Forest soils under alternatives to slash-and-burn agriculture in Sumatra, Indonesia

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Abstract

A global project on 'Alternatives to Slash and Burn' agriculture was initiated by a consortium of international and national research institutes to facilitate intensification of the use of converted forest land, in order to help alleviate poverty and protect the remaining forest areas for their biodiversity values and their role in mitigating greenhouse gas emissions.

Data for the Indonesian benchmark areas in the lowland peneplain, piedmont and mountain zone of Sumatra are presented. A significant amount of forest land, especially in the lowland peneplain, has been converted in the last ten years into agricultural use, usually following 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 on better soils (inceptisols), rubber agroforests (still) characterize the area. Agroforests have emerged during the 20'th century as the major alternative to slash-and-burn agriculture, based on a shift of emphasis from food crops to cash-earning tree crops. Emphasis on food crops, however, continues in government resettlement schemes.

Differences in organic C content of the topsoil between forests and crop land are about 0.5 % C, with agroforests and tree crop plantations in an intermediate position. A new size-density fractionation scheme for soil organic matter demonstrated larger changes in light and intermediate fractions. Forest soils can be significant sinks for methane and thus partly compensate for the methane emissions in lowland rice production.

Overall, the Sumatra benchmark areas demonstrate 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.

Introduction

The need for alternatives to slash-and-burn agriculture

One-and-a-half century before *Nye* and *Greenland* (1960) wrote their seminal 'the soil under shifting cultivation', *Marsden* (1811) described swidden practices in Sumatra. His contemporary sources in Sumatra were well aware of the importance of soil organic matter as the source of soil fertility in the few years after opening a piece of forest by slash-and-burn methods and the fact that depletion of this fertility necessitated abandoning the plot to a period of fallow regrowth. Marsden was early in expressing revenence for the rain forest so destroyed 'I could never behold this devastation without a strong sentiment of regret', 'it is not difficult to account for such feelings on the sight of a venerable wood, old, to appearance, as the soil it stood on, and beautiful beyond what pencil can describe, annihilated for the temporary use of the space it occupied'. Nowadays concern about forest destruction expressed by outside interest groups is usually articulated in terms of biodiversity conservation, watershed protection and greenhouse gas emissions, but the underlying emotions may be close to the ones formulated by Marsden.

In the early part of the 20'th century the debate on the role of shifting cultivation in the stil forested landscape of Sumatra, focussed on the need for technical developments allowing a more intensive land use, partly necessitated by the increasing allocation of land to large scale plantation crops (*Koens*, 1925; *Hagreis*, 1930). Intensification of land use for crop production was expected to depend on better management of soil organic matter and nutrient content. At the same time the development of *Imperata* grasslands was attributed to overexploitation of the soil in failed attempts at intensification (*Danhof*, 1941). The global project on 'Alternatives to Slash-and-Burn' at the end of the 20'th Century thus has well-developed roots in Sumatra. Global concerns about the fate of tropical rain forests should be linked to the opportunities and constraints perceived by local land users.

Human exploitation of forests can be based on above as well as belowground resources (Fig. 1). Aboveground the usual division is between non-timber forest products

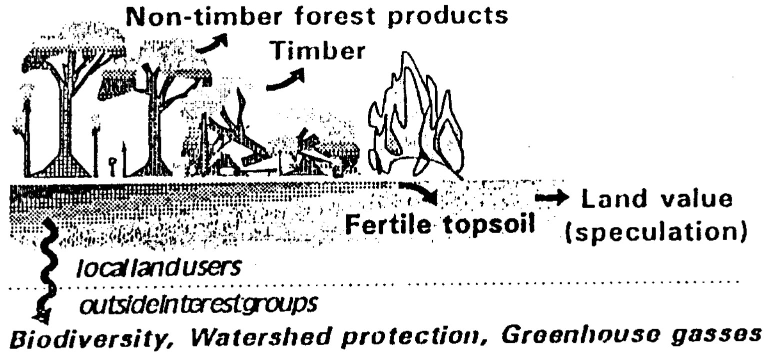

Figure 1: Functions of forest soils to local land users as well as external interest groups.

