes . Importantly, there were no indications of a relationship between occurrence of symbiotic N2-fixing bacteria and land use system. The occurrence of symbiotic N2-fixing bacteria seems to be influenced by the presence of suitable host legumes in the respective land use systems.

It may be that our conclusion of relatively small effects of land use on soil fauna is colored by the type of parameters measured. It is possible that greater differences would appear if more sensitive parameters were collected, e.g. specific groups of spiders and ants rather than the groups as a whole. Some evidence on much stronger response to land use change was collected as part of the intensive biodiversity survey in Jambi, where termite data were collected and sorted by trophic group (wood versus soil feeders). These (un-replicated) samples showed large differences between forest and agroforests on one hand and the cassava/*Imperata* plots in the other hand (Swift 1998).

II.4 Aboveground biodiversity

As part of the integrated survey of land use systems in the peneplains, aboveground biodiversity was assessed in terms of the richness of species and plant functional types (‘modi’) in standard-sized sample plots. In the data analysis a single vector ‘V index’ may be defined which gives a clear differentiation between *Imperata* grasslands as one extreme and natural forest as the other. The vector is composed of a large number of the plot-level measurements (Fig. II.6).

The V index classifies monospecific tree plantations with their associated ‘weeds’ as halfway on the scale between natural forest and *Imperata* grasslands, close to the vegetation of a logging ramp as part of logged forests. Old rubber agroforests are intermediate between logged and natural parts of natural forest, confirming earlier data on species richness (De Foresta and Michon, 1997). The V-index is based on a number of parameters, including basal area of trees, plant species richness and number of unique combinations (modi) of plant functional attributes (PFA). PFA diversity of rubber agroforests can equal that of natural forests, but the number of botanical plant species per modus is less. The data suggest that the ratio of botanical species and modi may be an informative single indicator of aboveground biodiversity of forests and forest-derived land covers. As may be expected, a good correlation exists between aboveground C stock and such indices of aboveground (plant) biodiversity (Fig. II.7).

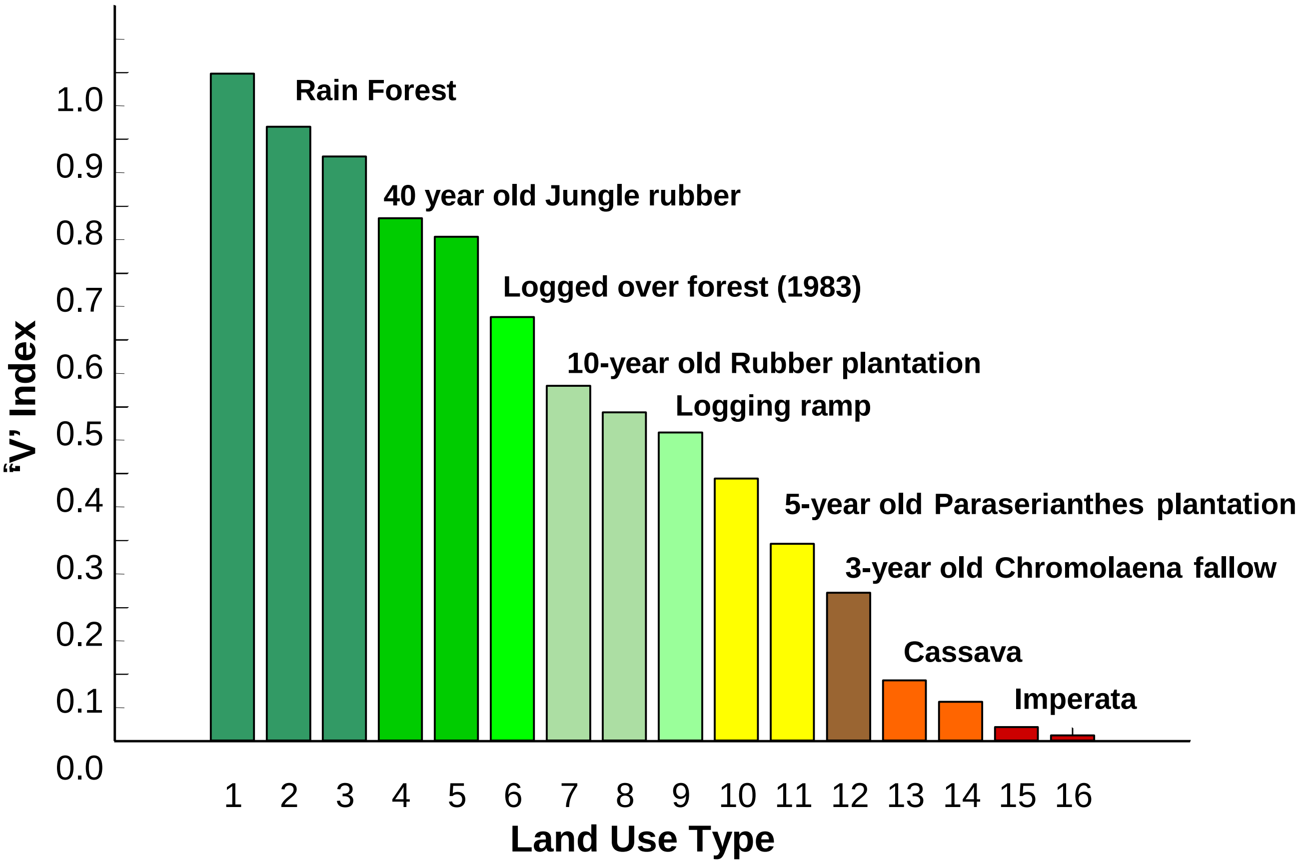


Figure II.6 *Overall classification of vegetation structure and plant biodiversity ('V' index) for intensive sampling points in Jambi; the V index is the most-discriminating single axis in multidimensional parameter space, which groups 'similar' plots*

