SOIL ASPECTS OF THE INDONESIAN BENCHMARK AREA OF THE GLOBAL PROJECT ON ALTERNATIVES TO SLASH AND BURN

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ABSTRACT

The global project on 'Alternatives to Slash and Burn' agriculture was initiated by a consortium of international and national research institutes to speed up intensification of the use of converted forest land, in order to help protect the remaining forest areas for their biodiversity values as well as role vis-a-vis greenhouse gas emissions. In the first phase of the project, benchmark areas were chosen and further characterized in Brazil, Cameroon and Indonesia. Data for the Indonesian benchmark areas on Sumatera are discussed here in the light of the hypothesis that 'Intensifying land use as alternative to slash-and-burn farming can help to reduce deforestation, conserve biodiversity, reduce net emission of greenhouse gasses and alleviate poverty'. We conclude that this hypothesis indicates only one of three necessary conditions. Apart from farmer-adaptable technologies, effective protection of the remaining forests is needed as well as a reduction of other driving forces of deforestation.

Benchmark areas were chosen in the lowland peneplain, piedmont and mountain zone of central Sumatra (in the provinces of Jambi and West Sumatra) and in Lampung. The latter represents higher population densities. Existing data were summarized for the purpose of the project and new data were collected on: vegetation, land use, soil type at family level, soil organic matter fractions, net flux of methane and a number of socio-economic indicators.

Traditional 'shifting cultivation' systems hardly exist any more in Sumatra, but slash-and-burn is widely used as technique for clearing forest land, mostly for planting tree crop based production systems (rubber, cinnamon). The past ten years have shown a significant amount of forest land converted to agricultural

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use in the two lowland peneplain benchmark areas, following after logging concessions. Soils on the peneplain are poor (oxi- and ultisols) and current intensive crop based production systems are not sustainable. In the piedmont zone outside the Kerinci Seblat National Park the lowland forest has been logged, but few migrants settled in the area, despite the better soil qualities (inceptisols) and a more stable rubber-based agroforestry system (still) characterizes the area. A new size-density fractionation scheme for soil organic matter revealed that the degradation of soil organic matter after forest conversion can be slowed down, but not halted, by the use of large amounts of organic inputs in the form of tree prunings. The tree component in such an 'alley cropping' system strongly competes with the crops, but yet is not enough to maintain the soil qualities of the original forest soil. Long term sustainability of land use is more likely under transformation to tree-based production systems.

Forest soils can be significant sinks for methane and thus partly compensate for the methane emissions in lowland rice production. After forest conversion, however, the methane sink strength is considerably reduced. An empirical correlation between methane sink strength and certain organic matter fraction deserves further testing. The net effect of forest on the methane balance may be their most important role in mitigating global warming due to emission of greenhouse gasses.

The discussion focusses on the need to combine intensification of land use at the field/household level with effective protection of remaining forest areas at the community level and reducing other driving forces of deforestation at the national level. Hypotheses for further research in phase 2 and 3 of the project are formulated.

1. INTRODUCTION

Human exploitation of forests and forest soils can be based on four types of 'products': non-timber forest products, timber, soil fertility after slash-and-burn, or the value of the deforested land as such. The damage done to the forest ecosystem and its 'environmental service functions' increases in this order and the last category is the most drastic one, permanently converting forests to other land uses. Interactions between these activities are common. For example, logging roads provide easy access to farmers opening the remaining forest by slash-and-burn methods. Slash-and-burn methods may be used both for the third (short term exploitation of soil fertility) or the fourth ((semi)permanent use of the land for farming) type of activity.

Slash-and-burn farming methods, especially of the third type, are generally viewed as having a low productivity for the amount of damage they do to forest resources (Sanchez *et al.*, 1990). The global project on 'Alternatives to Slash-and-Burn' (ASB) is built on the hypothesis that: 'Intensifying land use as alternative to slash-and-burn farming can help to reduce deforestation, conserve biodiversity, reduce net emission of greenhouse gasses and alleviate poverty'. The hypothesis thus implies type 4 activities on a small area as alternative to type 3 activities on a large area. In the first phase of the project a broad ranging 'characterization and diagnosis' activity was initiated in Brazil, Cameroon and Indonesia to test the relevance of this hypothesis. If and where this hypothesis is true research can have a strong 'agroforestry technology development' component, preferably in close cooperation with the land users. For conditions where the hypothesis does not seem to apply, we may need different types of activities to achieve the aims of reducing deforestation.

The underlying model for the intensification hypothesis is : $Y = 1/X$, where Y is the amount of land needed for a given amount of agricultural products (ha per kg of product) and X is the productivity per unit land of the agricultural system (kg of product per ha) (Fig. 1a). If we compare the rice yields in a true shifting cultivation system (say 1.5 and 0.5 Mg/ha in two years of cultivation, alternating with 28 years of fallow: this leads to $2/30 = 0.067$ Mg ha^{-1}) with the 10 Mg ha^{-1} that is possible in intensive irrigated rice fields (at least two crops of rice per year a 5 Mg/ha each, no fallow periods), we can easily see that intensifying rice from shifting cultivation to intense paddy fields allows a 150-fold increase in production per ha and a reduction of the amount of land needed to feed one person (say 250 kg per person per year) from 3.7 to 0.025 ha. This type of intensification, provided that it is technically possible, can thus reduce the land claims for agriculture and allow more forest to be conserved. But will it happen that way?

The first thing to note is that Fig. 1a assumed a constant 'demand' for agricultural products. Fig. 1b indicates that increased demand for production, e.g. due to population growth, can be met by area expansion (the vertical arrow), intensification (the horizontal arrow) or by mixed strategies. Intensification may thus help to keep up with growing demands (population size and demands per person) as alternative to area expansion, rather than actually allowing currently, used land to go back to more natural systems. There is an important school of theory stating that in fact intensification of land use will only start when all opportunities for area expansion have been utilized.

In the project documents ASB has emphasized two situations: 'forest margins' where active forest conversion occurs and 'degraded lands'. The links between these two situations are manifold:

- forest conversion for unsustainable land use systems can lead to land degradation and continued 'land hunger' for the remaining forest,
- more sustainable land use systems directly following forest conversion may thus reduce the rate at which degraded lands are formed and slow down forest conversion,
- intensified land use on degraded lands may be an alternative to forest conversion,but only if the remaining forests are effectively protected.

Guidelines and procedures were developed for 'Characterization and Diagnosis' for the global project (Izac and Palm, 1994). We will summarize results for the Indonesian sites here, with particular attention tot the soil-related aspects. For a broader account, including socio-economic and policy aspects, the reader is referred to Van Noordwijk *et al.* (1995).

Three aspects of soil organic matter (SOM) deserve attention in the context of the ASB project:

- SOM is important for the **sustainability** of food crops production in slash and burn practices via its role on: (a) N and P mineralization, (b) Al detoxification, (c) maintaining a 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, methanotrophe bacteria etc.

Measurement of total soil-C is adequate for evaluating C-stocks in the soil, but not for studying soil-C dynamics on a short term, as only a small part of the total C is responding rapidly.

2. MATERIAL AND METHODS

The global guidelines and procedures for 'Characterization and Diagnosis' (Izac and Palm, 1994) specify a stepwise approach to the choice of study sites based on stepwise stratified sampling, in order to extrapolate results in a later stage to the strata identified beforehand.

Benchmark area were chosen in the lowland peneplain, piedmont and mountain zone of central Sumatra (in the provinces of Jambi and West Sumatra) and in Lampung. The latter represents higher population densities. Existing data were summarized for the purpose of the project and new data were collected on: vegetation, land use, soil type at family level, soil organic carbon fractions, net flux of methane and a number of socio-economic indicators.

As part of the procedure, existing databases were analyzed. In the 1980's a coherent set of 1: 250 000 soil maps of Sumatera has been prepared by the Centre of Soil and Agroclimate Research (CSAR-AARD, Bogor), in the context of the LREP (Land Resources Evaluation and Planning Project) project. The data are stored in a soil database and were analyzed for the ASB project for the relation between soil organic matter content, soil type and land use (Van Noordwijk et al, *submitted*).

Preliminary measurements were made on methane and N_2O sources and sinks in various land use types derived from forest soils. Gas samples from a small sampling chamber (Murdiyarso *et al.*, 1994) were transported to Bogor in airtight bottles for analysis with a Gas Chromatograph. From a linear regression of concentration against time, the source (positive slope) or sink (negative slope) strength were derived.

Development and testing of improved soil management practices would be easier if more sensitive indicators for SOM dynamics were available. A size density fractionation 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 (Hairiah *et al.*, this volume). 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.

3. RESULTS

3.1 Indonesia as Benchmark Area

Indonesia was chosen to represent the humid tropical forest zone in Asia for the global ASB project. Indonesia still has large forest areas, but forest conversion to other land uses is rapid. The transformation from primary to secondary forest types is largely due to timber extraction, with a smaller rôle for traditional shifting cultivation systems. Subsequent transformation of secondary and logged over forest types generally is based on 'slash-and-burn' practices, by a variety of actors for a variety of reasons. Part of the forest is converted to (temporary) crop land, either in government sponsored schemes or by spontaneous migrants. These lands can evolve into *Imperata* grasslands (alang-alang) or into permanent tree-based production systems (agroforests or tree (crop) plantations). Both the 'forest margin' and the 'degraded land' focus of the global ASB project are relevant in Indonesia.

Characterization at the regional/national scale should identify broad agro-ecological-economic areas. The historical transformation of 'shifting cultivation' to 'permanent agriculture' has occurred at different rates in various provinces of Indonesia. Broadly speaking four groups can be distinguished (Fig. 2; Richards and Flint, 1993):

I. Java + Bali, where the transformation to permanent agriculture occurred before1880
II. North and West Sumatera and South Kalimantan, where the transformation was nearly complete by the middle of the 20'th century,
III. Most of Sumatra, where most of the transformation took place during the middle of the 20'th century,
IV. The rest of Kalimantan and Irian Jaya which are still in the early stages of the transformation.

It was decided to start the ASB project in Sumatra (group III), but Kalimantan and Irian Jaya may offer other perspectives in a later stage.

The next step was to identify 'benchmark areas', defined as 'homogenous areas in terms of the biophysical and general socioeconomic factors that influence slash and burn activities'. Sumatra is 350 km at its widest, almost 1 700 km long, and is cut in two roughly equal parts by the equator; the highest peak is Mount Kerinci (3804 m a.s.l.). Its total land area is 480 000 km^2. The agro-ecological zonation of Sumatra which has found the widest acclaim is the one given by Scholz (1983) in "The natural regions of Sumatra and their agricultural production pattern, a regional analysis" (Fig. 3).

