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Modelling and measuring soil organic matter dynamics and greenhouse gas emissions after forest conversion

Report of workshop/ training course
8-15 August 1994, Bogor/Muara tebo
Indonesia

Edited by:
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ASB
ALTERNATIVES TO SLASH-AND-BURN

ASB-Indonesia Report number 1
1994, Bogor, Indonesia

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Foreword

The problems of slash-and-burn agriculture are complex phenomena because they involve people, land hunger and poverty on one side and preservation of natural resources on the other side. The solutions can not be simple and very likely have to be site specific since the human environment and socio-cultural systems play a central role. However, the global phenomena need to be characterized in such a way that a coherent diagnosis may be carried out based on common methodologies.

The ASB Project is one of many initiatives aimed at reducing deforestation caused by unsustainable slash-and-burn agriculture, by providing technical alternatives and policy options that eliminate the need to clear additional forest land and by encouraging to reclaim the degraded and abandoned lands. This is a worldwide research and development project based on intensive partnership between national and international agencies.

ASB-Indonesia, which is hosted by the Agency for Agricultural Research and Development (AARD), has selected four sites in the Sumatra benchmark area, *i.e* Air Dingin, Sitiung, Bungo Tebo, and North Lampung representing various ecological and socio-economic conditions. The studies will be focused on soil organic matter dynamics and comparison of greenhouse gas emissions at various land use systems, tree and crop productivity, farmer decision making and the effectiveness of the existing policies in promoting sustainable use of natural resources.

The workshop which is reported here, was the first activity within ASB-Indonesia which attempts to integrate the potential collaborators/researchers involved in the project before they are actually going to characterize the respective field sites. Having done that, it is expected that they will generate ideas on how to tackle the problems they will encounter in the field.

I am grateful that the participants of the workshop represented a wide variety of disciplines and institutions. I hope that the collaborative spirit and enthusiasm generated during the workshop will prosper in their future work.

I would like to take the opportunity to extend my congratulations and appreciation to the organizing committee who has worked very hard since the preparation until the production of this report. Last but not least I would like to express my gratitude to Dr. Paul Woomer and Dr. Cheryl Palm from TSBF in Nairobi, who contributed so much to the success of the workshop.

September 1994
Dr. A.M. Fagi
Chairman Technical Working Group ASB-Indonesia

1. Introduction

A global research program was started in 1994 to search for sustainable alternatives to slash-and-burn agriculture. Funds were obtained from the Global Environmental Facility (GEF) to start a cooperation between a large number of international institutes and a group of national research institutions (in phase I: Indonesia, Brazil and Cameroon).

The objectives are to reduce deforestation in order to protect biodiversity and mitigate the distortions of the global C balance, by helping farmers to find sustainable, long term livelihoods as alternative to destructive slash-and-burn agriculture, and by helping governments to develop policies which facilitate such transformation.

Phase I of the project concentrates on a detailed characterization of slash and burn practices and a diagnosis of constraints and opportunities for improvement. In Indonesia the peneplain zone of Sumatra was chosen as a focus of interest, with research sites in Jambi (low population density, forest margin) and North Lampung (high population density on similar soil, degraded lands); sites in Sitiung and the buffer zone of the Kerinci Seblat National Park will be studied as well.

The research will be carried out by a consortium of institutes under the Agency for Agricultural Research and Development (AARD), the Agency for Forestry Research and Development (AFRD), other Government research institutions, Universities and NGO's, together with staff from international research institutes such as ICRAF, IRRI and CIFOR.

At the start of the first phase of the global project on 'Alternatives to Slash and Burn' (ASB) in Indonesia, we proposed to have a training course/workshop on 'Modelling and measuring soil organic matter dynamics and greenhouse gas emissions after forest conversion'. The objectives were that:

1. Key Indonesian participants in the ASB project be familiar with the standardized methods for the ASB site characterization, including measurements of greenhouse gas emissions, so that these methods can be applied on the four benchmark locations in Sumatera,

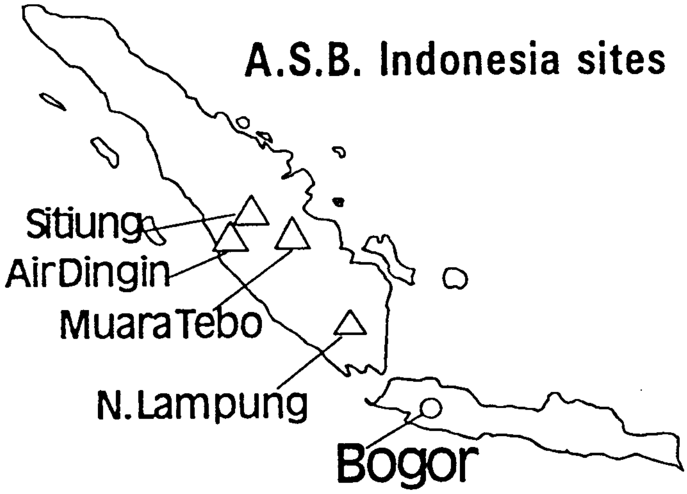
2. Participants be familiar with the CENTURY model for predicting soil organic matter dynamics for various land use options, as this model will be used to evaluate and extrapolate results from field experiments in the project.