II.5 Landscape level assessments

Some first steps were made towards landscape level diversity assessments, including diversity among different sample points in the same land use class. The basic question may be phrased as: are all forest sites the same ('if you've seen one forest you've seen them all') or do they contain more internal variation then human-derived land covers, with the *Imperata*/ cassava system as extreme.

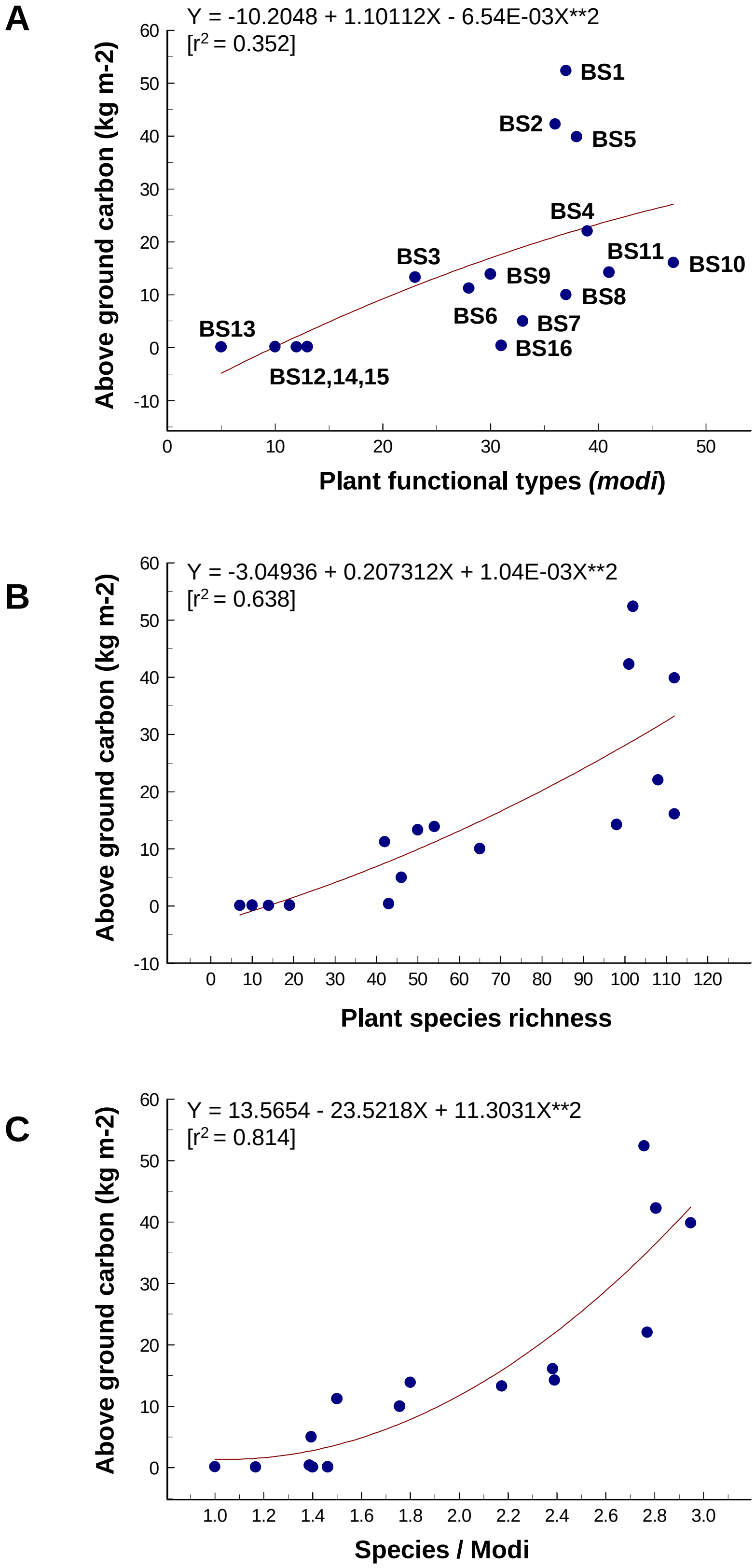


Figure II.7 *Comparative relationships between above-ground carbon, plant functional type richness, species richness and species / modi ratios along a gradient of land use types, Jambi, Lowland Sumatra*