Most of Sumatra is in the humid tropics. Oldeman *et al.* (1979) classified climatic regions in Sumatra according to the number of humid (> 200 mm of rain) and dry (< 100 mm of rain) months. Climate zones A (> 9 humid months, <2 dry), B (7-9 humid, < 2 dry) and C (5-6 humid, 3 dry) cover most of the island; drier climate zones D (3-4 humid, 2-6 dry) and E (<3 humid, up to 6 dry) occur especially in the northern part. Within Sumatra five major agro-ecological zones are identified with boundaries running from N.W. to S.E. approximately parallel to the coast:

1. a narrow Western coastal zone, the lower slopes of the mountain zone on the S.W. side, with various soil types; climate zones A and B;
2. a mountain zone, dominated by andosols and latosols of reasonable to high soil fertility; climate zones A and B and small patches of D and E;
3. a narrow piedmont (foothill) zone, the lower slopes of the mountain range on the N.E. side, dominated by latosols and red-yellow podzolics; climate zone B;
4. a broad peneplain zone, almost flat land with Tertiary sediments, deposited in the sea; at present its altitude is less than 100 m above sea level and it consists for about 10% of river levees and floodplains with more fertile alluvial soils and for 90% of uplands with a gently undulating landscape and mostly red-yellow podzolic soils; climate zone mostly B, with zone C in the S.E.;
5. a coastal swamp zone with peat and acid sulphate soils; climate zones C, D and E.

The zones 1, 2 and 3 contain the most fertile soils and have been inhabited for long periods of time. The coastal swamps and the peneplain were inhabited sparsely as human population was traditionally concentrated along the river banks on relatively favourable sites.

Since the beginning of 20th Century, population density in Sumatra increased also in the peneplain by transmigration from Java both spontaneously and sponsored by the government. A clear gradient in population density occurs from the South (Lampung) to the middle (Jambi, Riau) of the island. Although the major part of the land in Sumatra is considered to be government forest land, a substantial part of this land is no longer under forest cover. Figure 4 shows that the amount of 'forest damage' is correlated with population density at provincial level, with Riau and Jambi at one end of the spectrum and Lampung on the other.

In view of this zonation, five sites were chosen for detailed characterization for the ASB project (Table 1). In addition to the Sitiung and Air Dingin sites recommended by the original site selection team and were preliminary data collection has already started, these include two sites in Jambi province (one in the peneplain and one in the piedmont zone) and one in North Lampung (in the peneplain).

In the benchmark areas various groups of land users are important (Fig. 5). For the community scale characterization emphasis was given to indigenous farmers, spontaneous migrants and government-sponsored transmigrants, but also to their mutual interactions and interactions with 'white-collar absent farmers' and 'plantations' as far as these occur in the benchmark area. Figure 6 summarizes the stepwise selection process and the presumed extrapolation domains for the characterization data.

3.2 Effects of Land Use on Soil Carbon Content on Sumatera

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').

To judge the validity of the data for the current purpose, we have to consider how they were collected. For each map sheet aerial photographs and satellite images were interpreted for 'land forms' (physiographic). For each land form, a number of 'facets' (e.g. hill,slopes and valleys) were distinguished. For each facet a number of sample sites (pedons) was chosen (at random) and the soil profile was described in the field, soils were analyzed for texture and chemical characteristics and the current land use was recorded. The soil was classified according to the US Soil Taxonomy. The sampling procedure was thus a stratified random sampling with two levels of strata (land forms and facets). The total results may not reflect the true average values, as relatively rare pedons can be over-represented. Yet, this data set may be the best available for analyzing land use by soil type in Sumatra. Peat soils are of particular interest, as they contain about half of all organic C in all tropical forest soils of the world on only about 0.5% of the area still under tropical forests (Eswaran *et al.*, 1993). Peat soils thus contain 100 times the average C content per ha and 199 times the average of non-peat soils.

Figure 7 shows a classification of land use by soil type. 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'). For figure 7 the 70 land use types were combined into 5 groups: swamp vegetation (mostly forest), primary forest, secondary forest (including 'jungle rubber' systems), a group tentatively indicated as S&B series (including shrub-land, *Imperata* grasslands (alang-alang) and land currently used for annual crops) and a group with permanent crops (various tree crop plantations and sawah rice fields). The size of the circles in Figure 7 shows the number of data in the five soil groups. The Andisols form only 3.9%, the Histosols 10.3, the wetland soils 23.9 and both of the upland soil groups about 31% of the data set. Figure 7 shows that swamp vegetation is mostly (but not completely) restricted to the two wetland soil groups. Secondary forest is the most important group overall (41.3%). This group includes large areas of 'jungle rubber' (Gouyon *et al.*, 1993) and 'fruit tree enriched agroforests', which were not separately classified for the LREP study. Primary forest is only 8% of the three upland soil groups. The S&B series is remarkably evenly distributed over the soil types (15.7-26.8% of all non-swamp land use, with the lowest value for the Histosols and the highest for the two main upland soil types).

Nearly half of the Andisols (43.2%) is used for permanent cropping (mostly tree crops). On the other soils permanent crops represent 13.5-19.8% of the data set, with the lowest value for the Oxi- and Ultisols and the highest for the wetland soils (mostly sawah).

The group indicated as S&B group consists of annual crops and two vegetation types which may be interpreted as fallow land: shrub and *Imperata* grasslands. This interpretation is only a first approximation, as some of the shrubland, esp. on the wetland soils may be natural. Figure 8 shows the relative composition of the S&B series on the three upland soil types. Crops are 14% of the S&B series on the Oxi- and Ultisols (indicating an overall crop: fallow ratio of 1:7, a very rough estimate), 21% on the alluvial upland group (tentative crop: fallow ratio 1:5) and 29% on the Andisols (1:3.5). This ratios correspond with a trend of increasing soil fertility from the Oxi- and Ultisols to the Andisols. Interestingly, on all soils the area under *Imperata* grasslands is equal to the area used for annual crops. The ratio of permanently cropped land and the S&B series is lowest on the Oxi- and Ultisols (1: 2), highest on the Andisols (2:1) and intermediate (1.2:1) on the other soil orders.

The Histosols, which cover 10% of Sumatera, 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 (Incepti+sols) 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. 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 S&B 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 form 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.

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 (Fig. 9). 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. Sumatera in the early 1930's was similar to the average for the whole of lowland Sumatera, 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 (Fig. 10) 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 break down 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 2). 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 from zero. In this regression, the effects of altitude are studied separately from the different altitudinal 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 mechanisms 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:

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

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.

3.3 Soils, Land Use and C Balance in Benchmark Areas

For the ASB project about 5 000 ha in each benchmark area was mapped at the 1 : 50 000 scale. Field soil characterization was conducted along transects, based on the differences on land form, soil catena, and land use. Undisturbed soil and bulk samples were collected to determine the soil physical and chemical properties respectively. Table 3 summarizes the results.

The Bungo Tebo and North Lampung are dissected peneplains, consisting of acid tuffaceous sediments. The Sitiung is also a dissected peneplain and consists of acid clayey sediment alternating with acid volcanic tuff cover. The Rantau Pandan represents a piedmont area which was built mainly by granite and andesitic lava.

Soils in Bungo Tebo and Sitiung predominantly are very deep, well drained, very acid, and low soil fertility status. Soils in Rantau Pandan are more varied and complex than the ones in Bungo Tebo. The soils range from shallow to very deep, moderate to fine in texture, well to moderately excessive drained, very acid, and low soil fertility status.

Soils in North Lampung are very deep, well drained and very acid, with a low soil fertility status; iron concretions are often found within the soil profiles. Soil erosion has occurred throughout the area with various intensities depending on land management.

Dominant soil types are: Typic Hapludox in Sitiung, Typic and Oxic Dystropept (Rantau-Pandan), Typic Kandiudox (Bungo-Tebo) and Plinthic and Typic Hapludox (N. Lampung) (Table 3).

A forest map by Van Steenis (1935) shows that although the major part of the island was still under forest cover by that time, it started to look like an Emmenthaler cheese with big holes. Forest conversion by that time had taken place mainly in a) coastal zones, esp. Aceh, W. Sumatra, Bengkulu and Lampung, b) close to the major rivers in the eastern peneplain, esp. the Musi river in S. Sumatra and the Batanghari river in Jambi and c) N. Sumatra, the area of the plantation boom in the late 19'th, early 20'th century (tobacco, rubber, oil palm).

In 1982 forest conversion had affected most of the remaining forest in Lampung and South Sumatra, but in Jambi had not changed much in comparison with 1932 (FAO/MacKinnon, 1982). The completion of the Transsumatra Highway and associated Transmigration projects in the early 1980's would soon make their presence felt, however. The ASB-benchmark areas in Jambi are thus located in an area where forest conversion along the major rivers took place before the 1930's but which remained under forest cover at least until the early 1980's. The N. Lampung benchmark area neighbours on one of the few forest patches left in the Lampung-S.Sumatra part of the E. peneplain.

A vegetation map (scale 1: 250 000) for Sumatra has been published in three map sheets by SEAMEO-BIOTROP, based on Landsat MSS satellite data for the period 1983-1985. A description of the various vegetation types is given by Laumonier (*in press*). The vegetation description is based on natural vegetation (100 legend units, 82 for uplands and 18 for swamp vegetation) and cultivated types (21 legend units, often 'mosaics' of one or more crops and secondary vegetation).

Fig. 11 gives a flow scheme of the major vegetation types of interest to the ASB project. The upper part of fig. 11 shows the natural succession in a schematic form; volcanic eruptions, land slides, earthquakes and similar events will initiate a 'primary succession', leading to various forest types, depending on elevation and soil type. The central and upper part of fig. 11 show the various types of 'shifting cultivation', 'long rotation fallow' and 'short rotation fallow', where forest or shrub land is opened to grow food crops. The grass fallows which are formed, esp. after prolonged cropping, tend to be perpetuated by fire and can lead to an 'arrested succession' in the form of large ('sheet') alang-alang (*Imperata cylindrica* grasslands). The lower part of fig. 11 shows the major 'alternative to slash and burn' in Sumatra, in the form of 'agroforests' or man-made forests, with a large share of directly useful trees. These can be seen as the ultimate form of 'enriched fallow systems', in the sense that the trees planted in the fallow are the major source of income for the farmers and the food crops grown in the initial years are no longer the major 'raison d'être' of the land use system.