(NTFP), which may include medicinally used roots, and timber, where the first may be collected in less destructive ways then timber harvesting (logging), although this is not true for all products. Belowground we can distinguish between the short term benefits of soil fertility after slash-and-burn conversion of forests in a long-fallow rotation and the value of the deforested land for permanent agricultural or plantation use. This latter may include a speculative element. Apart from these values of the forest for local users and newcomers, there is increasing attention for its value to the outside world for biodiversity conservation, watershed protection and as mitigator of greenhouse gas emissions. These 'environmental service functions' refer to the soil as well as aboveground part of the forest ecosystem.

The damage done to the forest ecosystem and its 'environmental service functions' increases from collecting NTFP, via logging and long-fallow rotations to conversion into non-forest land uses, either consisting of short-fallow rotations, semipermanent agriculture or non-agricultural land use. 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 short term exploitation of soil fertility (in the 'slash-and-burn agricultural system') and for (semi)permanent use of the land for farming or other types of activity.

Compared to other methods of forest clearing, slash-and-burn methods have less impact on soil physical conditions of forest soils and they should be preferred over bulldozer land clearing (*Alegre* and *Cassel*, 1996). Losses of nutrients due to leaching may be high in the first few years after burning (*Juo* and *Manu*, 1996), however, and this may lead to a gradual decline of soil fertility with each slash-and-burn cycle. The soil organic matter content of ex-forest soils is of crucial importance to the productivity of subsequent crops (*Nye* and *Greenland*, 1960; *Palm* et al., 1996).

Slash-and-burn farming systems exploiting the forest for its soil fertility effects are generally viewed as having a low productivity relative to the amount of damage they do to forest resources (*Sanchez* et al., 1990; *Brady*, 1996). 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 (semi)permanent activities on a small area as alternative to extensive slash-and-burn activities on a large area.

If and where this central ASB hypothesis is true, research and development efforts should be aimed at supporting farmers in developing land use technology, in which agroforestry options may play a central role. For conditions where the hypothesis does not seem to apply, we may need different types of activities to achieve the aims of reducing deforestation.

In the first phase of the ASB project a broad ranging 'characterization and diagnosis' activity was initiated in Brazil, Cameroon and Indonesia to collect baseline data on the nature of current slash-and-burn conversion of tropical forests in the three continents and judge the relevance of this intensification hypothesis in the local context of farmers, other users of forest resources and government institutions. 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 to the soil-related aspects. For a broader account, including socio-economic and policy aspects, the reader is referred to *Tomich* and *Van Noordwijk* (1996) and *Van Noordwijk* et al. (1995).

After describing the various land use options which exist, we will focus on soil organic matter (SOM) and its changes during conversion of forests to other land uses, as it is important for at least three of the functions of forest soils:

– SOM is important for the sustainability of food crop production in slash and burn (fallow rotation) systems via its role in: (a) N and P mineralization, (b) Al detoxification, (c) maintenance of 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,

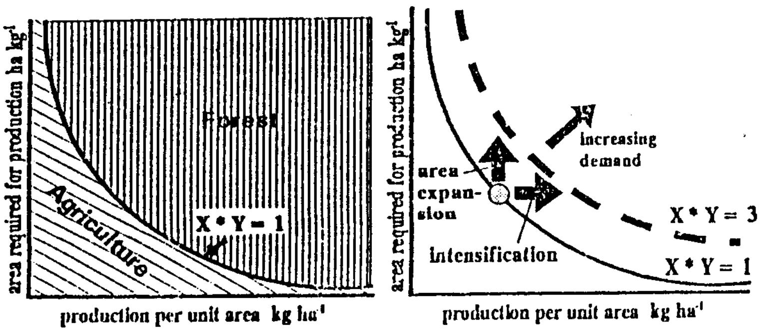

Figure 2A: The amount of land needed for agricultural production is the inverse of the productivity per ha; thus 'land use intensification' can contribute to forest protection. B. Increase in production can be achieved by both area expansion and intensification.

– 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. Thus methods are needed for quantifying specific fractions of soil organic matter (*Hairiah* et al., 1995).

We will first discuss the theoretical basis of the intensification hypothesis, then summarize the characterization and diagnosis data for Sumatra, focussing on land use patterns and soil organic matter and then return to the intensification hypothesis and its relevance for Sumatra.

Intensification hypothesis

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. 2A). If we compare the rice yields in a true shifting cultivation system (say 1.5 and 0.5 Mg ha^{-1} 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^{-1} 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. 2A assumed a constant 'demand' for agricultural products. Fig. 2B 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 (*Boserup*, 1965).

