2.2 Choice of benchmark sites and soil C data for ASB-Indonesia

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2.2.1 Introduction: characterization procedure

The overall target of the 'Alternatives to Slash-and-Burn' (ASB) project is to investigate the technical and policy options for replacing unsustainable slash-and-burn farming methods by more intensive production systems, which require less area per person and thus allow more land to be conserved as forest. In the research equal attention may be given to 'stabilizing the forest margin' and to 'rehabilitating lands degraded by unsustainable slash-and-burn'. In Table 2.2.1 a procedure is described for zooming in on research priorities.

Table 2.2.1. Schematic presentation of procedural guidelines for characterization and setting research priorities for alternatives to slash and burn sites.

Characterization at global scale -> humid tropical forest areas affected by slash-and-burn practices

Characterization at the regional/national scale -> broad agro-ecological-economic area within the slash-and-burn areas

Characterization at benchmark sites -> working typology of land-use systems within agro-ecological-economic zones of target area

Characterization at community/household/farm scale -> typology of households/farms within the land use systems

Diagnosis at the household/farm scale -> resources and constraints -> research priorities

2.2.1.1 Regional scale

The first step in this sequence has identified Indonesia as a country which may represent the humid tropical forest zone in Asia - a logical choice which hardly needs further discussion. Indonesia still has large forest areas but forest conversion to other land uses is rapid: deforestation generally occurs in steps, with the transformation from primary to secondary forest types largely due to timber extraction and the subsequent transformation of secondary (and logged over) forest types to (temporary) crop land followed by *Imperata* grasslands (alang-alang); alternatively, more permanent tree-based production systems can be developed on previous forest land. Both the 'forest margin' and the 'degraded land' focus of the ASB project are relevant, although the transformation of primary to secondary forest is mainly driven by other factors.

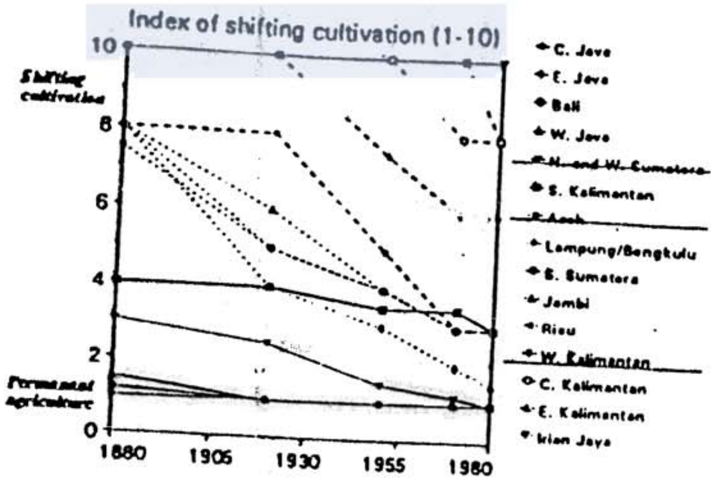

Figure 2.2.1. Historical transformation of shifting cultivation into permanent agriculture for various provinces of Indonesia, based on Richards and Flint (1993).

The next step in the characterization scheme is too choose a representative region within Indonesia for studying these processes. Figure 2.2.1 gives an estimate by Richards and Flint (1993) of the historical transformation of 'shifting cultivation' to 'permanent agriculture' in various provinces of Indonesia. Broadly speaking four groups can be distinguished:

I. Java and 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 (in S. Kalimantan the transformation appears to have been interrupted)

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 is to identify 'benchmark areas', defined as 'homogenous areas in terms of the biophysical and general socioeconomic factors that influence slash and burn activities'. Considering the benchmark area as a 'homogenous area' has obvious advantages for extrapolation of results: if the observation sites can be treated as 'random' or 'stratified/representative' samples of the area, results can be used at the next larger scale.