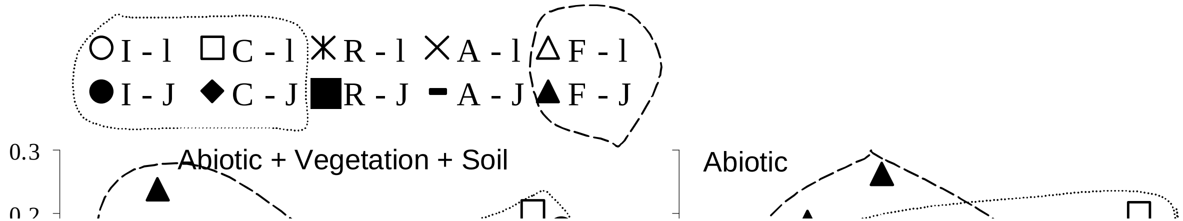


Figure II.8 *Ordination (showing the two first principal components) of sample points for all parameters in the integrated survey (abiotic + vegetation + soil) or different subsets of these parameters; the lines indicate the domains for forest sample points as natural background and Imperata + cassava as extremes of human modification, I= Imperata, C=Cassava, R= Rehabilitation (young AF system), A= Agroforest, F= Forest, L= Lampung (open symbols), J= Jambi (closed symbols)*

Figure II.8 presents the 31 points for the integrated survey, using different parts of the total data set for defining similarity among sample points. If only the abiotic soil parameters are considered, the area spanned by the forest points more or less coincides with that of the cassava/*Imperata* system, indicating that basic soil characteristics are probably little changed by forest conversion (upper right in Fig. II.8). The Lampung points (open symbols) fall in a different class than the Jambi points (closed symbols), and this dichotomy is conserved for all other parts of the data set. If the soil biological parameters are added to the abiotic soil descriptors (see lower right quadrant), the *Imperata*/cassava points stand a bit further out from the forest ones, but there are no simple tests of the statistical significance of such a difference. When the vegetation parameters are combined with abiotic soil descriptors (lower left), the cassava/*Imperata* points for Lampung are clearly outside the forest points, indicating that this conversion may have increased landscape level diversity. When all parameters are considered (upper left), distances are less pronounced.

The view that part of the 'savanization' (formation of grasslands) of forests can be seen as an increase of landscape level diversity is supported by analyses of large mammals in a landscape historical context. Boomgaard (1997) argued that large mammal populations initially benefited from human presence in forest landscapes.

The transformation of forests into agroforests may initially have added little to landscape level diversity, in the sense that all parameter combinations found in such agroforests are within the domain of natural forests. During this transformation, these agroforests have become a major reservoir for forest flora and fauna in the current landscape where natural forest has become scarce (Jambi) or near absent (Lampung). Current data indicate that old rubber agroforests indeed contain a substantial part of forest diversity. However, more detailed research on fern diversity (H. Beukema, research in progress) shows that the between-plot variation in species composition of natural forests is substantially larger than that for rubber agroforests, even if plot-level diversity is approximately the same. Translating the current plot-level assessments to landscape level statements about global environmental impacts is thus not a trivial exercise, which will need further attention in future assessments.

III. Sustainability indicators for land uses following forest conversion

A set of plot (field) level criteria and indicators was developed to evaluate the sustainability of a range of land use systems which can follow forest conversion (Weise 1998). Sustainability is a complex concept, as there are many reasons why certain land use activities can not be sustained. The original list developed for the ASB project (Van Noordwijk *et al.*, 1998) included criteria at field scale as well as ‘downstream’ and ‘down wind’ environmental effects of certain land use types. Effects of these externalities on broader notions of sustainability are beyond the scope of this phase of research, which is confined to field level sustainability criteria. The main issue then is whether or not farming activities degrade their resource base to a level that impairs future productive use of the land. Three major categories of threats to continued farming are considered:

- A. not maintaining soil of sufficient structure and biological activity,
- B. not balancing the budget of nutrient exports and imports,
- C. letting pest, weed and disease problems reach unmanageable proportions.

Any of these categories can become such a constraint to continued farming that land may have to be (temporarily) abandoned, therefore the most serious category of problems determines the overall sustainability.

For each of the criteria a number of indicators were developed which can be measured relatively easily, often using data already collected as part of the integrated survey of biodiversity, C stocks and greenhouse gas emissions. These measurements were made for specific land cover types (the FARCI (or ICRAF) series: forest (F), mature agroforest (A), young tree-based systems (R(egrowth)), long-term cassava cropping (C) and temporarily abandoned *Imperata* grassland (I)), in the Jambi as well as Lampung benchmark area. For the current purpose ‘land use systems’ have to be reconstructed from these measurements, as for example agroforests as a land use have an early as well as a mature phase. All measurements were made in the previously specified benchmark areas, and they thus contain the confounding effects of land use history and current management practices typical for the various actors. For example, continued production of food crops (cassava) is restricted to former transmigration settlements that were cleared from previous forest cover by bulldozer. Current levels of soil compaction may date back to this event regardless of the current land use, but this still forms part of a broader ‘syndrome’ of land use decisions.

No agricultural land use can consistently harvests produce without putting management efforts into maintenance of the system, so all judgements of sustainability depend on a specified management regime and farmer efforts to overcome obstacles. For each indicator a tentative threshold was developed, which allows a final judgement in three categories:

0 (RED) = Problems may get beyond the means of farmers to resolve

0.5 (AMBER) = Additional effort will be needed to address these issues, which may affect the profitability of the land use system, but may otherwise be within the farmer's management options

1 (GREEN) = No major problems beyond what normal farm management can deal with.