3. A coordinated plan for the biophysical aspects of phase I activities be developed.

The training course, as held in Bogor and Muara Tebo from 8 - 15 August 1994 met these objectives, and also helped form a 'team spirit' for the coming research. Appendix 1 and 2 give the list of participants and the course program, respectively. In this report, we tried to synthesize the ideas and information provided during the training course/ workshop.

Thanks are due to all course participants for contributions, but especially to Dr. Paul Woomer and Dr. Cheryl Palm from the Tropical Soil Biology and Fertility program in Nairobi who came to Indonesia for the course and helped both with the contents and with the atmosphere of the course (see back cover).

Bogor, November 14, 1994
Daniel Murdiyarso, Kurniatun Hairiah and Meine van Noordwijk *(editors)*



2. Characterization of Sumatra as site for the Alternatives to Slash-and-Burn (ASB) project

2.1 Characterization requirements from the global perspective

Cheryl Palm
Tropical Soil Biology and Fertility (TSBF), Nairobi, Kenya

Figure 2.1.1 summarizes the conceptual framework of the project: farmer objectives and decision making processes are seen as the direct determinant of specific land use systems. Some of these land use systems lead to deforestation, loss of resources and poverty, others may lead to increased and sustained production. The aim of the project is to replace destructive forms of slash and burn agriculture by sustainable production systems. Farmer decisions are at least partly based on the available resources and the existing constraints. Government policies modify both

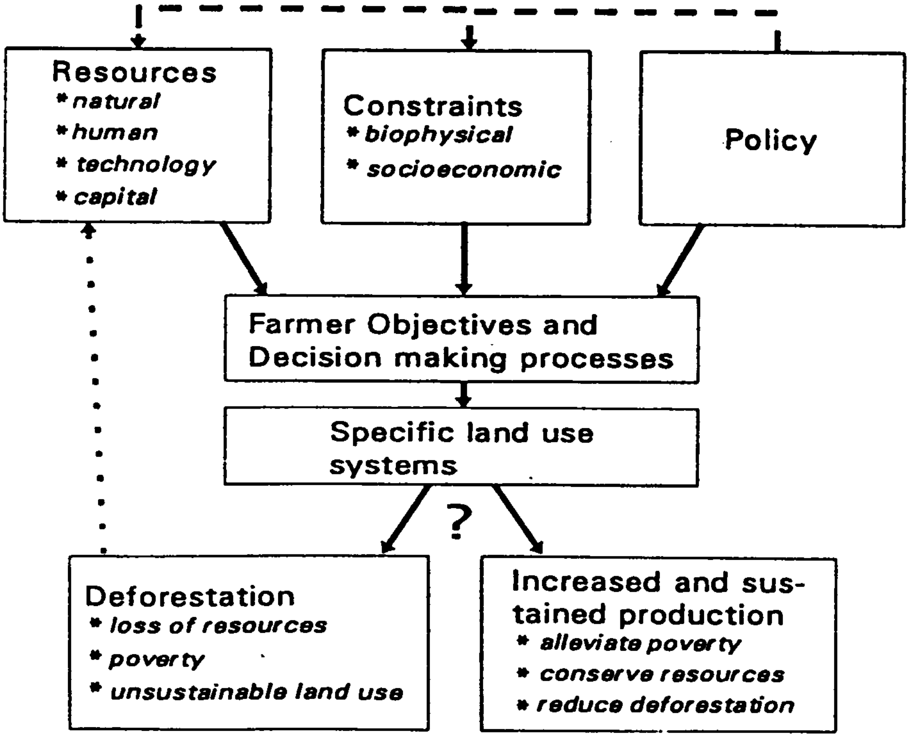


Figure 2.1.1. Conceptual framework for development of the Alternatives to Slash and Burn research program.

the access to resources and the various biophysical and socioeconomic constraints and thus have a bearing on farmer decisions and land use systems. Government policies may also have a direct bearing on farmer decisions. In Phase I of the project, the emphasis will be on a proper characterization of a number of key sites for the global project on alternatives to slash and burn agriculture. The characterization has three objectives:

1. To collect baseline information on biophysical and socioeconomic conditions under which slash and burn agriculture occurs at the moment and of the policies influencing farmer's decisions in these systems. This information should allow us to set research priorities for the next project phase to focus on the major constraints and opportunities for farmers to intensify land use and avoid soil degradation on newly converted forest soils and/or to reclaim already degraded lands.

2. To allow data synthesis and cross-site comparisons between the three continents; for this purpose a minimum dataset should be collected according to standardized procedures at all sites.

3. To allow extrapolation of results and recommendations to similar sites, locally, regionally and globally; for this purpose the critical processes must be related to general indicators for which widespread databases are available.

'Procedural guidelines for characterization and setting research priorities for alternatives to slash and burn sites' have been distributed to all participants. It includes a list of parameters to be collected at the site and benchmark level (compare Figure 2.1.2).