The 'agroforest' land use type has not been recognized in many of the previous descriptions. For example, the land use classification system proposed for Indonesia by Malingreau and Christiani (1981) and used in the LREP project only recognizes 'taungya' type tree plantations with food intercrops as 'agroforestry'.

Fig. 12a shows the vegetation/land use types of the three benchmark areas according to the 1986 vegetation map. Figure 12b shows the new situation in 1994. Figure 13 gives the changes in land cover for Jambi province as a whole for the 1986-1992 period.

By overlaying the digitized images from 1986 (Laumonier *in press*) and Landsat TM images of 1992 or 1994 the ILWIS software gave the change in land use in tabular form indicating the change of vegetation types and their areas. The most severe change from primary forests into secondary types occurred in the limestone forest (92%), followed by lowland (13.6%), montane (12.3%), hill (9.07%), and submontane forest types (6.65%). Less frequent primary forests was directly (or at least within a 6-year period) converted into cultivated types. In swamp forest this happened on 11.3 % and in lowland forest on 6.5% of the area. Most cultivated areas were formed from logged-over lowland forest (22.7%) and logged-over swamp forest (9.8%). Logged-over peat swamp forests remained unchanged. Direct change from logged- over forests into grassland was very rare i.e. 0.02 percent for lowland, 0.1 percent for swamp and none for peat swamp. The study indicated that the rate of deforestation in Jambi involved 30 percent of the primary forest covering an area of about 400,000 ha. During the period of 1986 - 1992 forest conversion in Jambi was mostly from logged-over forests and it is very likely that slash and burn agriculture was responsible for most of the carbon released. It may be assumed that conversion of forest land to permanent agricultural has reduced the carbon stock by burning the biomass.

The estimated land use change obtained from the tabulated data can be used to estimate the changes in the above-ground biomass per unit area (Murdiyarso and Wasrin, 1995). Estimates of the amount of carbon in each vegetation type were used to calculate a matrix of carbon change after land use conversion. The change in above-ground biomass is the most important component of this change. The conversion of biomass into amount of carbon held in the vegetation follows the method proposed by Houghton *et al.* (1983) where the amount of carbon held in the vegetation is 49 percent of the volume over bark (VOB) or 50 percent of the biomass.

The largest change occurred in the conversion of secondary forests and logged-over forests into cultivated areas, involving areas of 4,386,110 ha and 2,363,000 ha, respectively, or 43.5 and 21.2 percent of the initial areas.

During the six year period 1986-1992 the amount of carbon released from land use changes in Jambi was 176,403,000 ton or 29,400,000 ton/yr. In comparison with country by country estimate of 0.19 Gt C/yr for Indonesia (IPCC, 1990), Jambi has contributed some 16 percent. This is much more than proportional to its surface area and 2.9 t C ha^{-1} yr^{-1}.

Similarly, table 4 estimates the net C emission or sink strength for the three main [illegible]B benchmark areas for the period 1986-1994. The Rantau Pandan benchmark may have been a net C sink (3.1 t C ha^{-1} yr^{-1}), as the jungle 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 (6.8 and 9 t C ha^{-1} yr^{-1}).

3.4 Effect of Burning on Nutrients and Soil Organic Matter

In the North Lampung benchmark area data were collected on the direct effects of burning on ash and soil nutrient content (Table 5). The ash layer was sampled separately for the top 3 cm and anf the 3-5 cm layer. It consisted of burned plant material, fine charcoal and as well as true ash. The table shows that soil pH was increased by at least two points, due to accumulation of base cations came from burnt above ground biomass. Exchangeable cation content as well as available P content increased dramatically.

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) contents. As total soil organic matter content is a poor indicator of functional pools, attempts are made at fractionation. A new size-density fractionation scheme for soil organic matter (Fig. 14, Hairiah *et al.*, this volume) showed large differences between forest soil (both before and after a burn) and soil of 9 year continuous cropping. Intermediate values were obtained for hedgerow intercropping plots, where frequent application of tree prunings was slowed down the soil degradation. The data show, however, that the degradation of soil organic matter after forest conversion can not be completely avoided by this practice. The trees with the highest polyphenolic content of the prunings (*Calliandra* and *Peltophorum*) have the largest heavy pool, which indicates soil carbon closely linked with mineral particles. Further tests of the functional significance of these pools for N and P mineralization are underway.

Although the tree component in such a system can help to maintain soil fertility, the 'hedgerow intercropping' or 'alley cropping' system has not lived up to the expectations that it would be a 'stable alternative to shifting cultivation' (Sanchez, 1995). The competition effects of trees on the crops often exceed the direct positive effects of maintaining soil fertility. The soil improvement can only be fully utilized by the crop after the hedgerows have been removed. Long term sustainability of land use is more likely under transformation to tree-based production systems where trees provide a major part of the cash income, rather than only playing a supportive role in crop-based production systems.

3.5 Methane (CH_4) Oxidation and N_2O Emission in Forest Soils

Figure 15 shows that, at least in the dry season, secondary and logged-over forest and rubber plantations 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.

Initial data on N_2O emission are shown in table 6. 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.

3.6 Intensification effects on the C balance

We may now revisit the links between soil productivity and global C balance suggested by Sanchez *et al.* (1991), by quantifying the effects of replacing slash-and-burn farming by more intensive crop production systems. To do so, we will use the following parameters:

C_F = C stock of natural forest, averaged over its cycle length [Mg ha^{-1}],
C_S = C stock of shifting cultivation system, averaged over its cycle length [Mg ha^{-1}],
C_c = C stock of [permanently cropped field,averaged over its cycle length [Mg ha^{1}],
a_c = part of total area needed for permanent crop production,
a_s = part of total area needed for shifting cultivation,
P_c = crop production rate of permanently cropped field [Mg ha^{-1} $year^{-1}$],
P_s = crop production rate of shifting cultivation system [Mg ha^{-1} $year^{-1}$],
P_{sc} = crop production rate of cropped part of shifting cultivation cycle [mg.ha^{-1}.$year^{-1}$],

f_r = fallow: crop ratio of shifting cultivation system.
P_s and P_{sc} are related by $P_s = P_{sc}/f_r$.

If a constant crop productivity is required from either permanent cropping or shifting cultivation, we obtain:

$$a_c = \frac{a_s\ P_{sc}}{f_r\ P_c} \qquad 1$$

If the area not used for shifting cultivation or permanent cropping is covered by natural forest, we obtain for the total C stock associated with shifting cultivation, C_{ts}:

$$C_{ts} = C_f\ (1 - a_s) + a_s\ C_s = C_f - a_s\ (C_f - C_s) \qquad 2$$

and for the total C stock associated with permanent cropping, C_{tc}:

$$C_{tc} = C_f\ (1 - a_c) + a_c\ C_c = C_f - a_c\ (C_f - C_c) \qquad 3$$

Substituting (1) into (3):

$$C_{tc} = C_f - \frac{a_s\ P_{sc}}{f_r\ P_c}\ (C_f - C_c) \qquad 4$$

The C benefit of changing to permanent cropping and protecting the natural forest can now be calculated from:

$$C_{tc} - C_{ts} = a_s\ [\ C_f\ (1 - \frac{P_{sc}}{f_r\ P_c}) - C_s + C_c\ \frac{P_{sc}}{f_r\ P_c}] \qquad 5$$

This difference is positive if:

$$\frac{C_f - C_s}{C_f - C_c} > \frac{P_{sc}}{f_r\ P_c} \qquad 6$$

This condition will normally be met. For example, if C_f is around 400 Mg ha^{-1}, C_s is 200 Mg ha^{-1}, C_c = 50 Mg ha^{-1}, f_r = 10 and $P_{sc} = P_c$, the inequality reads 0.57 > 0.1. For a moré intensive fallow rotation with f_r = 3, C_s = 100 Mg ha^{-1} and P_{sc} = 0.8 P_c, it reads 0.86 > 0.26.

If land not necessary for shifting cultivation is left under natural forest, an intensification of crop production thus indeed leads to an increased C storage in terrestrial ecosystems. However, permanent crop production depends on fertilizer inputs, to replace soil organic matter's role of nutrient supply; this fertilizer supply is based on an annual fossil fuel consumption, of X Mg ha^{-1} $year^{-1}$. Also, fossil fuel use will have to replace the fuelwood collected from the fallow vegetation previously, to the amount of Y Mg ha^{-1} $year^{-1}$. The initial advantage of the permanent cropping will thus turn into a disadvantage after $(C_{tc} - C_{ts})/(X + Y)$ years. Stimulating the transformation of shifting cultivation systems into more intensive permanent cropping systems, thus only gives a temporary benefit for the global C budget, which after some time will turn into a loss. The positive effect on biodiversity conservation of maintaining larger areas of natural forest along with more intensive crop production can be a lasting effect, however.

4. DISCUSSION

We will now come back to the central hypothesis that 'Intensifying land use as alternative to slash-and-burn farming can help to reduce deforestation, conserve biodiversity, reduce net emission of greenhouse gasses and alleviate poverty'.

Traditional 'shifting cultivation' systems hardly exist any more in Sumatra, but slash-and-burn is widely used as technique for clearing forest land, mostly for planting tree crop based production systems (rubber, cinnamon). The past ten years have shown a significant amount of forest land converted to agricultural use in the two lowland peneplain benchmark areas, following after logging concessions. Soils on the peneplain are poor (oxi- and ultisols) and current intensive crop based production systems are not sustainable. In the piedmont zone outside the Kerinci Seblat National Park the lowland forest has been logged, but few migrants settled in the area, despite the better soil qualities (inceptisols) and a more stable rubber-based agroforestry system (still) characterizes the area.

The intensification model of Fig. 1 probably holds if 'all other things are equal'. But not necessarily if total demand is increasing.

An important reason that local demand can increase is migration, either spontaneous or government sponsored. This brings us to the main lesson from Sumatera for the global ASB project. The experience of the rubber agroforests in Sumatera, which go back to the start of the 20'th Century, shows that:

a) economically attractive tree based production systems exist as alternative to extensive food-crop based systems,
b) they do help to alleviate poverty, but
c) they speed up rather than slow down the rate of natural forest conversion, especially because they attract an inflow of migrants who want to share the benefits of such systems.

Other reasons under which the central ASB hypothesis would not hold true are that other factors than the need for agricultural products may be the main driving force of forest conversion, such as logging, mining or land speculation and the privatization of formerly communal land. In the Minangkabau area of West Sumatera and Jambi (and possibly elsewhere) this privatization is based on slash-and-burn practices followe... y tree planting; this may be a major reason for the existence of extensively managed 'jungle rubber'.