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.

Landscape level processes and driving forces of human migration may be at least as important as field level technical aspects of the land use system.

Sites and methods

Benchmark areas

The global guidelines and procedures for 'Characterization and Diagnosis' for the ASB project (*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 (Fig. 3).

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 (Table 1; Fig. 4). 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.

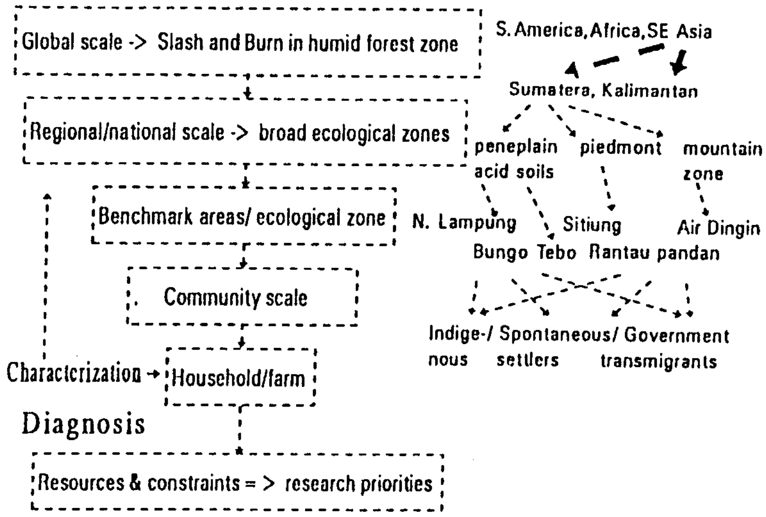

Figure 3: Stepwise choice of research sites and extrapolation domains.

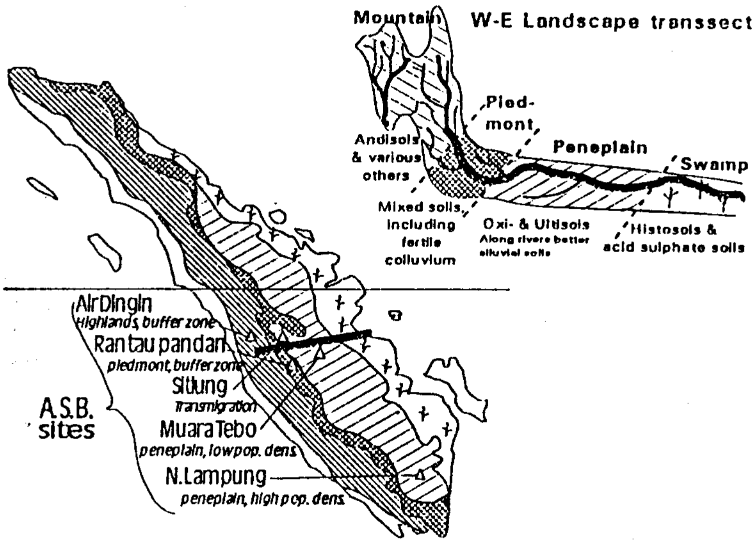

Figure 4: Ecological zones of Sumatra according to Scholz (1983) and benchmark areas characterized for the ASB project.

Greenhouse gas emissions

Preliminary measurements were made on methane (CH_4) and nitrous oxide (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.

Soil organic matter fractions

A size-density fractionation method for soil organic matter was used (*Meijboom* et al., 1995; *Hairiah* et al., 1995) to separate macro-organic matter of the 150–2000 µm size class into light, intermediate and heavy fractions, using Ludox (silica) suspensions of 1.13 and 1.3 g cm^{-3} for the density distinctions.