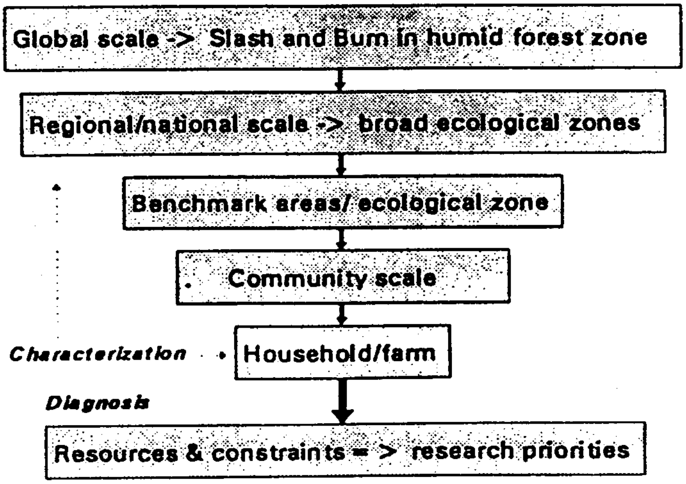
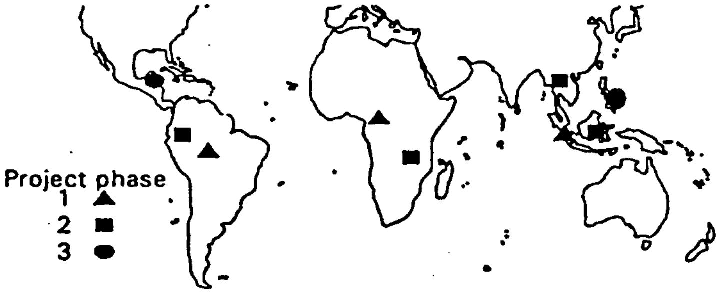


Figure 2.1.2. Procedure for characterization of issues for the ASB project.

Figure 2.1.3 summarizes the decisions made on benchmark areas and locations for the ASB project at a global level. The availability of funds has led to a distinction between Phase 1, 2 and 3 as the start of activities in the various countries.

Figure 2.1.3. Different scales and locations of the ASB project.



Region/Continent	Nation	Benchmark area	Community
Latin America	Brazil	1. Acre/Rondonia	Novo California, Theobroma
	Mexico	2. Mayan zone	to be selected
	Peru	3. Upper Amazon Basin	Yurimaguas Iquitos Pucallpa
S.E. Asia	Indonesia	1. Sumatra	Sitiung, Jambi, N. Lampung
		2. Kalimantan	To be selected
	Philippines	3. Mindanao	Claveria
	Thailand	2. Northwest	Chiang Mai
Sub-Saharan Africa	Cameroon	1. Humid forest	M'Balmayo
	Zambia	2. Miombo woodlands	Kasama

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

Meine van Noordwijk
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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.

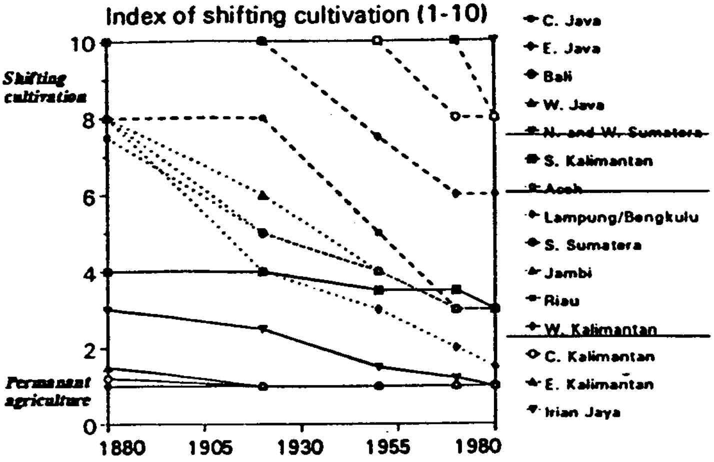

Figure 2.2.1. Historical transformation of shifting cultivation into permanent agriculture for various provinces of Indonesia, based on Richards and Flint (1993).

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.