In summary, we can conclude that three requirements can be formulated for the intensification hypothesis:

1. The intensification techniques must be ecologically and agronomically sound, socially and economically feasible and lead to marketable products,
2. The forest which is supposed to be saved from conversion by this intensification must be effectively protected and boundaries enforced,
3. The inflow of people from elsewhere must be brought under control.

Increased involvement of local communities in forest management may help to address both issue 2 and 3. Hypotheses for further research in phase 2 and 3 of the project are formulated (Table 7) and will be tested in the coming years.

ACKNOWLEDGEMENTS

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REFERENCES

ESWARAN, H., E. VAN DEN BERG, and P. REICH, (1993): Organic carbon in soils of the world. Soil Sci. Soc. Am. J. 57: 192-194.

GOUYON A., H. DE FORESTA, and P. LEVANG, (1993): Does 'jungle rubber' deserve its name? An analysis of rubber agroforestry systems in southeast Sumatra. Agroforestry Systems 22, 181-206.

HARDON, H.J., (1936):. Factoren, die het organische stof- en het stikstof-gehalte van tropische gronden beheerschen (Factors, controlling the organic matter and the nitrogen content of tropical soils). *Landbouw XI(12) :* 517-540.

HAERUMAN, H., (1992): Pembangunan dan keadan sumberdaya alam hutan di Sumatera [Development and condition of natural forest resources in Sumatera]. pp16-26 in: Biotrop Special Publication No. 46, SEAMEO-BIOTROP.

HAIRIAH, K., G. CADISCH, M. VAN NOORDWIJK, A.R. LATIEF, G. MAHA-BHARATA, and SYEKHFANI, (1995): Size-density and isotopic fractionation of soil organic matter after forest conversion. *This symposium.*

HOUGHTON, R.A., SKOLE, D.L. and LEFKOWITZ, D.S., (1991): Changes in the landscape of Latin America between 1850 and 1990. II. Net release of CO_2 to the atmosphere. For. Ecol. management 38, 173-199.

IZAC, A.M. and C.A. PALM, (1994): Guidelines for characterization and diagnosis for the global project on alternatives to slash-and-burn. ICRAF, Nairobi.

LAUMONIER, Y., (1995): The vegetation of Sumatra. *in press*

MEIJBOOM F.W., HASSINK J. and VAN NOORDWIJK, M., (1995):. Density fractionation of soil macroorganic matter using silica suspensions. Soil Biol. Biochem. .., ..-..

MURDIYARSO, D.M., K HAIRIAH, K. and M. VAN NOORDWIJK, (Eds.): Modelling and Measuring Soil Organic Matter Dynamics and Greenhouse Gas Emissions after Forest Conversion. Proceedings of Workshop/ Training Course 8-15 August 1994, Bogor/Muara Tebo. ASB-Indonesia publication No. 1.

RICHARDS, J.F. and E.P. FLINT, (1993): Historic land use and carbon estimates for South and Southeast Asia, 1880-1980. Carbondioxide information analysis center, Oak Ridge National Laboratory, Environmental Sciences Division Publication No. 4174. 326 pp.

SANCHEZ, P.A., C. A. PALM, and T. J. SMYTH, (1990): Approaches to mitigate tropical deforestation by sustainable soil management practices. **In: SCHARPENSEEL, H.W., SCHOMAKER M. and AYOUB A. (Eds.):** Soils on a Warmer Earth. Elsevier, Amsterdam. p. 211-220.

SANCHEZ, P.A., (1995): Science in agroforestry. Agroforestry Systems 30: 5-55.

SCHOLZ U., (1983): The natural regions of Sumatra and their agricultural production pattern. A regional analysis. Central Research Institute for Food Crops (CRIFC). Bogor.

VAN NOORDWIJK, M., T.P. TOMICH, R. WINAHYU, D. MURDIYARSO, S. PARTOHARJONO and A.M. FAGI (Eds.), (1995): Alternatives to Slash-and-Burn in Indonesia, Summary Report of Phase 1. ASB-Indonesia Report Number 4, Bogor, Indonesia

VAN NOORDWIJK, M., C. CERRI, P. L. WOOMER, P, K. NUGROHO, and M. BERNOUX, (1995): Soil carbon dynamics in the humid tropical forest zone. Geoderma (*submitted*)

Table 1: Site selection for characterization and diagnosis activities by ASB-Indonesia

Benchmark Area	Ecological Zone	Main Focus in ASB	Population density relative to resources
Air Dingin, W. Sumatra	Mountain	Buffer zone of National Park (KSNP) in highlands	High, emigration
Rantau Pandan, Jambi	Piedmont	Buffer zone of National Park (KSNP) in piedmont, rubber agroforests, traditional shift. cult.	Intermediate
Sitiung, West Sumatera	Piedmont/ peneplain	Transmigration villages interacting with local farmers	Intermediaterecent immigration
Bungo Tebo, Jambi	Peneplain	Forest margin: spont. settlers, transmigrants	Low, immigration
North Lampung	Peneplain	Degraded land rehabilitation as alternative to migration	High, immigration + emigration

KSNP = Kerinci Seblat National Park

Table 2: Multiple linear regression of $\log(C_{org})$ for Sumatera 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)

Table 3: Relative area (%) covered by the four great soil groups in the detailed soil maps of the four benchmark areas

Great groups		Rantau-pandan	Sitiung	Bungo-Tebo	North Lampung
Entisols		12	7	11	7
Inceptisols	88	-	-	29	
Ultisols		-	62	-	-
Oxisols		-	31	89	64

Table 4: Estimated total C balance of three benchmark areas for 1986 - 1994 period (8 years)

	Area (ha)	C-loss (t)	C-gain (t)	Net C-loss (t) ($t\ C\ ha^{-1}\ yr^{-1}$)
Rantau pandan	63,73	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

Table 5: Chemical properties of forest soil before and after burn in N. Lampung.

layer cm	pH		C-org %	P-Olsen mg kg^{-1}	K	Ca	Mg
						cmol$_e$ kg^{-1}	
	H_2O	KCl					
Before burn:							
0 - 5	6.2	4.7	2.44	5.0	0.20	1.44	0.62
5 - 10	5.6	4.6	2.12	2.0	0.20	1.85	0.52
After burn:							
0 - 3	8.1	7.5	7.55	51.4	5.37	25.5	4.47
3 - 5	8.3	7.2	4.28	25.6	2.02	14.8	3.46
5 - 10	7.2	6.0	1.94	6.7	0.29	3.12	0.63
Soil surface ash				384	176	23.6	17.6

Table 6: Preliminary N_2O emission data (mg m^{-1} 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

Table 7: Hypotheses for phase-2 research of ASB-Indonesia

I. Hypotheses on dynamics of land use change and poverty

1. Intensified land use by local farmers in already converted forests can, in the absence of immigration, alleviate pressure to convert remaining local forest,
2. Intensified land use in already converted forests or degraded lands can reduce the 'poverty push' to migrate to new forest margins,
3. Local community involvement in forest management, including logging, can reduce the 'pull' attracting migrants ('forest squatters'),
4. The combination of cheap labour, via recent (trans)migrants, abundant land access to local people and profitable (tree) crops accelerates forest conversion
5. Where communal forest land has to be cleared before it can be claimed by individual families, this tenure arrangement accelerates forest conversion,
6. Technical options for intensification exist for all but the most marginal soils,
7. Improved market access, physical as well as economical, is a key to intensified land use, esp. on 'marginal' soils,
8. 'Protection' and 'conservation' forests have to be actively protected and conserved by (external) stakeholders from local exploitation; 'bufferzone agroforestry' by itself is not enough to achieve such protection.

II. Hypotheses on greenhouse gas emissions and sinks

1. Upland forest soils can be a considerable sink for methane,
2. Burning forest vegetation, esp. logs, can produce considerable amounts of methane,
3. The source/sink relations of land use systems for methane are more important for the global climate than the source/sink relationships for carbondioxide

III. Hypotheses on biodiversity conservation

1. The biodiversity values of low-management intensity systems, such as jungle rubber, can be largely maintained while productivity is increased, if more productive rubber germplasm is introduced
2. Intensifying management intensity in agroforests such as jungle rubber systems leads to a large loss of biodiversity and only moderate gains in productivity
3. Soil biodiversity and active soil organic matter fractions can fall below critical levels during intensification of land use

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Figure 1. A. The amount of land needed for agricultural production is the inverse of the productivity per ha; thus 'land use intensification' can contribute to forest protection. B. Increase in production can be achieved by both area expansion and intensification

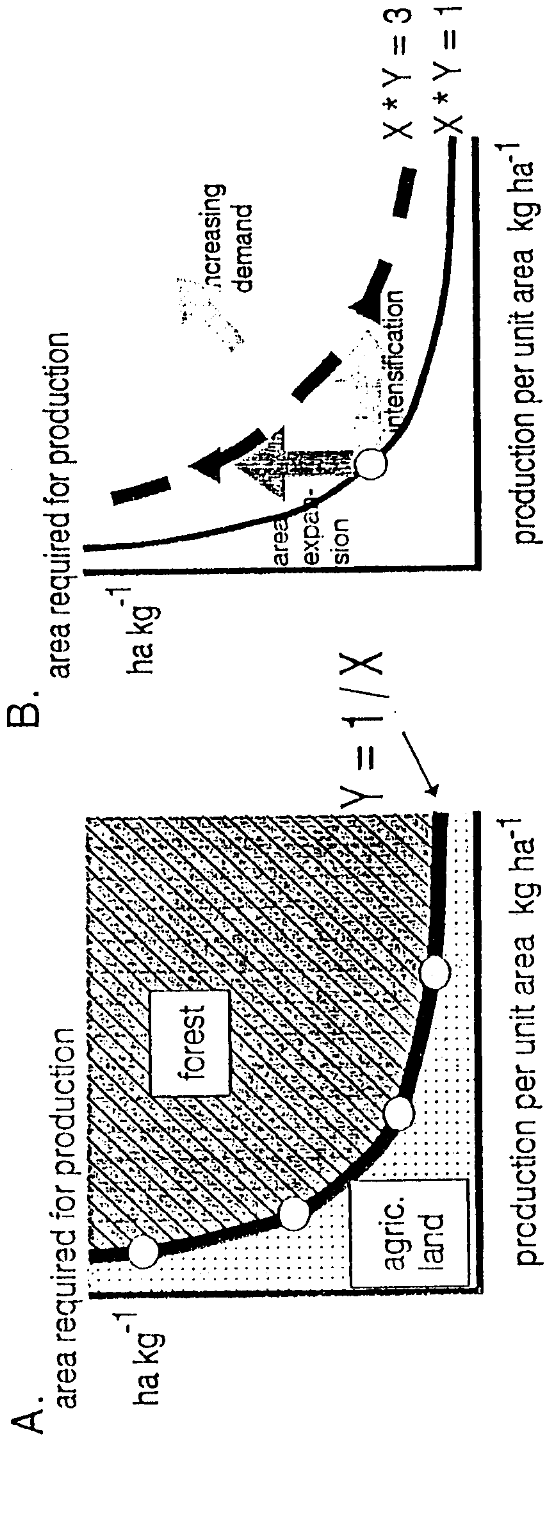


Figure 2. Historical transition of shifting cultivation into permanent agriculture for different provinces of Indonesia, according to Richards and Flint (1993)