Results and discussion

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 role 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 treebased production systems (agroforests or tree (crop) plantations). Both the

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, W. Sumatera	Piedmont/ peneplain	Transmigration villages interacting with local farmers	Intermediate, recent immigration
Bungo Tebo, Jambi	Peneplain	Forest margin: spont. settlers, transmigrants	Low, immigration
N. Lampung	Peneplain	Degraded land rehabilitation as alternative to migration	High, immigration + emigration

KSNP = Kerinci Seblat National Park

'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 agroecological-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 (*Richards* and *Flint*, 1993):

I. Java + Bali, where the transformation to permanent agriculture occurred before 1880

II. North and West Sumatra 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 1700 km long, and is cut in two roughly equal parts by the equator; its total land area is 480 000 km². Five major agro-ecological zones (*Scholz*, 1983) can be identified with boundaries running from N.W. to S.E. approximately parallel to the coast (Fig. 4):

1. a narrow Western coastal zone, the lower slopes of the mountain zone on the S.W. side, with various soil types,
2. a mountain zone, dominated by andisols and latosols of reasonable to high soil fertility,
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,
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 flood plains with more fertile alluvial soils and for 90% of uplands with a gently undulating landscape and mostly red-yellow podzolic soils,
5. a coastal swamp zone with peat and acid sulphate soils.

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 (trans)migration from Java both spontaneously and sponsored by the government. A clear gradient in population density exists from the South (Lampung) to the central part (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.

Forest conversion and slash-and-burn as a land clearing method

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

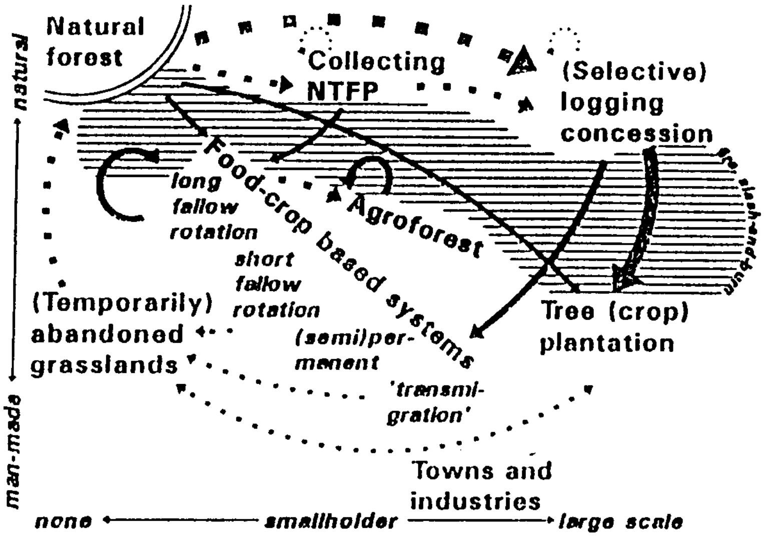

Figure 5: Transformations of forest soils to other land use types as found in Sumatra; all transformations in the shaded areas use 'slash-and-burn' as a method for land clearing; the 'agroforests' are the major farmer-developed alternative to slash-and-burn based food crop production systems.

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.

Slash-and-burn is the common method for land clearing in Sumatra. It is applied to a large range of forest types, however, by a range of land users and leading to a range of new land use systems (indicated by solid arrows in Fig. 5). The connotation of 'slash-and-burn' as a conversion of natural forest into temporary food-crop based land use systems in not the most common type. Slash-and-burn methods are used for converting logged-over forests into tree crop (oil palm) plantations, industrial timber estates or (typically crop-based) government resettlement (transmigration) schemes. Logged-over forests are supposed to get the chance to recover, but in practice large areas have been converted to such other land uses based on (local) government plans. A substantial part of the remaining logged forests were converted by spontaneous migrants, usually into rubber gardens. The negative sloping diagonal in fig. 5 shows the various types of 'shifting cultivation', 'long rotation fallow' and 'short rotation fallow', where forest or shrub land is opened to grow food crops. Intensive food crop based systems have been attempted by the transmigration program, but have been much less successful than the rubber agroforests of the local population. Where tree crops have been used for transmigration sites, poverty alleviation can be successful (Levang, *pers. comm.*). Intensification of the original long-fallow agricultural system by local farmers since the beginning of the 20'th century has led to rubber agroforests, rather than more intensive food-crop based systems (*Gouyon* et al., 1993). Elsewhere in Sumatra, on the better soils of the western coastal strip, the even more forest-like damar agroforests developed (*Torquebiau*, 1984). Agroforests, man-made forests, with a large share of directly useful trees, are thus the major 'alternative to slash and burn' in Sumatra. These agroforests 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. When the rubber agroforests are to be renewed, slash-and-burn methods are still used, however.