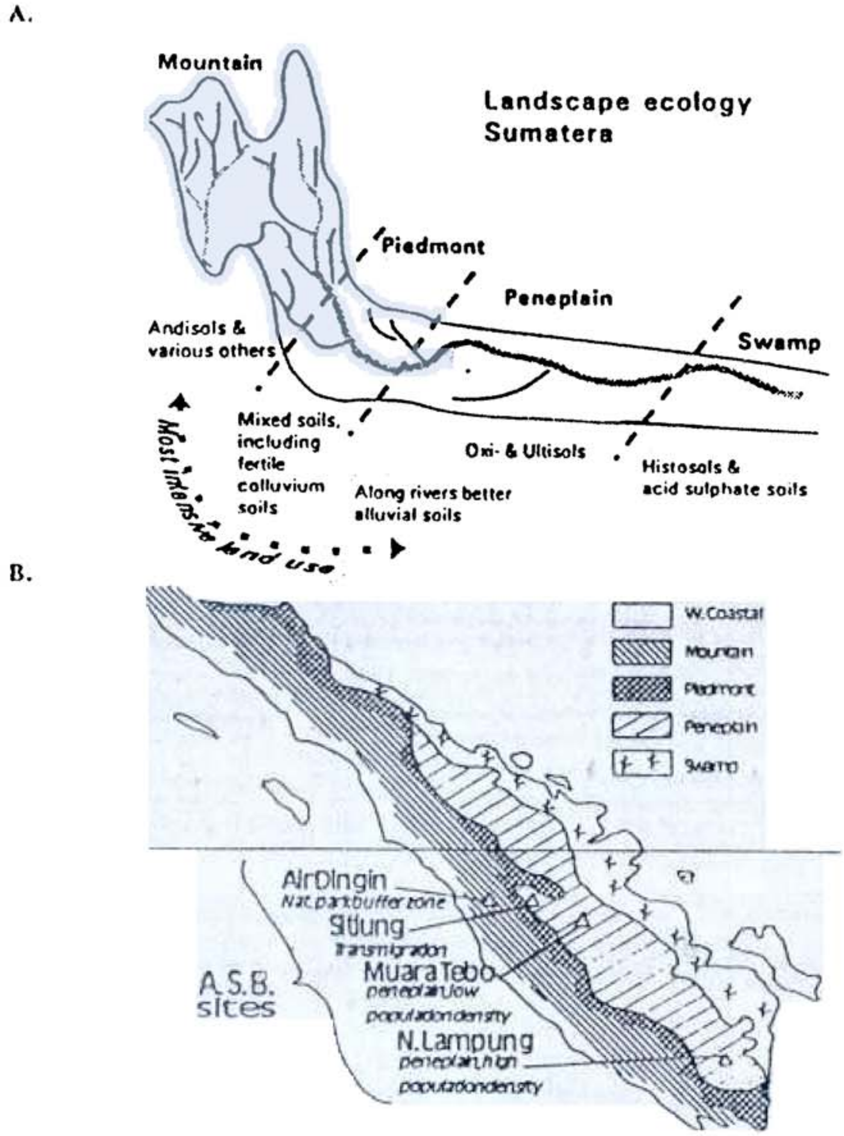

Figure 2.2.2. Ecological zones of Sumatra, based on Scholz (1983); A. Schematic transect, B. Map.

2.2.1.2 Ecological zones of Sumatra

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". 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 N. part.

Within Sumatra five major agro-ecological zones are identified with boundaries running from N.W. to S.E. approximately parallel to the coast (Figure 2.2.2):

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 the 20th Century, population density in Sumatra increased by transmigration from Java. Initially sites in zone 2 and 3 were chosen and located close to Java, but in the last three decades also less favourable sites on the peneplain (zone 4) throughout Sumatra became inhabited. The peneplain is a current focus of development due to its large area and low population density. The soil constraints are serious, but are largely of a chemical/biological nature; physically the soils generally have favourable physical conditions (good drainage, no serious erosion problems).

The peneplain covers large parts of the provinces of Riau, Jambi and S. Sumatra, the northern part of Lampung and just about touches the S.E. most corner of West Sumatra province.

2.2.1.3 Choice of a 'benchmark area' for ASB in Sumatra

The 'site selection' team in 1992 has suggested to concentrate ASB research in Indonesia on Sitiung and Air Dingin (Kerinci Seblat). The ASB planning workshop in December 1993, however, decided to review this choice in the light of the further guidelines for characterization.

Both Sitiung and Air Dingin are located in the Batanghari watershed, which like nearly all watersheds on the N.E. of the Barisan range, intersects four of the five ecological zones. The Batanghari river watershed is the largest in Sumatra, and includes parts of the Kerinci Seblat national park in the mountains, the Sitiung station in the foothills with mixed soil types and large areas of acid upland soils on the peneplain and more fertile soils along the rivers in the lowland, and finally a vast swamp and mangrove area. For slash-and-burn farming the peneplain may be the priority for research, as S&B crop production may be the least sustainable on such soils. The large areas of jungle rubber and agroforests form an interesting comparison with crop-based production systems. The meeting in December 1993 decided to take the "peneplain" zone of Sumatra as the first benchmark area for ASB Indonesia.

The peneplain has been and still is actively deforested/transformed for the last decades. It meets the definition, as it is reasonably homogeneous in soils and vegetation; there is a slight climatic gradient in this zone, with a more pronounced dry season towards the N and S extremes, but this does not have a major influence on the land use. Two strata should be distinguished: the river valley soils, which mostly have been settled for a long time and the poorer upland soils, which are being colonized now. A more important gradation exists in socio-economic sense with different distances to Java (migration) and to markets, but the completion of the Trans-Sumatra Highway has reduced these differences to a considerable extent. A major gradient in population density exists in the peneplain from Lampung to Riau/Jambi. As shown in Figure 2.2.3, population density largely accounts for the variation in degree of 'forest damage' (official 'forest land' which is not actually forested) among the provinces of Sumatra in 1990. The main outlier in this graph is S. Sumatra where forest damage is larger than to be expected from its population density.

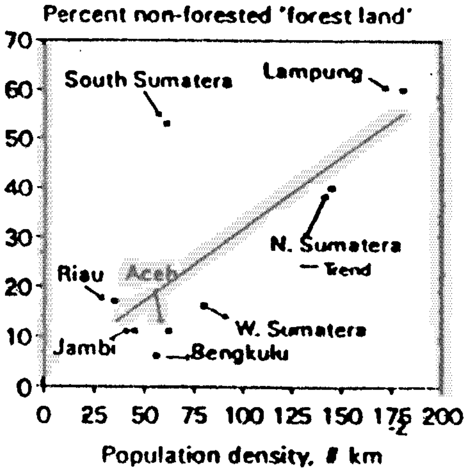

Figure 2.2.3. Forest damage in official forest area in Sumatra in relation to population density, based on RePPProT (1990) and Herman Haeruman (1992).