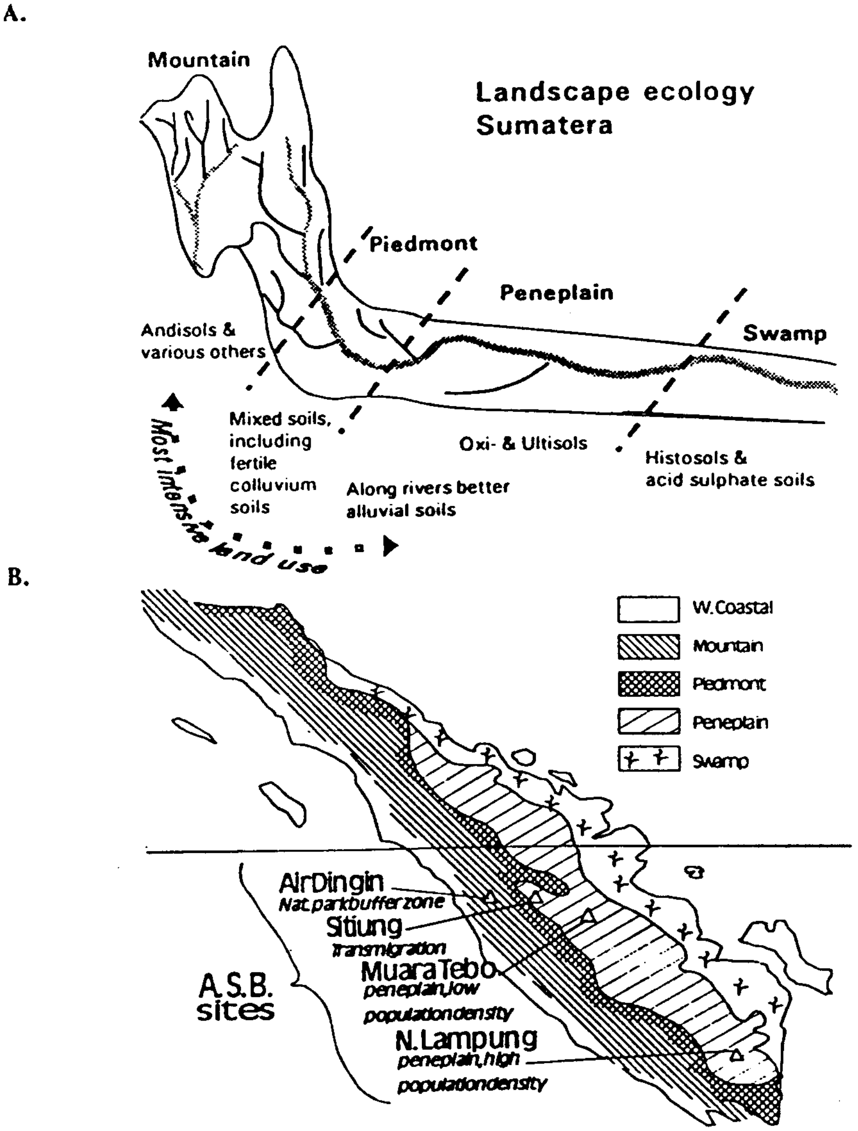

Figure 2.2.2. Ecological zones of Sumatra, based on Scholz (1983); A. Schematic transect. B. Map.

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.

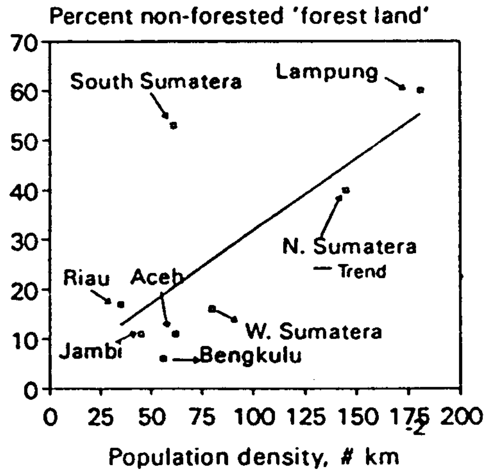

Figure 2.2.3. Forest damage in official forest area in Sumatra in relation to population density, based on RePPProT (1990) and Herman Haeruman (1992).

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

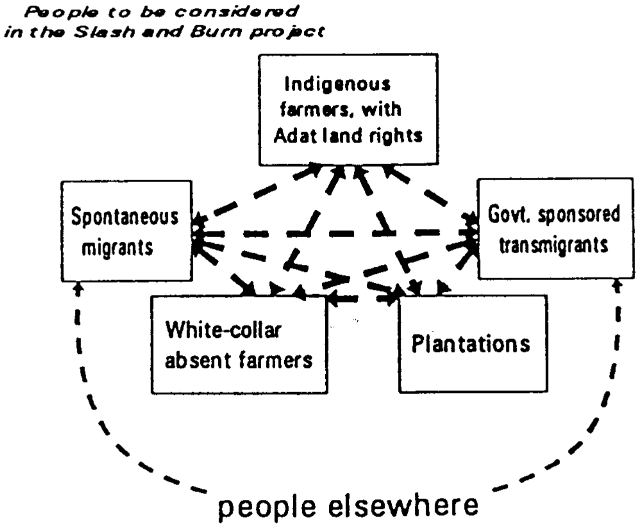

Figure 2.2.4. Actors in land use (change) to be considered in the slash-and-burn project.

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

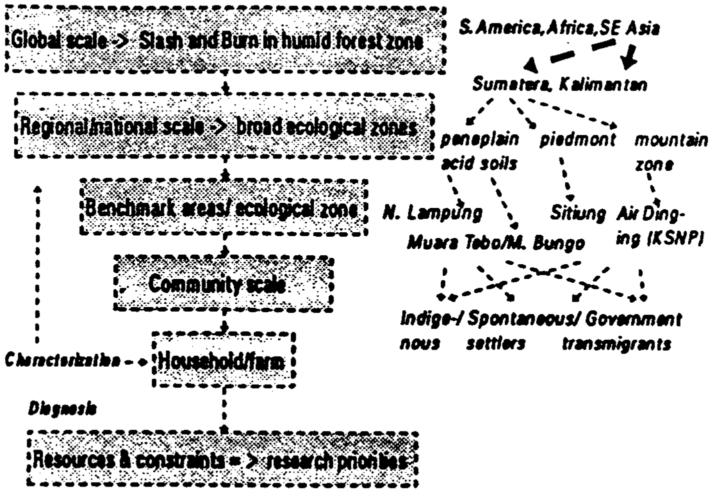

Figure 2.2.5. Selection of zones, benchmark areas and communities for further characterization for the ASB project.

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* neighbouring 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 rehabilitation as alternative 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

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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

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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.