The (*Imperata*) grass fallows which can be formed 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). Sometimes these grasslands are abandoned and farmers try their luck elsewhere, as happened in the early stages of the transmigration settlements in the benchmark areas (especially Lampung), but otherwise they can be reclaimed at a later stage. *Imperata* grasslands can also originate from failed attempts to develop tree (crop) plantations.

Current land use

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 (Land Resources Evaluation and Planning) project, recognizes 'taungya' type tree plantations with food intercrops as 'agroforestry'. In analyzing remote sensing images a distinction between 'rubber agroforests' and 'secondary forest' is difficult.

A vegetation map (scale 1: 250 000) for Sumatra was published in three map sheets by SEAMEO-BIOTROP, based on Landsat MSS satellite data for the period

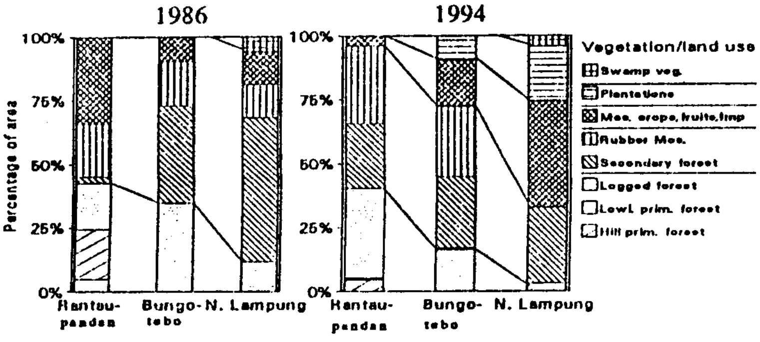

Figure 6A: Land use in three benchmark areas according to the 1986 vegetation map; B. *idem* for 1994, interpreted from Landsat TM images.

1983–1985. A description of the various vegetation types is given by *Laumonier* (1997). 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). Agroforests are not identified as a separate class on this map either.

Fig. 6A shows the vegetation/land use types of the three benchmark areas according to the 1986 vegetation map. Figure 6B shows the situation in 1994 and attempts were made to separate the 'agroforest' category. A substantial increase occurred in 'plantations' (oil palm, rubber, sugar cane and industrial timber). The 'mosaic of crops, fruit trees and *Imperata*' category mainly refers to transmigration settlements in the peneplain.

Soils in the benchmark areas

For the ASB project about 5000 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.

The Bungo Tebo and North Lampung sites are dissected peneplains, consisting of acid tuffaceous sediments. Sitiung is also a dissected peneplain and consists of acid clayey sediment alternating with acid volcanic tuff cover. The Rantau Pandan site 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).

Estimates of net C release due to land use change

The estimated land use change obtained from the overlays of land use maps at two time periods was used to estimate the changes in the above-ground biomass per unit area (Murdiyarso and Wasrin, 1995). 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 estimated as 176,403,000 ton or 29,400,000 ton/yr and 2.9 t Ca ha^{-1}. In comparison with the countrylevel estimate of 0.19 Gt C yr^{-1} for Indonesia (IPCC, 1990), Jambi may have contributed some 16 percent. This is much more than proportional to its surface area.

In 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}). These estimates of changes in average C-stock of land use systems do not yet include changes in belowground C stocks.

Effects of Land Use on Soil Carbon Content on Sumatera

Van Noordwijk et al. (1997) analyzed soil data for Sumatra obtained in the 1980's in the context of the LREP project. About 2800 profile data were found with complete records of soil type (Soil Taxonomy), land use, texture and C_{org}. Five broad soil groups emerged from the analysis with significant between group differences in C_{org}:

Histosols (peat, covering about 10% of Sumatra, but which may contain more than 90% of all C stored in Sumatran soils,

Andisols and wetland soils (Aquic groups) both contain about 10% of C_{org}. On the Andisols C is intimately bound to clay complexes (allophane), while in wetland soils, the

C is partially protected from decomposition by anaerobic conditions,

Among the remaining mineral soil types, two groups could be identified:

relatively fertile upland soils (mainly Inceptisols) and the Oxisols + Ultisols, with an average C_{org} content of 3.8 and 3.2%, respectively. The differences between all groups were statistically significant in a t-test.

In general, the C_{org} content decreases in the order: primary forest > secondary forest > tree crop plantations > areas used for food crops or covered by *Imperata*. 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 between natural forest and 'degraded' soils is probably in the range of 15–20 Mg ha^{-1}; belowground effects may thus be only 10% of aboveground changes in C stocks. 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.