A number of relevant research activities is or has been undertaken in this peneplain zone (from South to North):

- cropping systems research in central Lampung by CRIFC on the S. edge of the peneplain showing the possibilities of sustained crop production provided enough organic matter is produced and retained; later research concentrated on the benefits of introducing

mixed farming systems, including cattle,
- research on biological soil management in N. Lampung by Brawijaya University,
- Batumarta farming systems research in transmigration areas on *Imperata* grasslands, including the intensification of rubber systems,
- rubber-based research in the Palembang area,
- research on soil conservation and tree-based smallholder production around MuaroBungo and in the Kuaman Kuning transmigration area by CSAR and IBSRAM,
- research on 'permanent' forest plots around MuaroBungo by IPB,
- research on forest management around the 'research campus' of UGM in Muara Tebo,
- research on jungle rubber systems on various sites in Kabupaten Bungotebo by Biotrop researchers,
- various research groups around Sitiung, which is on the edge of the peneplain.

A comprehensive summary of the results of all these previous and on-going projects should be made, as part of the characterization process.

2.2.1.4 Socio-economic stratification within the 'benchmark area'

The next question (or one which should be simultaneously addressed) is to consider who are the actors and decision makers for current 'slash-and-burn' agriculture.

Broadly speaking five groups can be identified (Figure 2.2.4):

1. Traditional, indigenous S&B farmers (a considerable range of cultures and people, from the Minangkabau with strong government connections, via the Ogan of N. Lampung to the marginalized Kubu of the peneplain forests).
2. Spontaneous migrants to the forest margin (Transmigration Spontan).
3. Government-sponsored transmigration schemes (Transmigration Umum).
4. White collar (absent) farmers, employing labourers for farming.
5. Large scale plantation companies.

Decisions about land use are made locally (1, 2) or in the cities and the capital (3, 4 and 5). If the ASB project is to have any practical impact these differences are crucial. In practice, however, the boundaries between 2 and 3 are not sharp: many farmers from government transmigration sites move out of their village after some years, when they find that the land is not sufficiently productive and try their luck elsewhere. By doing so, they meet the dictionary definition of 'transmigrant':
'*passing through, esp. a country on the way to another*' (Concise Oxford Dictionary), '*an alien entering a country on his way to another in which he means to settle*' (Chambers 20th Century dictionary). This, however, is not the meaning which the Indonesian government wants to give to transmigration; the target is to provide the transmigrants with conditions which allow (permanent) sustainable livelihoods, at a higher level than possible in the areas where they migrated from. After considerable criticism on the previous transmigration schemes, the government now gives more emphasis on stimulating spontaneous migration. Group 2 may therefore be the most interesting group for our research.

The Amazon sites of the ASB project consider groups 2 and 3, the Cameroon site concentrates on 1. In Sumatra groups 1, 2 and 3 may all be considered in the ASB research. Group 1 covers a range of population groups, with different traditional land access rules. One interpretation of the extensive 'jungle rubber' systems is that they reflect a 'scramble for private

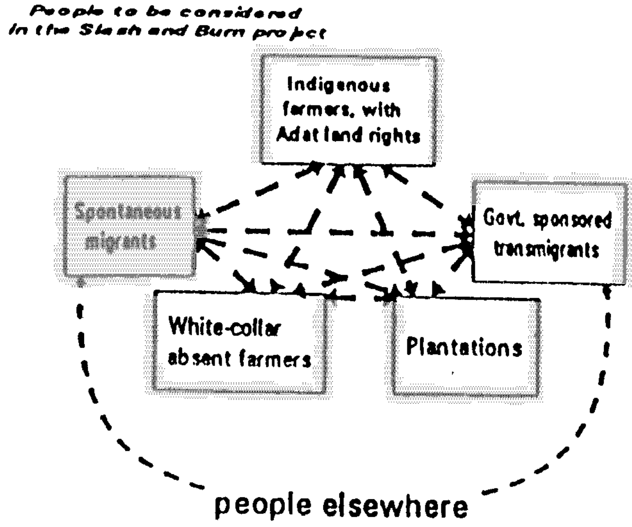

Figure 2.2.4. Actors in land use (change) to be considered in the slash-and-burn project.

land' at the end of a communal land property phase; by cutting the forest and planting rubber trees a family can develop a private claim to communal land, which is becoming scarce. If such a mechanism is driving the land use pattern, there is no direct need for intensification of land use: only when all land has been parcelled out, will land owners become interested in intensification (leading to higher yields per ha, but probably not per unit labour). In dealing with these issues the complex relation between the traditional rules (Adat) and current Indonesian laws is crucially important. According to the law, all land belongs to the government and private holdings can not exceed 5 ha (depending on the area ?); in practice, adat rules are respected unless a conflict with government targets arises. Changes in land use by these groups probably depend on changes in the laws or law enforcement.

Some preliminary observations around Sitiung suggest that groups 1 and 3 may interact in such a way that forest transformation into jungle rubber is speeded up: the transmigrants provide the labour and may benefit from the first years rice crop after slash-and-burn, the Minangkabau will own the land and rubber planted along with the rice. This interaction may be further studied.