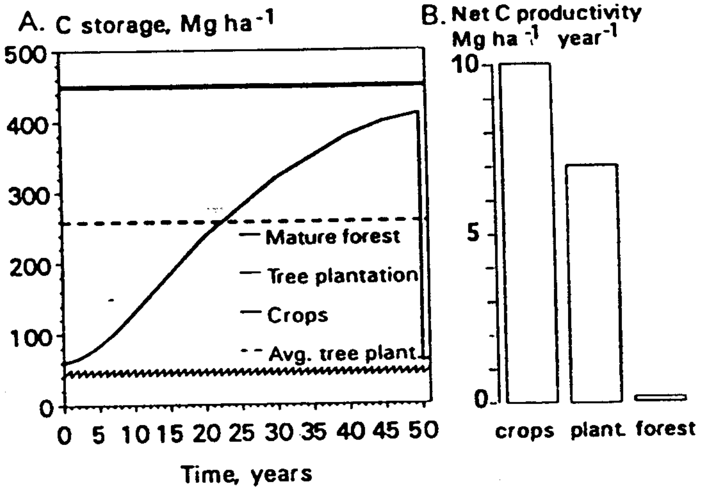

Figure 2.2.6. Schematic view on A. C storage, above plus belowground, in mature forests, forest plantations and permanently cropped land. B. Net C productivity of these systems, averaged over one cycle.

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

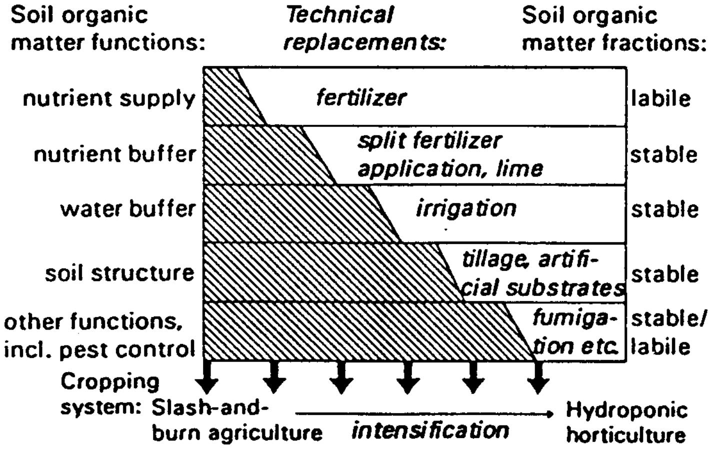

Figure 2.2.7. Soil organic matter functions in cropping systems and the technical replacements which can substitute for soil organic matter during agricultural intensification.

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

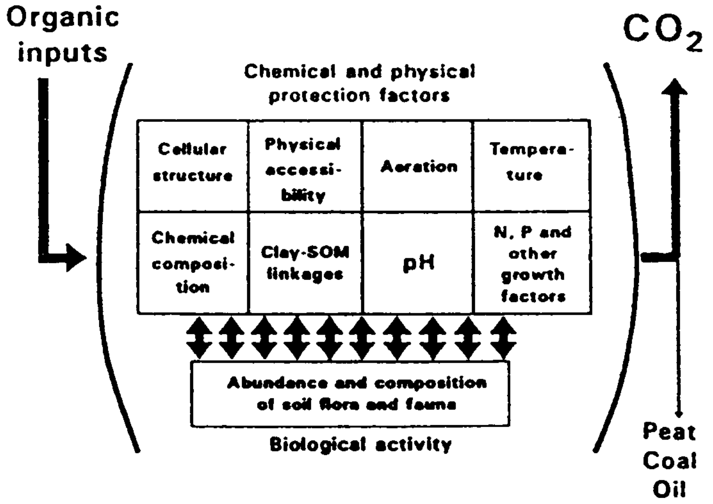

Figure 2.2.8. Factors influencing the rate of decomposition (CO$_2$ release) of organic inputs and providing partial and temporary protection from decomposing organisms.

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 shrubland, *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).

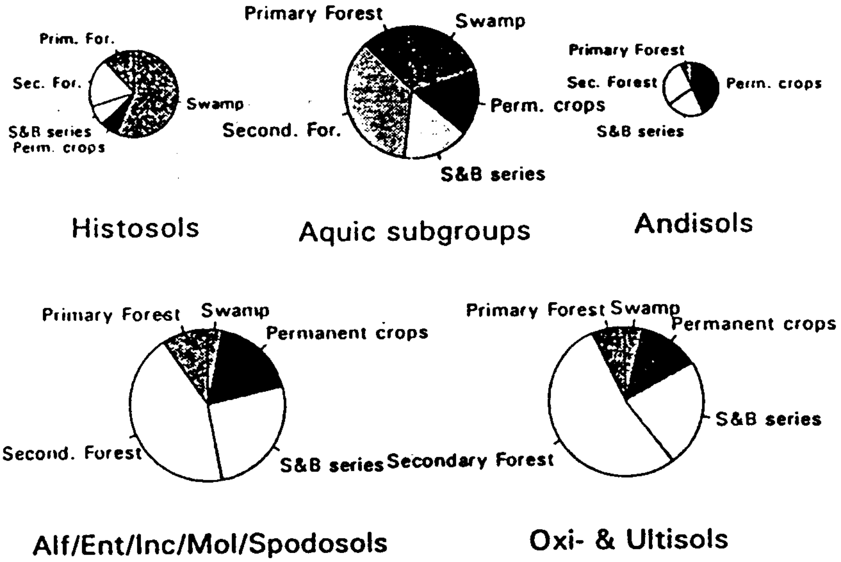

Figure 2.2.9. Land use by soil group in the CSAR soil database for Sumatra.