Before we discuss these indicators a certain ambiguity in the sustainability concept must be mentioned: the final criterion is the possibility to continue farming on a given piece of land, keeping all threats at manageable levels. Continued farming, however, may depend on the ability to change and develop a farm in new directions. Whereas certain land use practices, such as cultivation of very efficient nutrient scavengers such as cassava, may meet the criterion of persistence for a period of say 20 years, this practice is likely to reduce the number of future options, because the soil depletion it induced will require substantial re-investment in soil nutrient stocks before other crops can be grown. The current criteria refer to the field-level land uses per se, as these are measurable while a full land use transition matrix that can only be assessed by other means. We will come back to this in the final section of this chapter.

III.1 Soil structure and biological activity

The following indicators were used:

A1. **Soil compaction** as evident from soil bulk density (dry weight per unit volume) in the topsoil,

A2. **Soil carbon saturation**: organic carbon (Corg) content relative to that for forest soils of the same texture and pH**.** This criterion is based on a reference soil C level, Cref, which is estimated from regression analysis of a large soil data set for Sumatra (Van Noordwijk *et al.*, 1997):

$$\mathrm{Cref} = \exp(1.333 + 0.00994 \cdot \mathrm{Clay\%} + 0.00699 \cdot \mathrm{Silt\%} - 0.156 \cdot \mathrm{pH\text{-}KCl})$$

A3. **Active Soil Carbon** (ASC):

The globally proposed indicator based on microbial biomas relative to soil C could not be used because microbial biomass was not measured in a standardized way. Six other parameters are presented here, however:

- dry weight of light plus intermediate fraction for the LUDOX size-density fractionation procedure (Hairiah *et al.*, 1995),
- mineral ammonium and nitrate content of the topsoil during measurements,
- population count of total bacteria (colony forming units), relative to the Corg content (as suggested for the ASC indicator), and relative to the C saturation
- soil respiration (during lab incubation)

All six parameters can be judged against the values obtained for natural forest sites

A4. **Soil Exposure** (SE):

Number of months of low (< 75%) soil cover / length of system cycle in months

Available primary data for Lampung and Jambi are summarized in Tables III.1 and III.2. Bulk density data in Tables III.1 and III.2 refer to slightly different sampling depths, but indicate a clear difference between undisturbed forests and land under a cassava/*Imperata* cycle, with intermediate degrees of compaction under agroforests and other tree-based production system. Serious localized soil compaction was clear in logged-over forest where tracks and logging ramps were compacted beyond easy recovery. It is easy to compact a soil, but in systems without soil tillage it can take a long time before the soil recovers. Soil compaction can have an impact on water infiltration, root growth and greenhouse gas emissions, but probably stayed below critical levels in all cases observed. For a number of land use systems the overall rating is thus 0.5 (see table III.3).

The carbon saturation data show that no land use systems fully maintain the soil organic matter levels in the top soil of a natural forest (once corrected for soil texture and pH of the site; many values are above 1.0 as the equation for Cref was based on data for the top 10-15 cm of forest soils), but serious declines were only found for the cassava/ *Imperata* land use type, with the lowest values measured in cassava fields. Reductions of soil organic matter content to this range is evidence of substantial depletion of organic nutrient stocks in the soil and may affect soil physical properties as well as nutrient buffering against leaching. As with soil compaction, problems can be created much faster than they can be solved. For the A2 indicator only the cassava/*Imperata* cycle gets a warning flag (0.5 score). As mentioned before for soil compaction, the low current value of C saturation may have been partly due to reclamation history as well as current land use (bulldozer land clearing can remove part of the topsoil out of the field boundaries), but frequent fires, low organic inputs through cassava litterfall and frequent soil tillage can account for the low values found.

Table III.1 *Measured soil fertility indicators for the integrated biodiversity and GHG emission survey in Lampung (L) and Jambi (J) ASB benchmark area (September - November 1996)*

Land cover type (number of observations)	Bulk density 2-7 cm, g cm^{-3}	Corg/ Cref	Light + interm. fraction, g kg^{-1}	Ammonium	Nitrate	Bact. pop/ Corg	Bact. pop. * Cref/ Corg	Soil resp. mg CO_2 C kg-^{1} day^{-1}
Lampung	1.27	0.84	2.25	23	11	17	43	7.0
Jambi	1.09	1.05	3.86	14	12	21	61	15.3
Group 1	L	0 – 5	L	L	L + J	L	L	L
Forest (3)	1.17	1.54	3.22	40	18	12	27	7.9
Agroforest (4)	1.18	**1.16**	2.48	28	13	16	41	7.2
Regrowing trees (3)	**1.32**	**1.12**	2.60	**11**	**8**	30	82	8.6
Cassava (3)	**1.34**	***0.71***	**1.12**	**16**	**10**	12	27	**4.6**
Imperata (4)	**1.41**	**1.02**	**1.88**	**16**	**6**	17	41	**6.7**
Group 2	J	5 – 15	J	J		J	J	J
Forest (4)	0.91	0.97	7.18	18		15	47	17.9
Agroforest (5)	1.01	0.82	**3.07**	18		24	65	16.2
Regrowing trees (2)	**1.22**	**0.74**	**2.46**	**8**		18	43	13.1
Cassava (2)	**1.17**	***0.55***	**3.11**	**11**		30	85	10.6
Imperata (2)	**1.28**	**0.72**	**3.44**	14		26	79	14.0
Fprob LUT	<0.001	0.009	0.006	<0.001	0.011	NS	NS	?
LUT*Prov	<0.001	NS	0.021		NS	NS	NS	0.026
LUT*Depth	-	0.021	-	-	-	-	-	-
SED (interaction)	0.08	0.22	1.26	4..1	3.5	10		2.8