The interactions between groups 2/3 and 4/5 are relevant, as the concept of a 'nucleus' estate plantation (with agro-industrial facilities) with surrounding 'plasma' smallholders is an important aspect of Indonesian development policies. A further differentiation of the type of plantation may be needed, as they differ in exclusiveness: oil-palm and sugarcane should be processed quickly after harvest and thus usually lead to a concentrated plasma area with a monopoly for one plantation. On the other hand of the scale, rubber and timber can be stored, transported and traded over a considerable distance and thus leads to less exclusive relations between plasma and nucleus. Such products thus offer more freedom to the farmer, and can be more easily integrated in a farm diversification drive to reduce risks (don't put all your eggs in

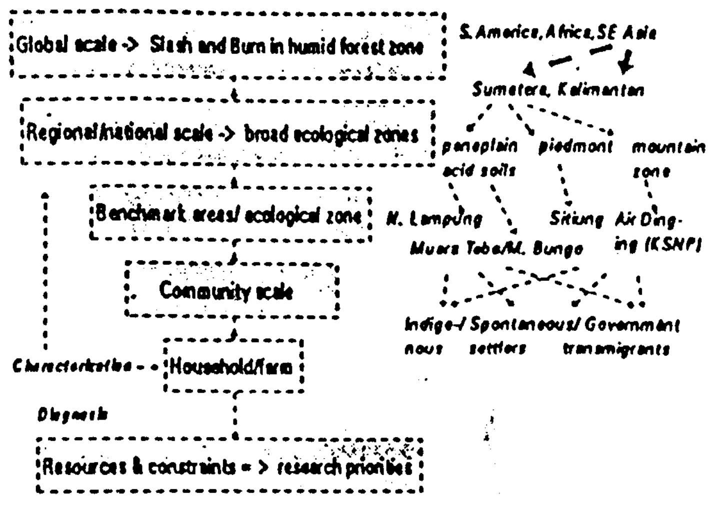

Figure 2.2.5. Selection of zones, benchmark areas and communities for further characterization for the ASB project.

one basket). The present exclusiveness in the relations between nucleus and plasma seems to go beyond what is really needed for technical reasons. A critical study of these relations may open new possibilities for development of diversified farming systems, while maintaining profitability for the nucleus estates and agro-industries.

Within the roughly ecologically homogeneous 'peneplain' zone, we have to distinguish between and choose from a number of socio-economic strata, e.g.
- an area where migrants and indigenous farmers have symbiotic relationships (to the benefit of both, not necessarily to the benefit of the forest),
- an area where migrants and indigenous farmers compete for scarce resources,
- a recent transmigration scheme *without* neighbouring plantation,
- a recent transmigration scheme *with* neighbourlng plantation,
- an area with spontaneous in-migration *without* neighbouring plantation,
- an area with spontaneous in-migration *without* neighbouring plantation.

2.2.1.5. Choice of benchmark areas and communities

Based on the above considerations and further discussions, the Technical Working Group (TWG) of ASB Indonesia decided to initiate site characterization for four 'benchmark areas' as indicated in Table 2.2.2. Figure 2.2.5 gives the decisions made with respect to the scheme on Table 2.2.1. Table 2.2.3 gives a list of topics for the research in Phase I and Phase II of the project. In Phase I the emphasis will be on characterization and diagnosis of opportunities and constraints, and research design for potential solutions and sustainable land use systems.

Table 2.2.2. Description of benchmark areas in the 'call for proposals' for ASB-Indonesia.

Benchmark Area	Ecological Zone	Main Focus in ASB	Population density relative to resources	Links with on-going research
Air Dingin/ Kerinci Seblat National Park	Mountain	Buffer zone of National Park in highlands	High, out-migration	Bina Kelola, WWF
Sitiung, West Sumatra	Piedmont/ transition	Transmigration villages interacting with local farmers	Intermediate (recent) inmigration	AARD-Sitiung IRRI-upland rice
Muara Tebu/ Muara Bungo (Jambi)	Peneplain	Forest margin, productive buffer zone between forest and settlers	Low, in-migration	UGM-Wanagama2 IPB/Biotrop ODA-forestry plan
North Lampung	Peneplain	Degraded land reha- bilitation as alter- native to moving on	High, recent in migration,	UniBraw-EC project, Unila

2.2.2. Exploring the biophysical/technical issues for ASB

Sustained food crop production on upland soils in the humid tropics still presents a major challenge for agricultural research. In the traditional shifting cultivation system, new plots are opened when the yield per unit labour on the previous plot decreases, due to a combination of (a) weeds, (b) nutrient depletion and (c) soil physical degradation. A fallow vegetation, if of sufficient duration, can restore soil fertility and suppress weeds. Nowadays, more intensive land use is required and the soil restoring functions of a fallow have to be obtained in an 'improved fallow' (of reduced duration) or they have to be fully integrated into the cropping system. Cover crops or trees can be incorporated into the cropping system to serve this function. Guidelines for evaluating the vast array of possible cropping systems are required, which should not only have the desired ecological/technical effect, but should also socio-economically fit into the farming system.