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 range for LREP data for major upland soils. 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 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.

In a multiple regression analysis the relative importance for C_{org} was estimated of soil pH, texture, elevation (a proxy for temperature), slope, land use and soil type (*Van Noordwijk* et al., 1997). The quantitative factors pH and texture 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 elevation ($p < 0.01$) and for slope ($p < 0.05$) also differed significantly from zero. In this regression, the effects of elevation are studied separately from the different altitudinal distribution of soil groups. They indicate a positive effect on C_{org} of lower temperatures. Compared to the average contents per soil type and land use, the C_{org} conten 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 elevation and decrease by 0.3% per percent increase in slope. The following equation emerged for predicting C_{org} in the upper 15 cm of mineral soil from Sumatra under forest cover:

C_{org} = exp (1.256 + 0.00994 * Clay% + 0.00699 * Silt% – 0.156 * pH + 0.000427 * Elevation + 0.834 (if soil is Andisol) + 0.363 (for swamp forest on wetland soils)

As relative C-levels for non-forest land uses, assuming no change in soil pH, the data set suggests 91% for upland crops, 83% for land under tree crops of various types, 85% for *Imperata* grasslands and 81% for young secondary vegetation (shrub). The relative values for crop land become 77 and 65% if pH is increased by 1 or 2 units, respectively. No indication was obtained that tree-based production systems in plantations differ in C_{org} content from land used for annual crops. The agroforests, however, were not recognized as a separate group.

These changes in soil C stocks may be smaller than often assumed. Contributing factors may be the fact that on Sumatra prolonged cropping of a soil, depleting its C stocks is not common as *Imperata* takes over in such cases and the use of livestock for ploughing is limited. 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 the Histosols may release more CO_2 into the atmosphere from current soil sources than the belowground effects of transforming all remaining forests into *Imperata* grasslands.

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 2). The ash layer was sampled separately for the top 3 cm and 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 biomass. Exchangeable cation content as well as available P content increased dramatically; these data, once again, demonstrate that slash-and-burn methods are

Table 2: Chemical properties of forest soil before and after burn in N. Lampung.

Layer cm	pH H_2O	pH KCl	C_{org} %	P-Olsen, mg kg^{-1}	K^+	Ca^{2+}	Mg^{2+}
					cmol. kg^{-1}		
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	7.15[1]	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

1. This probably includes partly burnt charcoal

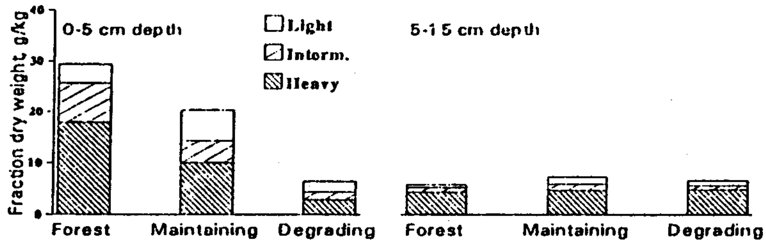

Figure 7: Fractionation of soil organic matter for the 0–5 and 5–15 cm layer of soils under forest, under the best local practices and under soil degrading conditions (including frequent fire and/ or tillage) in the North Lampung benchmark area (*Hairiah* et al., 1995).

an effective way of supplying available nutrients to the next vegetation.

Soil organic matter fractionation

In a survey of the organic matter content of topsoil in the N. Lampung benchmark area (*Hairiah* et al., 1995), three groups of land use practices could be differentiated on the basis of size-density fractions of the top 5 cm of mineral soil (Fig. 7):

a. Forest (remnants of logged-over primary and various types of secondary forest)

b. SOM-maintaining practices: woodlots, forest plantations established with slash-and-burn land clearing, home gardens and unburnt *Imperata* grasslands,

c. Degrading lands: burnt *Imperata*, sugar cane plantations with annual burning of residues and forest plantations established with bulldozer land clearing.