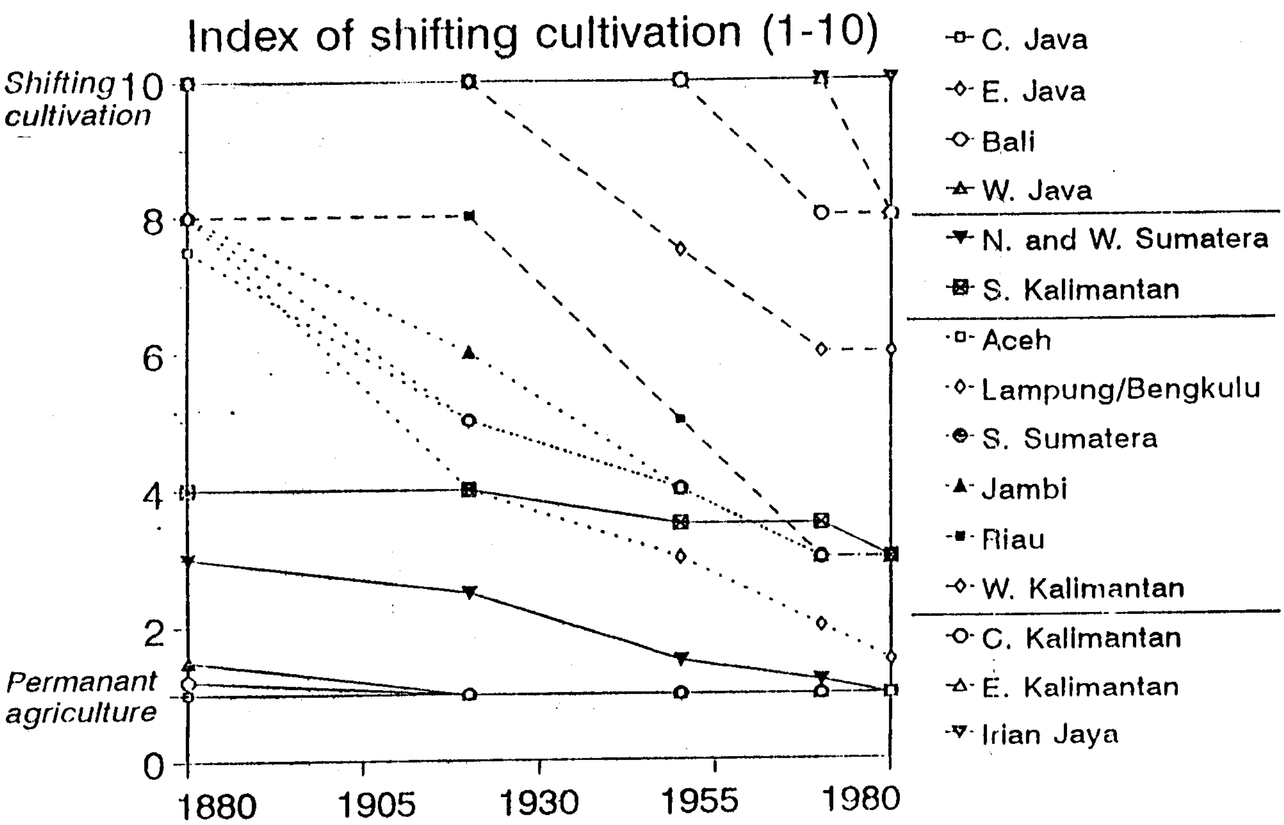


Figure 3. Ecological zones of Sumatera and research sites for the Alternatives to Slash and Burn (ASB) project

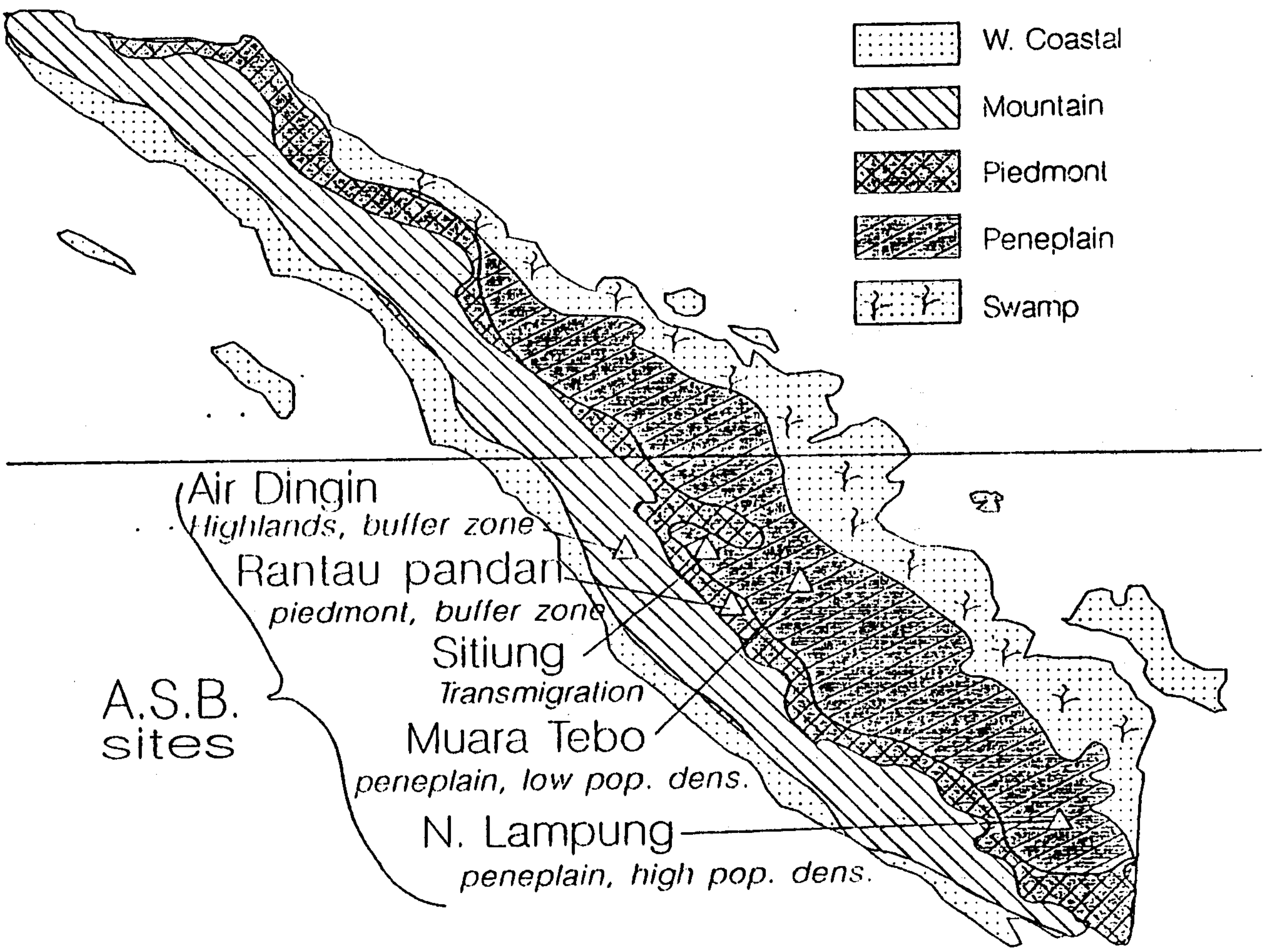


Figure 4. Relation between population density and 'forest damage' (percent non-forested state forest land), based on Haeruman (1992)

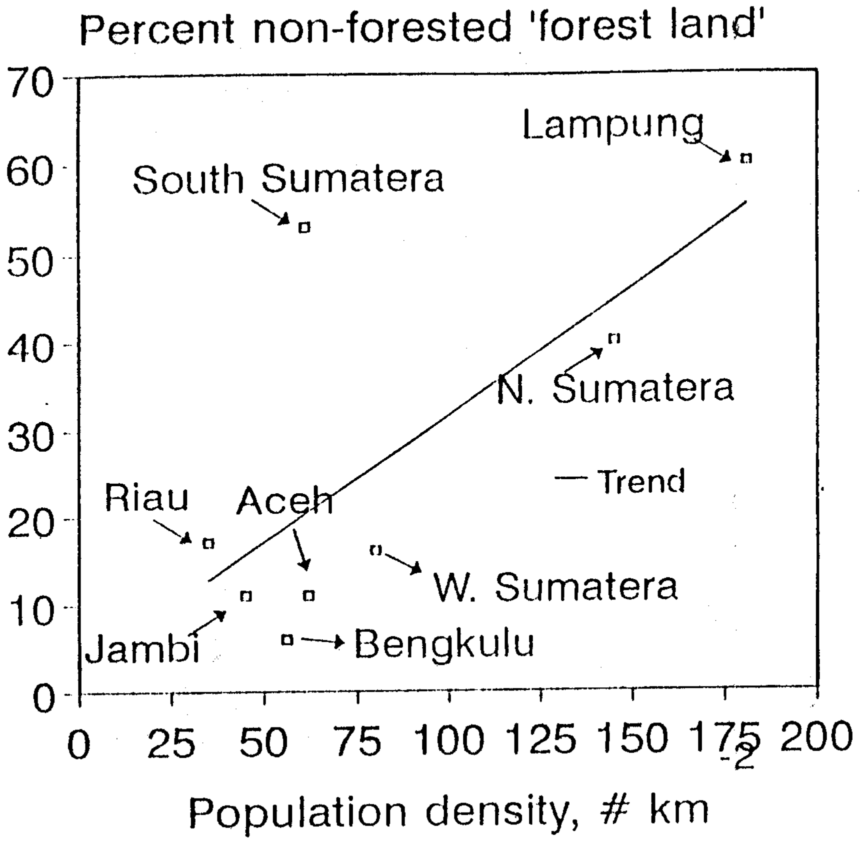


Figure 5. Major groups of land users to be considered in the ASB project; the 'people elsewhere' as potential source of future migrants can not de directly sampled