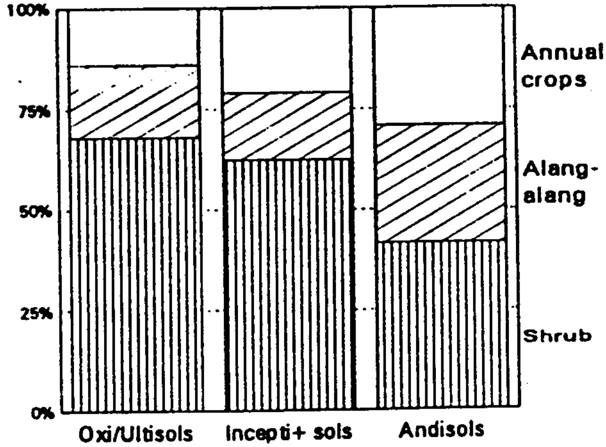

Figure 2.2.10. Composition of slash-and-burn (S&B) series on the three groups of upland soils.

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 2.2.10 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.

Figure 2.2.11 shows the average soil C content of the topsoil (about 15 cm) on vartious soil groups classified by land use in the late 1980's. Histosols obviously have the highest C_{org} content. Based on data of total profile C storage of Eswaran *et al.* (1993) we may expect that the Histosols, which cover 10% of Sumatra, contain more than 90% of all C stored in Sumatransoils. 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 Oxi- and 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.

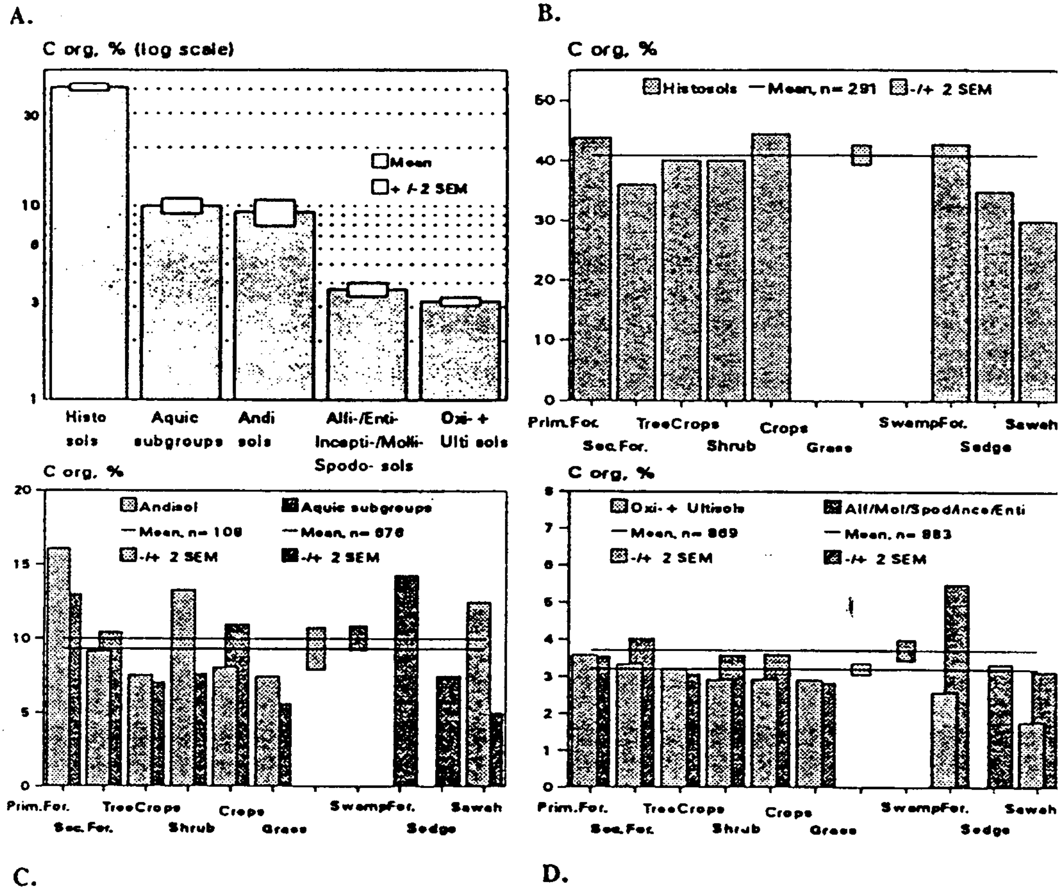

Figure 2.2.11. Average C_{org} content of the topsoil according to the soil database for Sumatra (Indonesia) of the Centre for Soil and Agroclimate Research, Bogor. A. Average per soil group (note logarithmic scale); B, C, D average values per land use category, the horizontal line indicates the averaghe per soil group, the error bar indicates plus and minus two times the standard error of the mean (SEM).