The various indicators of soil biological activity in Tables III.1 and III.2 may give a partially conflicting signal: the mineral N supply at the time of measurement was higher in the forest and mature agroforests than in other land uses, indicating that N supply from mineralization may have exceeded current N demand from the vegetation around the time of measurement (end of dry season); these same land uses had a relatively high respiration rate, but when estimates of total microbial population size are scaled by soil organic matter content or by C saturation, the 'active fraction' of the total soil organic matter pool in forests appears to have been lowest. On the basis of this evidence (and other data in the soil biodiversity survey) we conclude that there is no lack of active soil biota in any of the land uses, and *Imperata* grasslands are not 'depleted' ecosystems from a soil biological perspective, even though their soil organic capital has been reduced.

***Table III.2** Additional soil data from intensive biodiversity survey in Jambi (November 1997); data refer to duplicate samples per land cover type*

Land cover	Bulk density (0 - 5 cm)		Corg/Cref	Ground cover (kg m^{-2})			Land Use
	mean g cm^{-3}	Coeff. variab.	0 - 5 cm depth	Dead wood	Litter	Green biomass.	
Natural forest	0.68	0.224	1.37	12.73	1.33	0.07	Natural forest NTFP extraction
Logged-over Forest	0.77	**0.342**	1.20	13.40	1.18	0.02	Commercial logging
(Logging ramp)	**1.20**	0.181					
5 year old Timber Plantation	0.69	0.119	1.23	7.76	0.77	0.03	
40 year old Rubber AF	1.01	0.131	1.38	7.75	1.41	0.17	Rubber agroforests
10 year old Rubber Plantation	0.73	0.148	0.99	10.0	0.73	0.10	Rubber monoculture
							Oil palm monoculture
Chromolaena fallow	0.77	0.103	1.16	0	0.56	0.34	Upland rice/ bush fallow rotation
Cassava	**1.19**	0.069	**0.58**	0	**0.10**	0.20	Cassava/*Imperata*
Imperata	**1.23**	0.117	0.81	0	**0.05**	0.25	rotation

The indicator of soil cover (A4) requires inferences over the lifespan of the system rather than point measurements. The data in Table III.2 show that the nature of soil cover can shift from dead wood and leaf litter in forests to covers dominated by green biomass. Bare soil is rarely exposed in the landscapes of the peneplains. In all land use systems with a slash-and-burn land clearing event, soil may be exposed for about 6 months per cycle (or 2% of the time for a rubber system with a 25 year cycle). The only land use system where soil exposure may be an issue is the cassava/*Imperata* cycle where soil is exposed during the first 3 months of a cassava crop (unless heavily weed-infested or intercropped with crops such as rice, which is not possible at reduced soil fertility), and for about 1 month per year in all cases when the *Imperata* fallow is burned. Combined, this may lead to about 10% of the time with incomplete soil cover, when the soil is vulnerable to the direct impact of rain and sun.

Table III.3 *Sustainability rating of land use systems for Criterion A (maintenance of soil structure and biological activity); 1 = no major problems, 0.5 = problems within farmer management range, 0 = problems beyond what farmers can solve*

Land use system	A1 Compaction	A2 Carbon saturation	A3 Active soil C_{org}	A4 Soil exposure	Overall rating A	Comments on main issue which need attention
Natural forest	1	1	1	1	1	-
Community-based forest management	1	1	1	1	1	-
Commercial logging	0.5	1	1	1	0.5	Soil compaction in ramps and trails
Rubber agroforests	0.5	1	1	1	0.5	Soil compaction?
Rubber agroforests with clonal planting material	0.5	1	1	1	0.5	Soil compaction?
Rubber monoculture	0.5	1	1	1	0.5	Soil compaction?
Oil palm monoculture	0.5	1	1	1	0.5	Soil compaction?
Upland rice/ bush fallow rotation	1	1	1	1	1	-
Cassava/*Imperata* rotation	0.5	0.5	1	0.5	0.5	Soil compaction, low Corg, lack of soil cover

III.2 Nutrient balance

Three indicators were developed to judge whether the nutrient balance is (or could potentially be) maintained in a cropping system

B1. **Net Nutrient Export (NNE)** or nutrients contained in all harvested products minus those in fertilizer inputs for N, P, and K, in kg ha^{-1} year^{-1}. High net exports indicate the likelihood of depletion, high net surpluses, on the other hand, may indicate excessive fertilizer use and risks of pollution of ground- and surface water. Nutrient imports include fertilizers and N fixation through legumes in the system (none in the land uses considered here). For the net nutrient export, fertilizer inputs are taken at their nutrient value (Table III.4).