High rainfall conditions lead to rapid leaching of nitrogen, the most mobile nutrient, and thus to a low nitrogen use efficiency, especially when subsoil acidity restricts rooting depth. Based on models of N transformations and transport, a number of possibilities for increased efficiency of using nitrogen and other nutrients has been identified, based on improving synchrony and synlocality of nitrogen supply and nitrogen demand by crop roots. Maintenance of soil organic matter is a key issue in avoiding soil physical degradation. By inclusion of cover crops or hedgerow trees into the cropping system, sufficient aboveground plant residue can be produced to maintain soil organic matter at a desirable level. Despite the comparatively small changes in total C_{org} content by changes in land use, large differences in the amount of 'active

Table 2.2.3. List of research topics for proposal development for ASB Indonesia

I. Characterization (see the existing guidelines for details of the parameters needed !)
    A. Macrolevel characterization in broad ecological zone
        - Biophysical
        - Socioeconomic
        The macro-level characterization is mainly based on existing data, including historical trends
    B. Microlevel characterization at four benchmark sites
    C. Integration by Geographic Information System
II. Diagnosis, participatory analysis of constraints (weaknesses) and opportunities (resources, strengths) with land users on four benchmark sites
III. Potential solutions: sustainable land use options
    Critical review of past and on-going research, identify gaps and new opportunities to supplement on-going research activities:
    A. Tree product based production systems
        1. Rotan and other forest products
        2. Damar (resin)
        3. Timber
        4. Fruit trees
        5. Rubber
        6. Oil palm
        General issues:
        a. Integration with food crops,
        b. How to overcome transition period
    B. Crop based production systems:
        General issues:
        1. Overcoming constraints posed by
            a. Soil fertility
            b. Soil physical degradation
            c. Weeds (including *Imperata*)
            d. Pests and diseases (incl. pigs etc.)
        2. Integration with livestock production
        3. Integration with tree-based production systems
IV. External consequences of existing and alternative land use systems
    A. Greenhouse gass emissions
    B. Carbon budgets
    C. Biodiversity implications
V. Policies, legal and institutional arrangements related to slash-and-burn
    A. Describe existing policies (as part of macro characterization)
    B. Evaluate their effectiveness (as part of diagnosis)
    C. Develop new policy instruments

soil organic matter' may exist (masked by large amounts of 'stable' organic matter, protected from biological transformation by its chemical form or physical location). Recently, new methods have been proposed for measuring the active fraction of soil organic matter. If these methods work on acid tropical soils as well, they may provide a tool for comparing different soil management methods.

Weed infestation can be prevented by maintaining a continuous soil cover, by including winding leguminous cover crops in the rotation or periods with heavy shading by hedgerow trees. Possibilities for reclaiming Imperata-infested land by biological means exist and may be a low-cost alternative to the herbicide-based weed control practiced by plantations and larger farmers. *Imperata* control, and even reclamation of alang-alang lands can be based on leguminous cover crops (*Pueraria, Mucuna, Calopogonium*) or on hedgerows of fire-tolerant trees. It is possible to alternate crop production in between hedgerows of trees, with a period in which the hedgerow trees are left to grow, as an 'improved fallow'. It seems likely that such a system will off set the labour costs of pruning the hedgerow trees, by labour gained in land clearing and weed control in existing S&B systems. The choice of suitable tree species for such a system on acid soils is restricted, however. Positive experience with a local tree in N. Lampung, *Peltophorum dasyrachis* (soga) indicates that other species may be found among the early successional species. A survey of farmer's knowledge and reasoned biological guesses on the peneplain may reveal other candidate species. The current hypothesis that complementarity of root distribution between tree and crop is essential for success in simultaneous agroforestry systems, needs further testing.

Previous research has indicated that with the application of considerable amounts of lime, soil acidity in the topsoil can be easily overcome. The acidity of the subsoil, however, can only be modified by high-cost soil tillage or by a slow process of gradual improvement. The selection of acid soil tolerant germplasm is thus a clear research priority for a more intensive use of the acid upland soils. A better understanding of the interactions between soil organic matter and Al toxicity is needed, and a refinement of the parameters used to describe Al toxicity (based on concentrations of monomeric Al in soil solution, rather than exchangeable Al or 'Al saturation').

On the acid soils and with a high rainfall, the long term prospects for tree-based production systems are better than those for systems based on annual crops. For new migrants, however, the transition time untill trees become productive is a major obstacle (in established villages the young generation may inherit a farm with all production stages present). Trees have ecological advantages over annual crops: there is no period where the land is open and susceptible to erosion at the start of each cropping season; trees have a permanent root system and nutrient demand, which can lead to efficient use and recycling of nutrients. In most cases, however, the land area needed to sustain a family in tree-based production systems, exceeds that needed in crop-based systems. The income per unit labour can be higher in the tree-based systems. Technical research may explore various methods for establishing tree-based production systems while maintaining adequate crop production in the transition phase. This research may span the continuum of extensive jungle-rubber to intensive plantation type systems. Fruit trees (esp. the deep-rooted nangka (*Artocarpus*) and durian (*Durio zibethinus*)) are of interest too, but marketing constraints exist, although prices for Durian are sufficient to transport it to Java by road. The success of the *sengonisasi* scheme in Java (sengon = *Paraserianthes falcataria*) on Java has shown the prospects for smallholder timber production, as part of intensive production systems with land scarcity. On acid soils, however, *Paraserianthes* appears to be too competitive to combine with crops and possibilities of other timber tree species should be explored. The recent breakthroughs in Samarinda (E. Kalimantan) in getting dipterocarp trees established by vegetative propagation with the required mycorrhizal symbionts, has made it technically possible to plant the most valuable timber trees on acid soils. The time required for a full cutting cycle of such trees does not allow a small farmer to make a living, but as a small component of a farm they will be valuable in the long run. Research is needed on how to integrate such trees with components which are productive after a shorter period.