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- and Ultisols. Hardon's average topsoil content over all land uses (3.53 %) is close to the present average of 3.46% for these soil groups. We conclude that the average C_{org} content of the topsoil in Lampung/S. Sumatra in the early 1930's was similar to the average for the whole of lowland Sumatra, excluding volcanic, wetland and peat soils in the late 1980's. There is no indication of any change in soil C storage under forests in the 50 year time

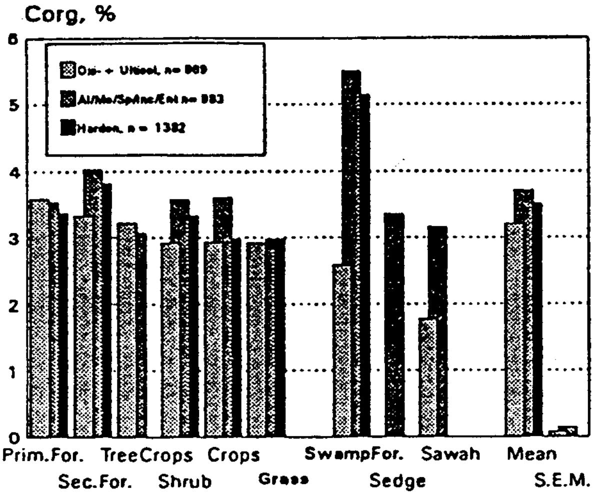

Figure 2.2.12. Comparison of C_{org} of topsoil in the 1980's, with a dataset for S. Sumatra from the 1930's (Hardon, 1936).

span during which atmospheric CO_2 concentration increased by 20% in this period, from 0.29 to 0.35%.

Figure 2.2.13 shows the relation between soil pH and the average C_{org} content of the pH class. The data set for the 1980's confirms a relation established in the 1930's by Hardon (1936). No indication what so ever of a change in C_{org} is found over a 50 year period. 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).

A multiple linear regression analysis of C_{org} on pH, texture, altitude and slope resulted in heterogeneous regression residues (data not shown). The C_{org} data were log transformed and this resulted in more homogeneous residues. The resulting regression model is therefore multiplicative instead of additive. The multiple regression analysis (Table 2.2.4), includes soil pH, texture, altitude, slope, land use and soil type. 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 significant from zero. In this regression, the effects of altitude are studied separately from the

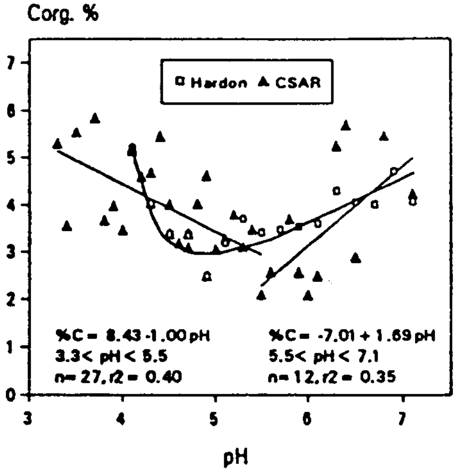

Figure 2.2.13. Relation between soil pH and organic carbon content of the topsoil in lowland (< 200 m) forests; data for the 1930's are indicated by squares (Hardon, 1936) and for the late 1980's by triangles; in both cases the average C_{org} content is given per class of soil pH (per 0.1 unit).

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:

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

In the overall data set the upward trend of C_{org} at higher pH was not very pronounced, and adding a quadratic term (pH^2) did not significantly improve the percentage of variance accounted for by the regression equation. 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. A point of caution is needed, however, as a considerable part of the variation in the data set remained unexplained. This may indicate inadequacies in the classifications used, or the importance of factors not included in this study, such as the time period elapsed since a change in land use occurred.

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. Evidence for a number of 'protection factors' could be obtained: waterlogging, low pH,

Table 2.2.4 Multiple linear regression of $\log(C_{org})$ for Sumatra soil database, derived by step function of Genstat V, with inratio=6 and outratio=6; a logarithmic transformation was used to obtain homogeneous residuals; only soils with complete texture data were included, Histosols were excluded for 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} (.. Secundary forest) +
-0.169^{NS} (.. Upl_crops) +
-0.245* (.. Alang-alang) +
-0.267* (.. Perennial crops) +
-0.288* (.. Shrub) +
-0.335* (.. Sedge) +
-0.433* (.. Sawah)

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mineralogy (Andisols), texture, altitude (temperature) and slope all have a significant effect on the C_{org} content of the top soil.

In peat soils rapid changes can occur after drainage. C losses can lead to subsidence of the soil profile (which is difficult to measure in a landscape without fixed points of reference), changes in bulk density and decrease in C content of the remaining soil. Nugroho and Widodo (1993) tested 7 peat soils in as column experiment were soils were drained for 1 month and then irrigated for 2 months. The C_{org} content decreased from 55 to 40% on 4 soils derived from a shrub vegetation and from 55 to 50.5% for 3 soils derived from swamp forests on Sumatra and Kalimantan. This substantial decrease only reflects of the C losses, as soil shrinkage (subsidence) was not measured. Total C losses can be estimated if we assume that the mineral parts of the soil remain unchanged and express the measured C content per unit mineral soil, instead of per unit dry weight, assume total organic matter content to be 1.7 times C_{org}, and mineral parts to be 100% - soil organic matter content. If $C_{org,0}$ and $C_{org,1}$ indicate the C_{org} content before and after drainage, respectively, the C losses relative to the initial amount equal:

$$\mathit{Relative\ C\ loss} = \frac{C_{before} - C_{after}}{C_{before}} = 1 - \frac{C_{org,1} \cdot (100-1.7 \cdot C_{org,0})}{C_{org,0} \cdot (100-1.7 \cdot C_{org,1})} \quad (1)$$

Applying this equation to the data of Nugroho and Widodo, we estimate the relative C losses in their experiment to be 85 and 60% of the initial stocks, respectively.