B2. **Nutrient Depletion Time Range (NDTR)** If nutrient stocks in soil and vegetation are large relative to net nutrient exports, nutrient offtake can be part of a wise natural resource management strategy; if exports are large relative to stocks, one can expect that yields will decline in the near future, unless nutrient inputs will be increased. Two types of estimates were used for nutrient stocks in the system: total nutrient content of soil *plus* vegetation and the directly available pool. Neither is directly satisfactory, as measures of the available nutrient pool necessarily use rather arbitrary fractions and there is considerable variation between plants in effectiveness of accessing 'non-available' nutrient sources. As nutrient stocks depend on the soil and vegetation cover, one can not directly assign an NDTR value to a land use system in the peneplains of Sumatra; the soils closer to rivers with a higher clay and silt content will have larger stocks than the sandier soils of the rest of the lowland peneplain. The values (Table III.5) only indicate an order of magnitude.

Table III.4 *Net Nutrient Export (NNE) based on partial nutrient budgets for different land uses (LU's}, based on yield and input data from farm profitability studies (Chapter IV)*

			OUT = harvest, kg ha^{-1} cumulative for 25 yr			IN = fertilizer, kg ha^{-1} cumulative for 25 year			In – Out kg ha^{-1} year^{--11}		
LU	Pro-ducts	Yield Mg ha^{-1}	N	P	K	N	P	K	N	P	K
NTFP harvesting	Various		0.02	0.002	0.03	0	0	0	0	0	0
Logging	Wood	13	63	6	38	0	0	0	-2.5	-0.2	-1.5
Rubber .AF	Rice	0.8	9	28	75						
	Rubber	11.8	78	96	428						
	total		87	124	502	0	0	0	-3	-5	-20
Rubber AF, improved	rice	0.8	9	28	75						
	rubber	28.6	189	234	1036						
	total		198	261	1111	74	50	0	-5	-8	-44
Rubber.monoculture.	rice	0.8	9	28	75						
	rubber	10.3	68	84	373						
	total		77	112	448	149	100	0	3	0	-18
Oil palm	palm oil	268	777	427	1656	2039	980	1794	50	22	6
Sh.Cult.long	rice	6	71	207	559	0	0	0	-3	-8	-22
Sh.Cult.short	rice	4	47	138	373	0	0	0	-2	-6	-15
Cassava	tuber	242	678	244	955	504	160	368	-7	-3	-23

1. Nutrient concentrations kg Mg^{-1}	N	P	K
Palm oil (bunch)	2.9	0.55	3.9
Rubber (DRC)	6.6	1.2	4.4
Cassava	2.8	0.36	3.9
Rice	11.8	2.9	2.7

NB Oil palm estimates based on removal of bunches without return of mill effluent; if fruits are sold instead of bunches, NPK exports will be lower

2. Fertilizer use kg ha^{-1}cycle^{-1} LUS	Urea	TSP	KCl
Rubber .agroforest	0	0	0
Rubber agroforests (int.)	165	250	0
Rubber monoculture	330	500	0
Oil palm	4530	4900	3900
Sh.Cult.long	0	0	0
Sh.Cult.short	0	0	0
Cassava	1120	800	800

Table III.5 *Nutrient Depletion Time Range.(NDTR) for the net nutrient exports of Table III.4 and an '**available**' nutrient stock of 800, 200 and 300 kg ha^{-1} of N, P and K, respectively, in vegetation, organic and directly accessible mineral forms in soil in a typical lowland rain forest of Sumatra's peneplains, and for a **total** nutrient stock (including less accessible pools in the soil) of 8000, 1200 and 3000 kg ha^{-1} respectively. NDTR has the unit time and indicates when nutrient stocks would be zero under a linear extrapolation of current trends. Negative net exports (inputs > exports) lead to negative NDTR values.*

	Av.Stock/(Out-In), (year)			Tot.Stock/(Out-In), (year)		
	N	P	K	N	P	K
NTFP harvesting	>10 000	>10 000	>10 000	>10 000	>10 000	>10 000
Logging	317	833	197	3175	5000	1974
Rubber AF	229	40	15	2290	242	149
Rubber AF clones	161	24	7	1614	142	68
Rubber monoculture	-281	424	17	-2814	2545	168
Oil palm plantation	-16	-9	-55	-159	-54	-545
Sh.Cult. long cycle	283	24	13	2825	145	134
Sh.Cult. short cycle	424	36	20	4237	218	201
Cassava	115	60	13	1152	358	128

Table III.5 shows that the substantial differences between the land use systems in net nutrient exports (Table III.4) are reflected in very different depletion trajectories. The nutrient where the most rapid depletion may occur is potassium (K). If only the directly available pool is considered, depletion within a 25-year time frame may occur for the rubber systems and shifting cultivation as well as cassava production. If total stocks are considered (at least part of non 'available' K can be accessed by plants), the time frame to depletion becomes several decades at least. For N no problems are to be expected for the land uses described here according to this calculation. However, our calculations do not include nutrient losses other than in harvested products and substantial N losses will occur during slash-and-burn clearing of forest lands, as well as by leaching during subsequent periods of low N demand by the vegetation relative to the N supply from mineralization. A more refined estimate would have to include the full spectrum of processes incorporated in the Century model (Palm *et al.*, 1998) and goes beyond the current sustainability assessment.