2.2.3. Soil carbon content as influenced by land use on various soil types in Sumatra

2.2.3.1 Introduction: Carbon sequestration and carbon stocks

Conversion of natural forests to agriculture in the humid tropics leads to a reduction in ecosystem carbon storage, due to the immediate removal of aboveground biomass and a gradual subsequent reduction in soil organic carbon. Soils do not loose all their carbon, however, as a considerable part of it is protected from microbial attack by a range of physical and chemical mechanisms. A reduction in organic inputs to the soil and/or accelerated losses after forest conversion lead to a decline in the more active (labile) C fractions in the soil. These changes influence crop productivity at a localized scale as well as the global C budget. We thus need to distinguish between 'stable' and 'active' soil organic matter fractions and to measure the importance of the various protection mechanisms.

The impressive biomass accumulated within a mature, tropical rain forest may lead one to expect that this ecosystem continues to accumulate carbon. Although this is true for the individual trees within the forest it is not the case for the forest as a whole. Decomposition rates of carbon in a mature forest are (approximately) equal to carbon fixation rates. Exceptions to this rule are the export of organic acids (tannins and humic acids), as common in fresh-water systems of the humid tropics followed by precipitation in estuaries (Brown *et al.*, 1993) and, more importantly, accumulation of organic soil horizons in swamp forests on peat soils. The enormous smoke development when a forest area is opened and burnt releases large amounts of C into the atmosphere. The fire concentrates in a few hours what might otherwise take a human lifetime to reach the atmosphere, but the vast majority of this C would ultimately have returned to the atmosphere in any event. Carbon is removed annually from the atmosphere in younger ecosystems, such as a forest plantations or forests regenerating from the impacts of logging, fire or other disturbance.

Figure 2.2.6 compares the C storage over a typical cycle length and the net C productivity of a mature forest, a tree plantation and an annually cropped area. If a patch of natural forest is considered, it will show a gradual build up, until a sudden decline following gap formation. For a larger forest area we may expect these saw-teeth to even out. A forest plantation will show a synchronized sawtooth pattern with a period of 10-100 years, depending on the tree species. In a cropped field a seasonal or annual pattern in total C stocks can be expected. The rates of gross primary production (CO_2 fixation) normally does not differ much between agricultural crops, young or mature natural ecosystems in a given climate zone. Net C productivity may be defined as the amount of fixed C which is removed from the system or accumulates in (semi) permanent C stocks within the system. The off-take can be in the form of wood or agricultural produce.

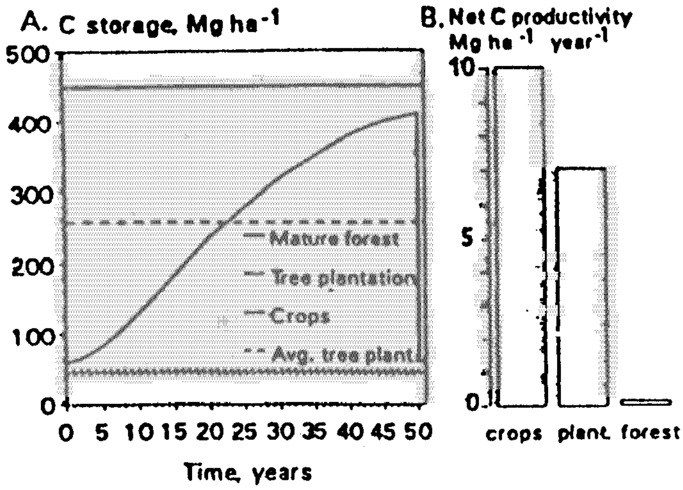

Figure 2.2.6. Schematic view on A. C storage, above plus belowground, in mature forests, forest plantations and permanently cropped land. B. Net C productivity of these systems, averaged over one cycle.