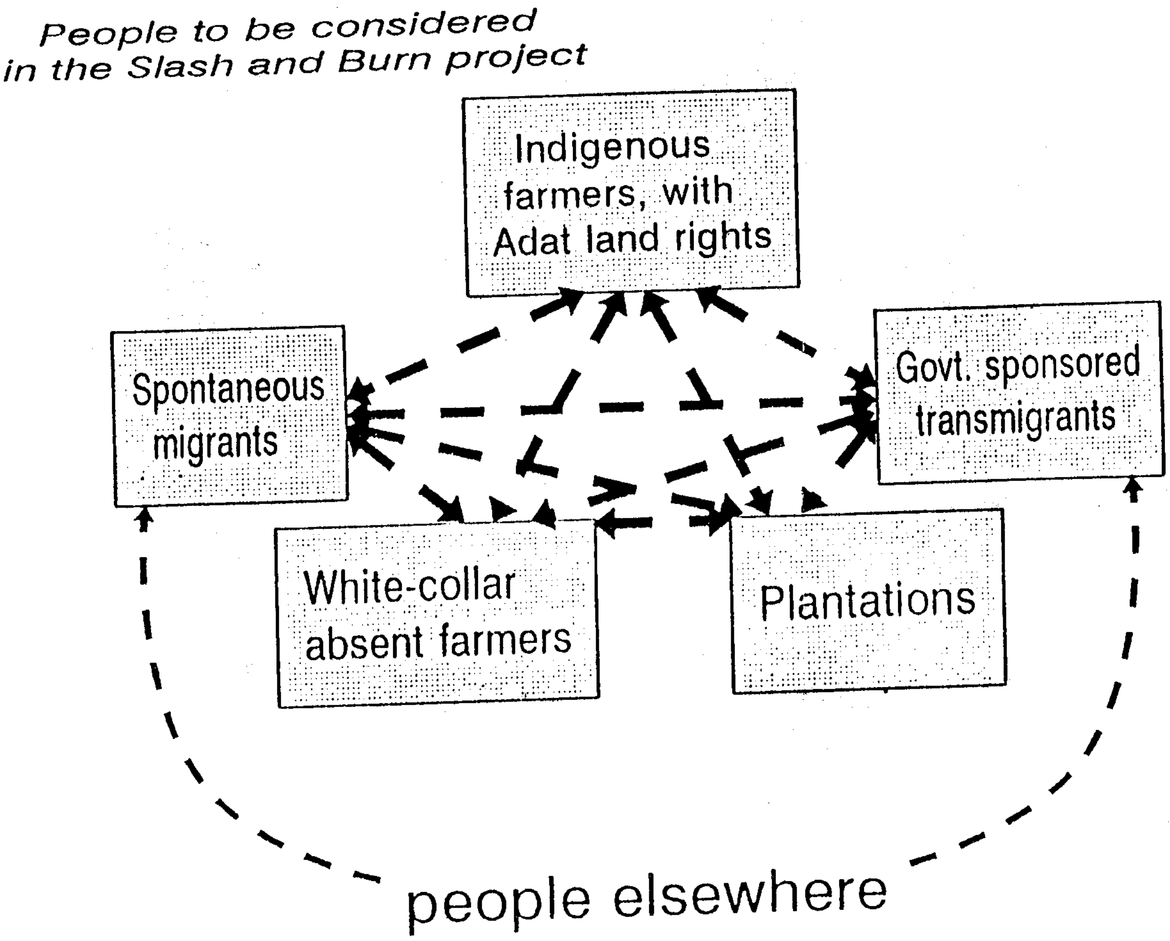


Figure 6. Stepwise choice of research sites and extrapolation domains

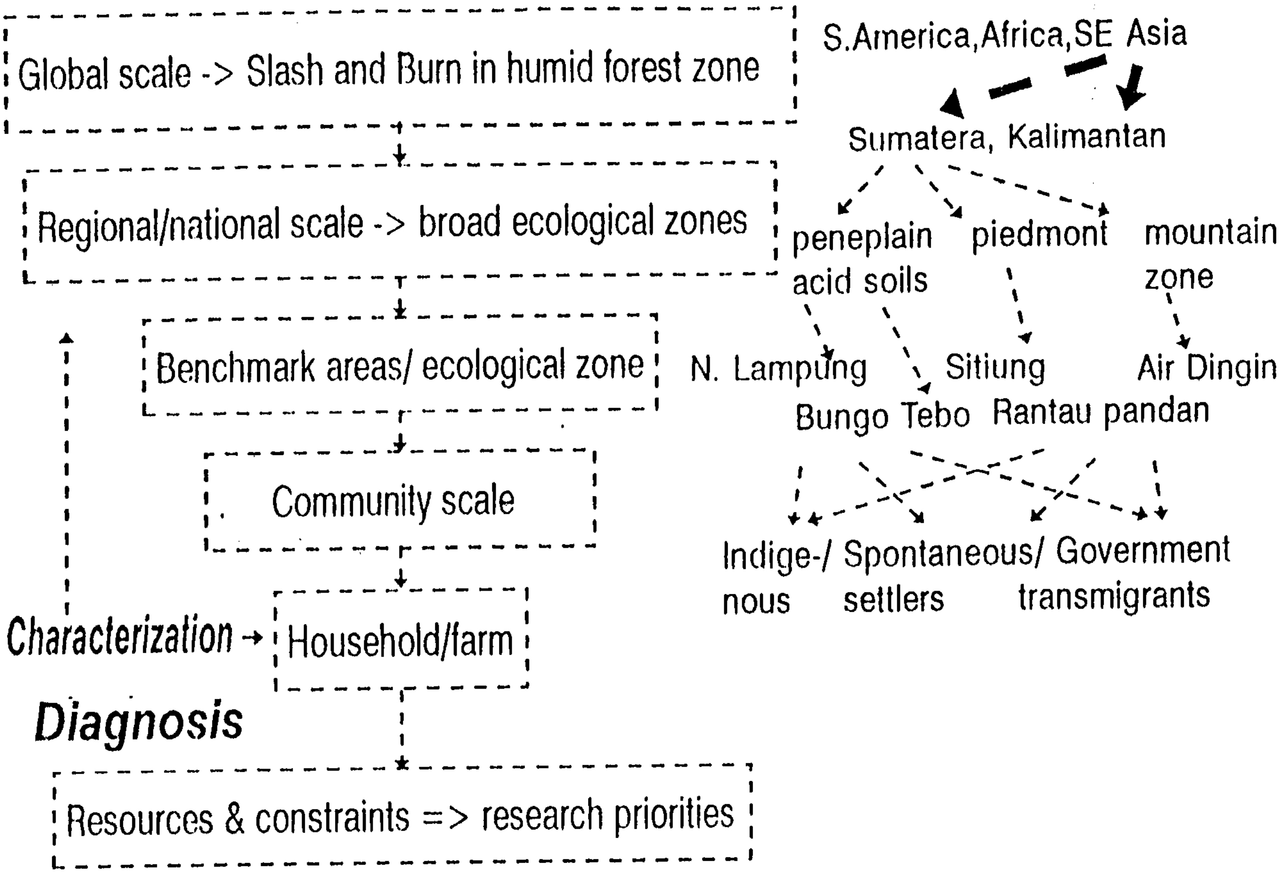


Figure 7. Land use by soil group in the CSAR soil database for Sumatra

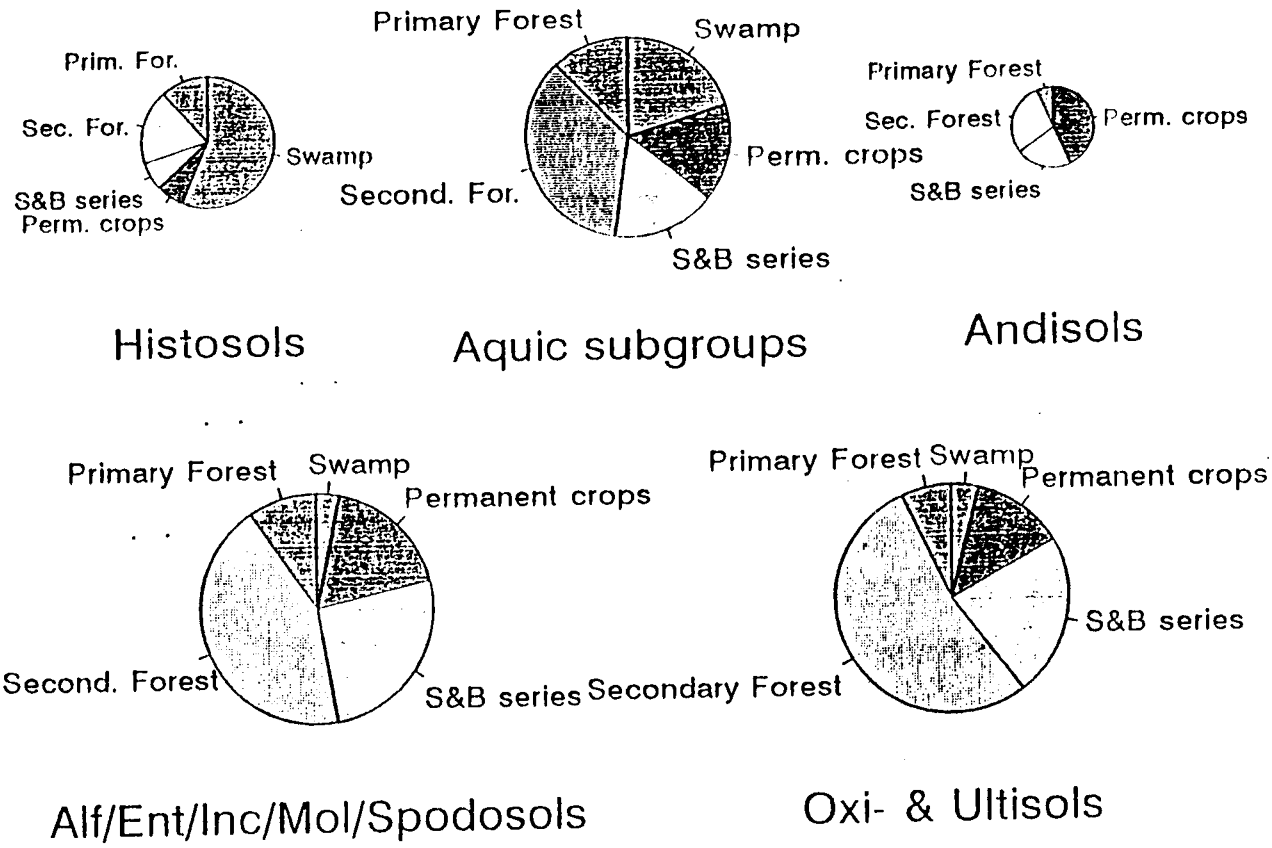


Figure 8. Composition of slash-and-burn (S&B) series on the three groups of upland soils in Fig. 7