The nutrient balance calculations were based on the technical specifications used for the profitability assessments in part IV. For the cassava/*Imperata* cycle, a moderate use of fertilizer was assumed, below replacement level, but at least mitigating nutrient depletion. Many farmers in the benchmark area appear to use no fertilizer at all in this system, however.

For such no-input versions the nutrient balance is clearly negative. A clear trade-off may exist for this land use type between sustainability and profitability.

B3. The **Relative Nutrient Replacement Value (RNRV)** relates the export of nutrients in harvested products to the costs of replacing them into the agro-ecosystem in the form of chemical fertilizer. This assessment is based on the harvested products rather than the full production system, but refinements could be made in as far as nutrient recoveries depend on the system context. In the calculations for Table III.6 (long term) nutrient recovery of 25, 20 and 30% has been assumed for N, P and K, respectively, while N fixing trees (petai (*Parkia)* and jengkol (*Pithecelobium*), included in the Non timber forest products (NTFP) scenario) are assumed to derive two thirds of their N from the atmosphere.

***Table III.6** Relative nutrient replacement value for main products of various land use systems (Rupiah prices before July 1997); modified and extended from Van Noordwijk et al. (1997)*

	Nutrient removal, g/kg product			Nutrient replacement value Rp/kg	Farmgate value of product, Rp/kg	Relative nutrient replacement value (RNRV)
	N	P	K			
NTFP - rotan	2	0.2	1	10	20000	< 0.001
NTFP - petai/jengkol	5	0.5	5	24	500	0.05
NTFP - durian	3	0.3	6	28	1000	0.03
NTFP - others						< 0.001
Timber	2.5	0.25	1.5	13	108	**0.12**
Rubber (latex)	6.3	1.2	4.4	42	2000	0.02
Oil palm (bunches)	2.9	0.55	3.9	25	60	***0.41***
Rice	11.8	2.9	2.7	70	400	**0.17**
Cassava	2.8	0.36	3.9	22	50	***0.44***

The Nutrient replacement value is obtained as the sum of nutrient contents and replacement costs per nutrient for N, P and K (neglecting other nutrients):

Replacement price per nutrient exported, Rp/g	2.3	12	2.9
Fertilizer price, Rp/kg	260	480	400
Nutrient fraction of fertilizer	0.45	0.2	0.46
Nutrient recovery by the crop	0.25	0.2	0.3

Most RNRV values are below 10% and this indicates that nutrient replenishment would be within reach of farmers if, when and where actual nutrient responses of the crop make fertilizer use necessary. For rice the value is around 15% and this indicates a range were details of fertilizer use (and the various assumptions on efficiency made here) will be important for farmers' decisions on fertilizer use. For oil palm and cassava the RNRV values are around 45%, indicating that fertilizer costs would be a major part of the farm budget if farmers would have to balance the nutrient budgets (when the 'free lunch' of living off the initial stocks is over). The low RNRV values for both products are caused by their low farmgate price per kg product. For oil palm, marketing of fruits instead of bunches could considerably reduce the nutrient exports and, hence, the RNRV. For cassava only a shift in farmgate prices of the product and/or of fertilizers could make fertilizer use more attractive.

The overall judgement for criterion B thus highlights the difficulties in maintaining balanced budgets for cassava at current prices (and based on estimated technical coefficients and recoveries), and indicates a number of concerns for upland rice rotations, oil palm production and the proposed intensified rubber at reduced fertilizer input management. Where the overall evaluation indicates values in the critical range, a more detailed assessment is needed for different soils, management practices etc.

III.3 Crop protection from weeds, pests and diseases

For criterion C two indicators have been proposed, both based on 'expert opinion' rather than direct measurements:

C1. **Potential for Weed Problems**:

> Weed problems becoming a major constraint in the system, unless addressed by additional labour and/or technical input

C2. **Potential for Pest or Disease Problems**:

> Pest or disease problems becoming a major constraint in the system, unless addressed by additional labour and/or technical input

Weed problems are mostly related to *Imperata*, which is hard to control without herbicides (too expensive for smallholder food production) or ploughing (Van Noordwijk *et al.*, 1997). Damage by pigs and monkeys to new planting material can be a serious obstacle when clonal (more expensive) planting material is used, whereas the existing system tolerates substantial tree losses by planting at high densities at low costs per seedling. The natural regrowth of rubber agroforests is probably less problematic as a 'weed' than the grass or fern vegetation which develops under attempts at 'weed control'.