For the second category of land use systems the sum of the Ludox fraction (g kg^{-1}) in the top 5 cm of soil may still decrease by about 20–30% from the forest level. Under degrading situations, the data suggested that 8–10 years after opening the forest, the sum of the Ludox fraction decreased by 70–80%. In the 5–15 cm depth layer, however, the converted forest sites exceeded the forest. Total content of the Ludox fractions (in g kg^{-1} of soil) for this second layer is only 20–50% of that in the top 5 cm. In the 5–15 cm soil layer the heavy fraction is dominant over the light and intermediate fraction in dry weight.

The size-density fractionation scheme also showed large differences between forest soil (both before and after a burn) and soil under 9 year of 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.

Methane (CH_4) oxidation and nitrous oxide (N_2O) emission in forest soils

Secondary and logged-over forest as well as rubber agroforests can act as sink for methane; values were in the range of 0.1 mg CH_4 m^{-2} hr^{-1}. A much lower sink strength was shown by newly burnt forest soil, which might be caused by less active methanotrophic 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 an estimated oxidation occurs of 9 kg CH_4 ha^{-1} yr^{-1}. As the net effect on global warming is supposed to be 25 times larger for CH_4 than for CO_2, this methane sink is equivalent to an annual sink of 165 kg C ha^{-1} yr^{-1}. This is equivalent to the changes in C stock from forest soils to *Imperata* grasslands if this change is allocated to a period of 60–100 years. Net emissions from rice-fields (*Nugroho* et al., 1996) are about 200 times higher per ha than the oxidation in forest soils, so a forest-paddy rice ratio of 200 would have to be maintained to potentially offset net emissions. Estimates of the total CH_4 release of smouldering logs after burning effects are difficult to obtain, but air samples next to such a site showed a CH_4 concentration of about 15 times as high as in normal air.

Initial data on N_2O emission show an opposite trend to those for CH_4, with the biologically more active forest soils emitting more N_2O than the more depleted rice and alang-alang soils.

Concluding remarks

The characterization results show that rapid conversion of forests takes place in the peneplain of Sumatra, but the initial expectation was not confirmed that this conversion is due to smallholders opening natural forests for food crop production systems. This type of conversion appears to be largely restricted to transmigration sites and normally the most valuable timber is removed by logging before such a conversion occurs. Widespread conversion of forests takes place for large scale plantation crops, often in a 'nucleus estate smallholder' project linked with transmigration villages. Spontaneous migrants, who may originate from transmigration villages, moved from elsewhere in Sumatra or came straight from Java, tend to convert logged-over forests primarily for growing rubber. Rubber agroforests have been developed as a major land use system on the peneplain. As prolonged cropping is rare, the average content of soil organic matter in agricultural soils is not as low as found elsewhere in the tropics. Yet a decline in 'active' soil organic matter is indicated by the results of the size-density fractionation scheme used. The main escape from negative soil degradation effects is apparently a shift to tree-based production systems in the form of rubber (and fruit tree) agroforests. Although in a biophysical sense the data for Sumatra may not be very different from the globally expected trends, the land use patterns differ substantially and the agroforests developed by farmers on Sumatra may be a major model as alternative-to-slash-and-burn elsewhere in the tropics.

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 still widely used as a land clearing technique. 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 leads to the main lesson from Sumatra for the global ASB project. The experience of the rubber agroforests in Sumatra, which go back to the start of the 20'th Century, shows that:

Table 3: 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 can produce considerable amounts of methane,
3. The source/sink relationships of soils for methane and nitrous oxide are as important for the global climate as that 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 tree *germplasm* is introduced,
2. Intensifying *management* 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, especially for annual food crops.

a) economically attractive tree-based production systems exist as alternatives 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.
d) the rate of forest conversion can be further increased by easy access via logging roads and temporary off-farm employment opportunities in the logging and lumber industry which helps to bridge the unproductive period of the tree crops.

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. Privatization of formerly communal land is based on slash-and-burn practices followed by tree planting in the Minangkabau area of West Sumatera and Jambi (and possibly elsewhere). This may be a major reason for the existence of extensively managed 'jungle rubber' (*Gouyon* et al., 1983), as it stakes claims recognized by the local community, though not necessarily by the government.

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; agroforests are a promising model,
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 the next phase of the ASB project are formulated (Table 3) and will be tested in the coming years.

Acknowledgements

The ASB project is financially supported by the Global Environment Facility (GEF) with UNDP sponsorship; thanks are due to Dr. Mike Swift for comments on an earlier draft and to many colleagues in the project for sharing ideas.

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