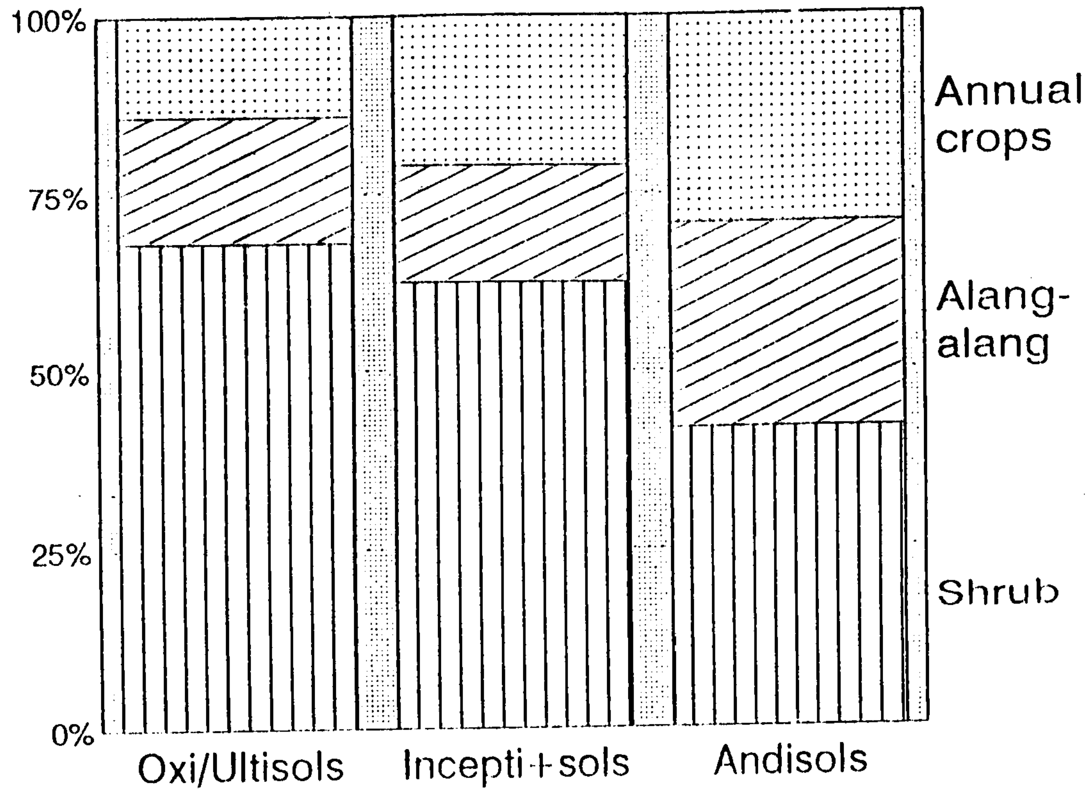


Figure 9. Comparson of average C-org content of topsoil for upland soils in the early '80's with data of Hardon (1936) for Lampung

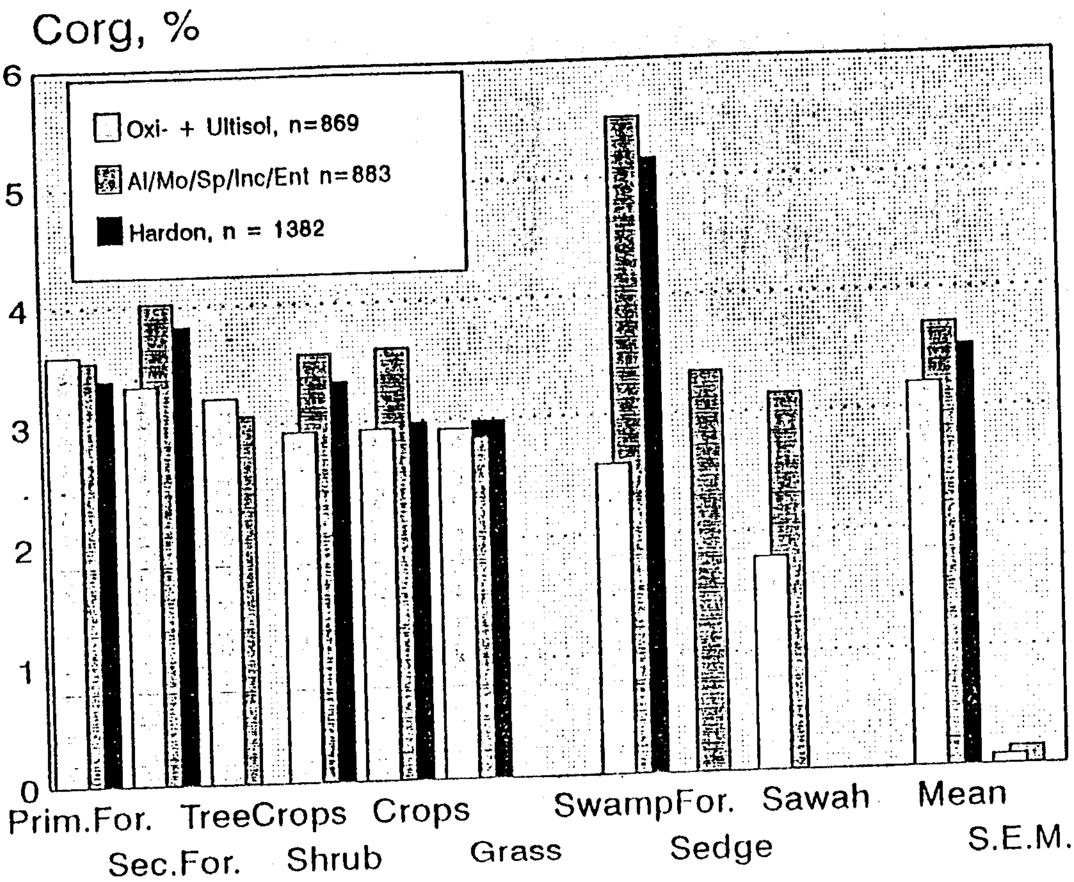


Figure 10. Relation between soil pH and C-org for forest soils in Sumatera; the squares refer to data of Hardon (1936), the triangles to recent data

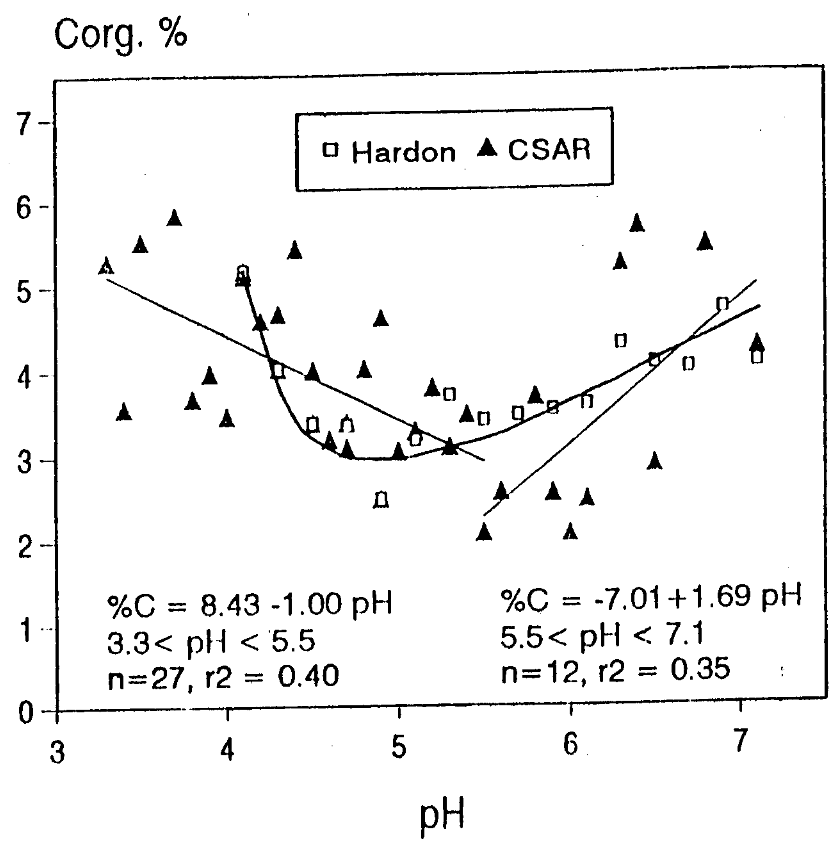
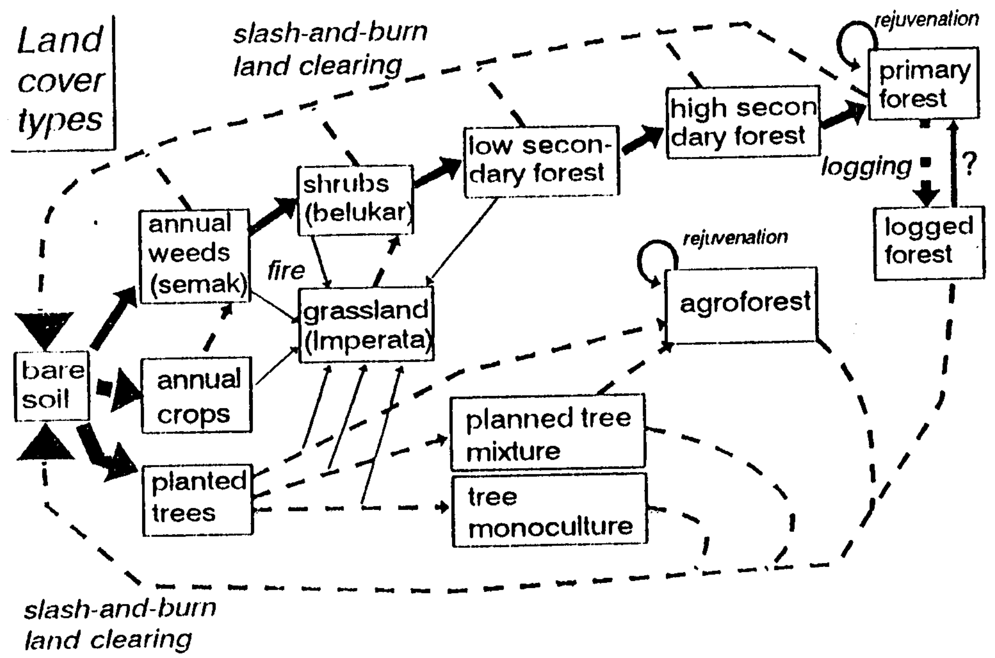