Carbon sequestration is often defined as the (semi) permanent removal of C from the atmosphere. Goudriaan (1993) pointed at the difficulty in defining C sequestration in systems which undergo a regular destruction, as occurs in many fire-prone tropical grasslands. Carbon sequestration may be defined as the net annual C productivity (Mg ha^{-1} $year^{-1}$) multiplied by the expected half-life time (year) of carbon fixed. The dimensions of C sequestration thus are Mg ha^{-1}, and it is thus a system characteristic and no longer a rate (Mg ha^{-1} $year^{-1}$). This definition shows that the annual rate of CO_2 release into the atmosphere by burning fossil fuels can only be off-set by C sequestration if the area involved, the half-life time of the products or the net C productivity keeps increasing. One may want to put an upper limit to the half life time to be considered, otherwise charcoal formation (with a near infinite half lime time) would come out as by far the best C sequestration method, however small the fraction of C transformed into charcoal when forests are burned. Mature forests do not (or hardly) sequester carbon according to this definition. A difficulty with this definition is that the C sequestration attributed to a system, largely depends on what happens to the products of that system elsewhere. The half-life time of wood depends on its use as firewood or timber and on any subsequent wood conservation methods. A considerable part of the C fixed by crops is transported from the field as harvest to markets in urban areas where it is in turn consumed and readily decomposed. If urban waste treatment methods were modified to conserve this C, conventional agriculture would become an important mechanism to sequester C. We may thus have to modify the boundaries of the systems considered, and can not attribute C sequestration to a land use system, without regard of the next steps in the food chain. Planting forests instead of agricultural crops may delay the ongoing increase in atmospheric carbondioxide concentration, during the lifetime of the forest and the resultant wood products. A delay at this time scale, however, offers only a partial solution to the on-going increase in atmospheric C due to fossil fuel use. Substitution of fossil fuels with newly produced biomass can be an alternative, but only in as far as the fossil fuel remains unexploited and safely protected from oxidation in deep soil layers.

Erosion leads to a transport and redistribution of soil material. Relocation of soil organic matter by erosion may actually conserve C, as soil carbon is protected from decomposition processes in acidic swamp environments or in fresh-water and marine sediments. Potentially, erosion may thus contribute to carbon sequestration, provided that the landscapes remain vegetated and maintain their gross primary productivity. From this perspective, land management techniques which seek to reduce soil loss may be at odds with broader objectives of C sequestration.

As the definition of C sequestration leads to complications in the delineation of the system, we may simply compare the carbon pool size averaged over a typical cycle length for each type of ecosystem. A shift from a system with a higher to one with a lower average C storage will lead to a one-time increase in atmospheric C, without bothering about the actual time course of the exchange with the atmosphere. A shift to a system with a higher average C stock may than be interpreted as a one-time reduction of atmospheric C. Sanchez *et al.* (1990) argued that agricultural intensification which would transform slash-and-burn agriculture (the carbon stocks of which might approximately follow a line as indicated for the tree plantation in Figure 2.2.6) into a permanent cropping system (with a much lower average C stock) will reduce the ongoing increase in atmospheric C, because it allows a larger part of the existing tropical forests to be

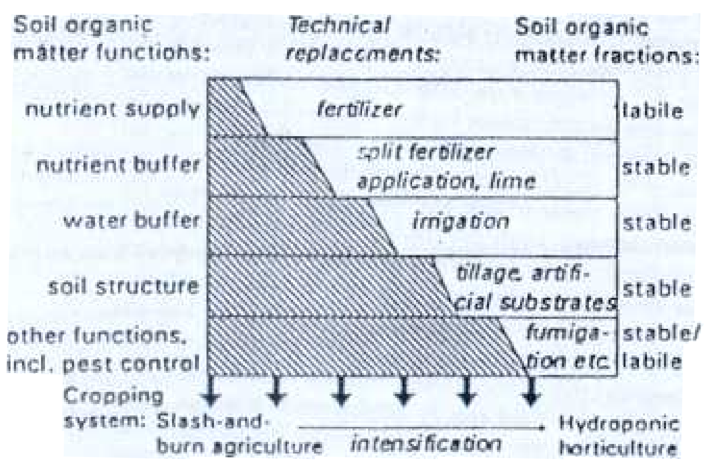

Figure 2.2.7. Soil organic matter functions in cropping systems and the technical replacements which can substitute for soil organic matter during agricultural intensification.

conserved as such. The argument is based on a comparison of the land requirements of extensive and intensive production systems at equal crop production and assumes that effective conservation efforts will protect the forest land not needed for crop production. Putz and Pinard (1993) argued that reduced-impact logging would lead to a smaller decrease of C stocks due to logging and a faster regeneration of the forest and thus to a higher time-averaged forest C stock than under current logging practices, at equal or higher timber productivity. Adoption of the reduced-impact logging methodology could be more cost effective in slowing down the increase of atmospheric C than other solutions considered so far as carbon-offset projects, such as tree plantations. In this particular case concerns on biodiversity conservation may coincide with concerns about C sequestration. In many other cases these two issues should be separated, as the natural forest which is most valuable for biodiversity conservation plays little role in on-going C sequestration and the biodiversity value of tropical forest plantations on degraded soils which may sequester carbon is not very impressive.

Soil organic matter plays a number of roles in cropping systems (Figure 2.2.7) and its dynamics merits special interest from those who seek to improve the sustainability of cropping systems, especially in the humid forest zone (Sanchez *et al.*, 1989). For all the roles of soil organic matter, technical alternatives exist and today's hydroponic horticultural systems show that it is not only possible, but even economically attractive under certain conditions, to grow crops without any soil organic matter, or even without soil. Yet, for the vast majority of tropical farmers these technical substitutions are not feasible and soil organic matter still fulfills all functions. A 'shadow price' of soil organic matter might be based on the price of the technical substitutes which are not (or less) necessary if soil organic matter levels are maintained. Figure 2.2.7 tentatively indicates 'labile' and 'stable' soil organic matterpools associated with the organic matter functions, but this needs further specification. A considerable part of current agricultural productivity in the tropics is based on the nutrients mineralized from (labile) soil organic matter pools accumulated under natural vegetation. Many of the positive effects of