***Table III.7** Indicators of current and potential nutrient balance; NDTR = nutrient depletion time range; RNRV = relative nutrient replacement value; 1 = no major problems, 0.5 = problems within farmer management range, 0 = problems beyond what farmers can solve*

Land use system	B1 Net export	B2 NDTR	B3 RNRV	Overall Rating B	Comments on main issue
Natural forest	1	1.0	1	1	
Community-based forest management	1	1.0	1	1	
Commercial logging	1	1	1	1	
Rubber agroforests	1	1	1	1	
Rubber agroforests with selected planting material	0.5	0.5	1	0.5	Output increased at low input?; K supply needs attention
Rubber monoculture	1	1	1	1	
Oil palm monoculture	1	1	0.5	0.5	Assumed fertilizer rates may be too high; RNRV rating supposes fruits sold rather than bunches
Upland rice/ bush fallow rotation	1	0.5	0.5	0.5	Fertilizer use required for intensification
Cassava/*Imperata* rotation	0.5	0.5	0	0	Nutrient balance can not be attained at current prices; K in short supply?

***Table III.8** Indicators of problems with crop protection from weeds, pests and diseases;1 = no major problems, 0.5 = problems within farmer management range, 0 = problems beyond what farmers can solve*

Land use system	C1 Weeds	C2. Pests & diseases	Comments on main issue
Natural forest	1	1	no problems
Community-based forest management	1	1	
Commercial logging	1	1	
Rubber agroforests	1	1	
Rubber agroforests with selected planting material	1	0.5	pigs & monkeys at replanting; fungal diseases when sensitive clones are used
Rubber monoculture	0.5	0.5	fungal diseases, pigs and monkeys at replanting; ferns as ground cover may be problematic
Oil palm monoculture	1	1	
Upland rice/ bush fallow rotation	1	0.5	vertebrate and insect pests are a constraint
Cassava/*Imperata* rotation	0.5	1	*Imperata* fallows are a weed problem unless farmers have draught power available

III.4 Synthesis of sustainability indicators

When all indicators are combined (Table III.9) we derive the following assessment:

- most land use systems considered have one or more aspects which need attention, but most of these stay within the range of solvable problems at farm level,
- the cassava/*Imperata* cycle has a number of issues associated with it and one of them (maintaining a nutrient balance) is so serious that it can probably not be resolved at the farm level within the current constraints.

III.5 Land use change matrix

Sustainability as defined above indicates the degree of reproducibility of a land use system: does it maintain the conditions required for its own continuation? In the real world, however, it is unlikely that land uses will remain unchanged over more than one (or a few) human generations, and it may thus be interesting to evaluate which options are kept open with a given land use system (Table III.10).

Natural forest can be used as starting point for all land use types, but in a strict sense can only originate from forests; community-managed forests, some logging techniques and extensive rubber agroforests can lead to a return of a vegetation close to natural forests. On the other side of the spectrum, the cassava/ *Imperata* cycle can be started after any land use system, but forms a 'dead end', as it can not maintain its own productivity and it takes substantial efforts and expense (nutrient replenishment and *Imperata* control) to return to other (more profitable ands sustainable) land use types. The various tree-crop systems appear to be freely convertible into each other, but extensive rubber agroforests will change in character once the seedbank of original natural vegetation is depleted and the site is out of reach of seed dispersal. Table III.10 strengthens the conclusion that the cassava/*Imperata* system is the most problematic of the land use systems considered here.

***Table III.9** Overall assessment of sustainability of various land use systems for the peneplain of Sumatra (compare tables III.3, III.7 and III.8)*

Land use system	A1	A2	A3	A4	B1	B2	B3	C1	C2	**Over-all**	Main issues[1]
Natural forest	1	1	1	1	1	1	1	1	1	**1**	
Community-based forest management	1	1	1	1	1	1	1	1	1	**1**	
Commercial logging	0.5	1	1	1	1	1	1	1	1	**0.5**	C
Rubber agroforests	0.5	1	1	1	1	1	1	1	1	**0.5**	C
Rubber agroforests with selected planting material	0.5	1	1	1	0.5	0.5	1	1	0.5	**0.5**	C, K, W,P
Rubber monoculture	0.5	1	1	1	1	1	1	0.5	0.5	**0.5**	C,W,P
Oil palm monoculture	0.5	1	1	1	1	1	0.5	1	1	**0.5**	C, Fert
Upland rice/ bush fallow rotation	1	1	1	1	1	0.5	0.5	1	0.5	**0.5**	Fert, P
Cassava/*Imperata* rotation	0.5	0.5	1	0.5	0.5	0.5	0	0.5	1	**0**	C, Fert, W

1. C = soil compaction; K = potassium balance; Fert = price of fertilizer; W = weeds; P = pests and diseases

***Table III.10** Table of land use transformations that are feasible in a 20-50 year period; crosses indicate where transitions from one land use system to another are possible*

Land use system	1	2	3	4	5	6	7	8	9	Comment
1. Natural forest	X	X	X	X	X	X	X	X	X	Universal starting point
2. Community-based forest management	?	X	X	X	X	X	X	X	X	
3. Commercial logging	?	X	X	X	X	X	X	X	X	
4. Rubber agroforests	?	X	?	X	X	X	X	X	X	
5. Rubber agroforests with clonal planting material		?	?	X	X	X	X	X	X	
6. Rubber monoculture					X	X	X	X	X	
7. Oil palm monoculture					X	X	X	X	X	
8. Upland rice/ bush fallow rotation		X		X	X	X	X	X	X	
9. Cassava/*Imperata* rotation					?	?	?		?	Self incompatible, a 'dead end'