Figure 11. Scheme of natural and man-made vegation types in the humid tropics and the major transitions between them



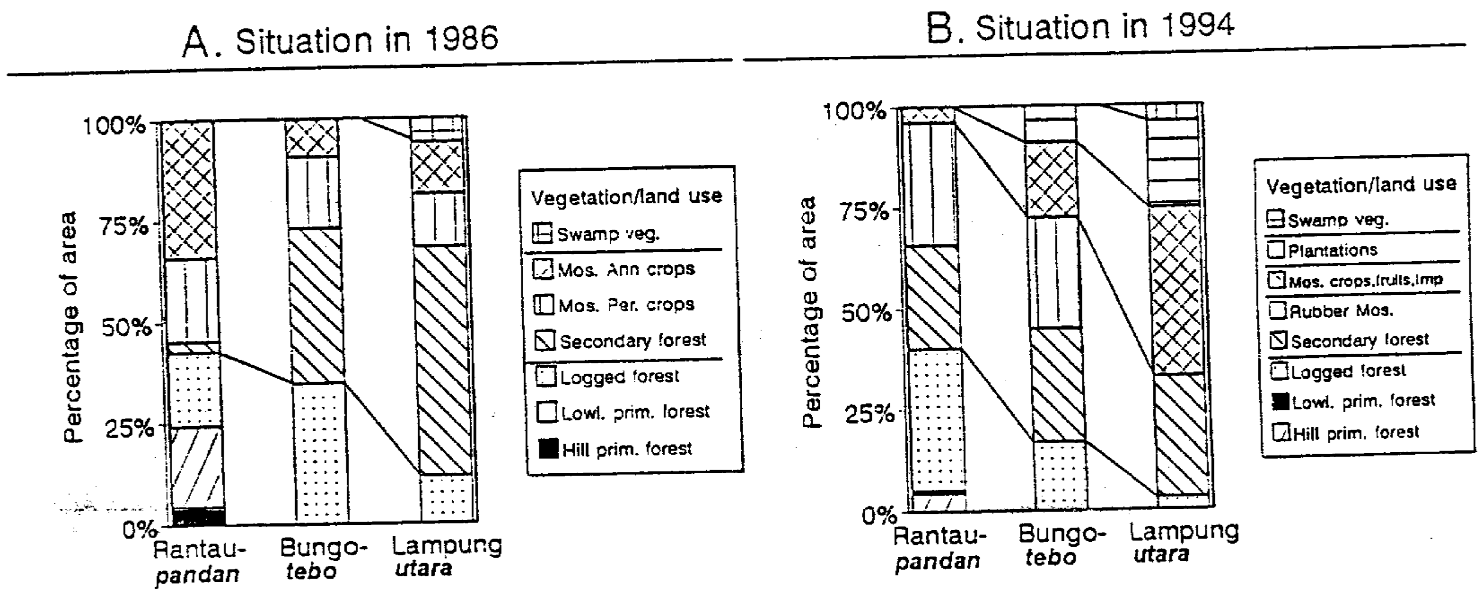


Figure 12. A. Land use in three benchmark areas according to the 1986 vegetation map; B. *idem* for 1994 Landsat TM images.

Figure 13. Land use change in Jambi province in the 1986-1992 period, according to Murdiyarso and Wasrin (1995); size of the boxes reflects area in, size of arrows absolute change, numbers in boxes and arrows relative changes (%)

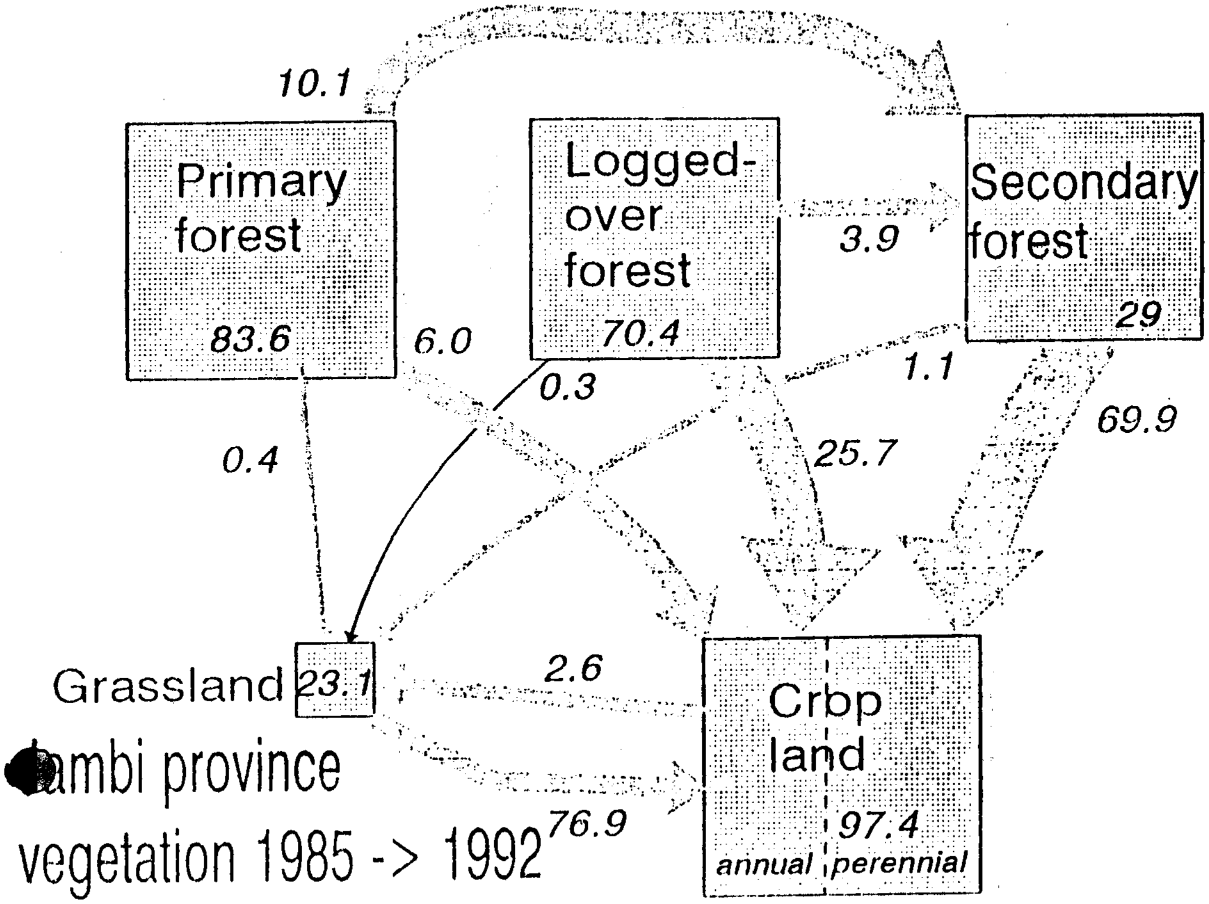


Figure 14. Soil organic matter fractions under secondary forest (upper bar), nine years of continuous cropping (lower bar) and various hedgerow intercropping treatments in N. Lampung

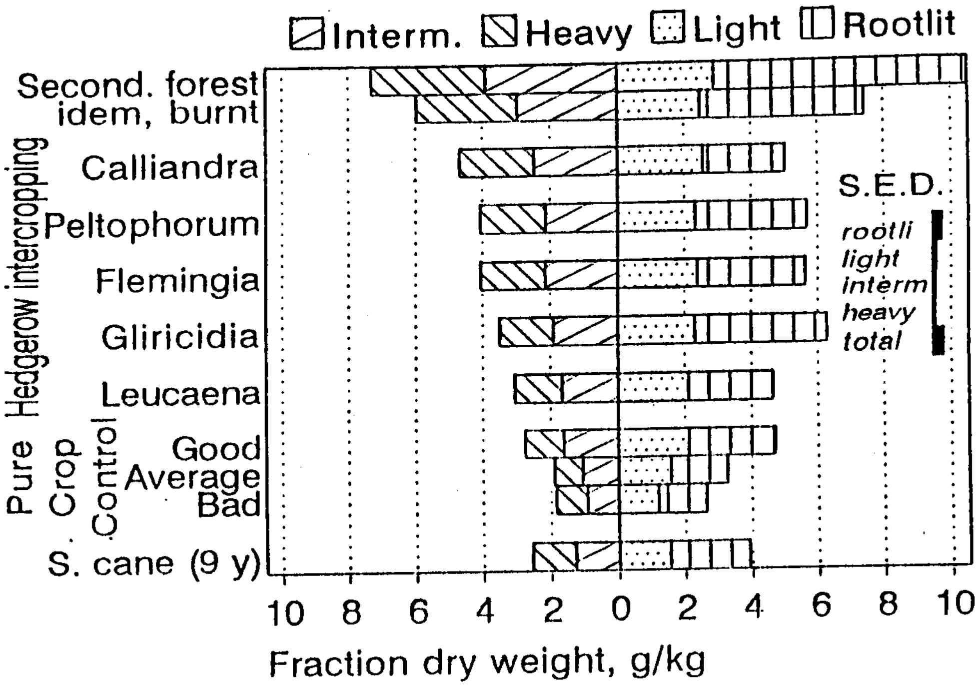


Figure 15. Methane consumption by topsoil of (semi)natural vegetation (left) and their intensively used c.q. degraded counterparts (right)