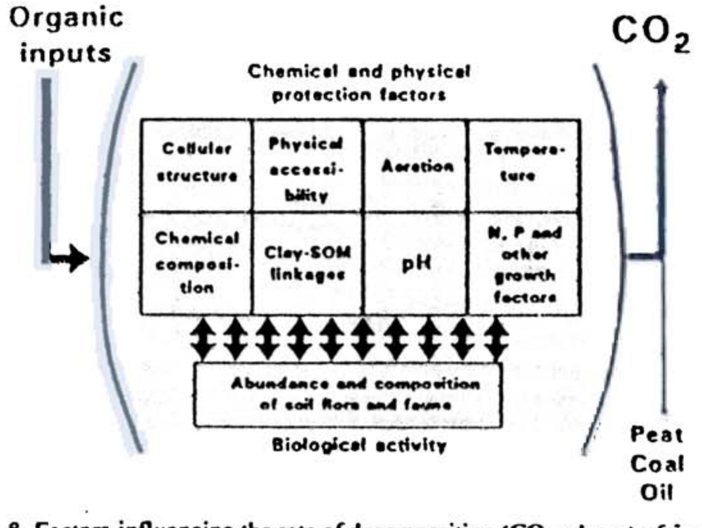

Figure 2.2.8. Factors influencing the rate of decomposition (CO_2 release) of organic inputs and providing partial and temporary protection from decomposing organisms.

agricultural practices such as ploughing, drainage and liming on crop yields result from accelerated breakdown of soil organic matter. A conflict thus exists between the role of organic matter as source of nutrients and its other roles. When not replenished, soil organic matter functions as a non-renewable resource and slash-and-burn (migrant) farmers may be tempted to follow or create new forest margins and leave a zone of depleted soil behind. In the humid tropics of Asia, such lands are generally occupied by grasses such as *Imperata cylindrica* which may partly restore the soil, or at least prevent further degradation. A diversity of biological, chemical and physical mechanisms is now known to selectively 'protect' different pools of soil organic matter from decomposition by soil micro-organisms (Figure 2.2.8).

2.2.3.2. Effects of land use change on soil C contents: analysis of Sumatra soil database
In the 1980's a coherent set of 1: 250 000 soil maps of Sumatra 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 recently analyzed for their soil organic matter content, as influenced by soil type and land use (Van Noordwijk and Nugroho, *in prep.*). Figures 2.2.9 - 2.2.13 show some of the preliminary data of this analysis. 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 2.2.9 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 2.2.9 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 2.2.9 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 2.2.9 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' 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).

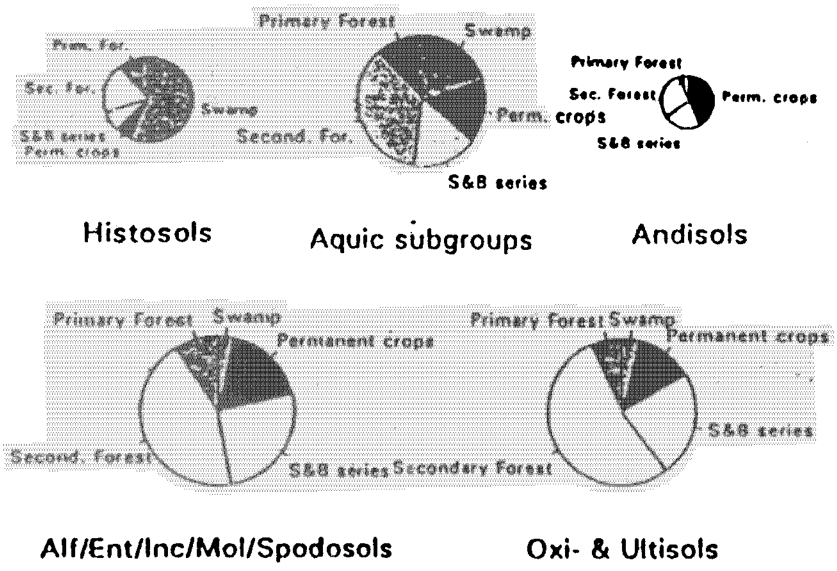

Figure 2.2.9. Land use by soil group in the CSAR soil database for Sumatra.

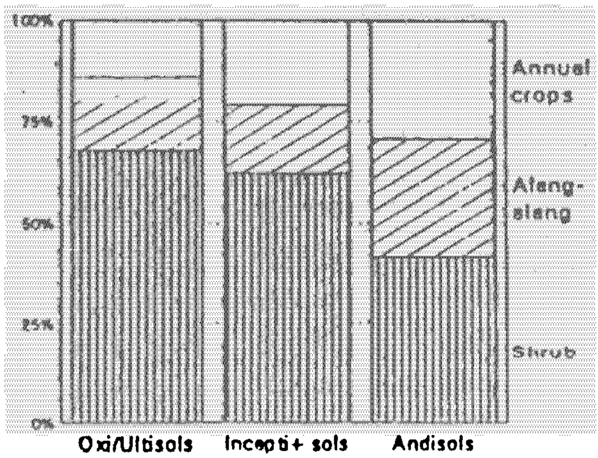

Figure 2.2.10. Composition of slash-and-burn (S&B) series on the three groups of upland soils.