From this tentative evaluation of the CSAR soil data base a number of conclusions (or hypotheses for further research) can be formulated for the ASB project:

- slash-and-burn farming methods occur on all upland soil types in Sumatra,
- on the poorest soils (Oxi- and Ultisols) the lowest crop: fallow ratios were found within the tentative S&B series,
- 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 on the other soil orders,
- existing land use, including S&B, on the Oxi- and Ultisols may be the least sustainable: the need to replace it by more permanent production systems may be highest on these soils,
- only small areas of primary forest remain on any of the soil types; the majority of the forest is 'secondary' forest and may contain large areas of jungle rubber and fruit tree enriched agroforests.
- 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 5% of the histosols may release more CO_2 into the atmosphere than transformation of all remaining forest into *Imperata* grasslands,
- no indication is obtained that tree-based production systems in plantation differ in C_{org} content from land used for annual crops.

2.2.3.3 Options for managing soil C and priorities for research

As emphasized by Lugo and Brown (1993), the prevailing concepts of change in soil C content due to changes in land use are too simple and possibly too pessimistic (if we agree that the highest possible soil C storage is the most desirable). There is a range of potential protection factors for soil C and land management options to increase their effectiveness are poorly explored.

From the data given here for Sumatra is seems that the protection of wetland soils and sites needs more attention if soil C storage is to be increased in the humid tropics. Changes in upland soil types are smaller than normally expected and will generally be less than 20 Mg C ha^{-1}. Within agricultural land use, soil tillage and liming operations should be considered critically as they affect two common C_{org} protection mechanisms. Although potentially reforestation on degraded grasslands leads to an increase in terrestrial C storage, the current techniques for large-scale reforestation of *Imperata* grasslands (based on intensive soil tillage to remove the grass, lime and fertilizer applications; Temmes, 1992) may have a negative effect on soil C storage, partly offsetting the gains aboveground.

Priorities for research on C sequestration in the humid forest zone should certainly include emphasis on sedimentation processes in colluvial and alluvial sites, ranging from a single hedgerow of trees to a river delta and on management effects on peat and other wetland soils. As research priorities, we may continue to focus on a number of incompletely known inputs (esp. fine root turnover) and on developing methods which measure the most active fractions of soil organic matter, as well as those fractions still protected from microbial attack by one of the many protection mechanisms.

Finally, we may 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:

$$a_c = \frac{a_s P_{sc}}{f_r P_c} \quad (2)$$

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}:

$$C_{ts} = C_f (1 - a_s) + a_s C_s = C_f - a_s (C_f - C_s) \quad (3)$$

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

$$C_{tc} = C_f (1 - a_c) + a_c C_c = C_f - a_c (C_f - C_c) \quad (4)$$

Substituting (6) into (8):

$$C_{tc} = C_f - \frac{a_s P_{sc}}{f_r P_c} (C_f - C_c) \quad (5)$$

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

$$C_{tc} - C_{ts} = a_s \left[C_f \left(1 - \frac{P_{sc}}{f_r P_c}\right) - C_s + C_c \frac{P_{sc}}{f_r P_c}\right] \quad (6)$$

This difference is positive if

$$\frac{C_f - C_s}{C_f - C_c} > \frac{P_{sc}}{f_r P_c} \quad (7)$$

Table 2.2.4 Carbon mitigation options in agriculture, as summarized for the 1995 report of the Intergovernment Panel on Climate Change (IPCC) ***(in preparation)***

A. Increased C stocks in agricultural soils

- A1. Increased use of local organic sources (crop residues, cover crops etc.),
- A2. Increased use of organic wastes from outside (town and agro-industrial wastes),
- A3. Slower turnover of soil organic matter (reduced tillage, reduced liming, etc.),

Tentative upper limit:
20 Mg C ha^{-1} (0.5 % C_{org} in upper 15 cm at b.d. 1.3 g cm^{-3}), distributed over a 50 year period:
-> 2% of annual current fossil fuel C release. No further effects after 50 years.

B. C-stocks preserved or built up outside agriculture, made possible by increased productivity of agricultural soils

- B1. Development of forests and swamps on set-aside land in temperate zones with current overproduction.
- B2. Less conversion of tropical forests into agricultural use, based on intensification of agriculture and reclamation of 'waste' lands

Tentative upper limit:
Per doubling of productivity 150 Mg C ha^{-1} can be protected/sequestered outside agriculture (more in humid tropics, less in subhumid and semi-arid tropics and temperate zone, more where swamp development is possible). -> 10-15% of current fossil fuel C release.

C. Reduced C flows from fossil fuel use in agriculture

- C1. Lower energy use in storage and transport
- C2. Animal traction and other renewable energy sources
- C3. Reduced dependency on N fertilizer

D. Reduced C flows from fossil fuel use outside agriculture

- D1. Biofuel production

Tentative upper limit for C + D:
Upper limit 5-10% of current fossil fuel use, no time limit.

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 more 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 $(C_{sc} - C_{u})/(X + Y)$ 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.

Table 2.2.4 summarizes the possibilities to reduce the impact of the rise in atmosphceric CO_2 levels (which is largely due to fossil fuel use) by changes in agricultural practices. The problems can be mitigated by increasing C stocks in terrestrial ecosystems, both in (A) and outside (B) agricultural use, and by reducing flows of fossil fuel CO_2 to the atmosphere (C and D). The tentative orders of magnitude of the various options need further checking. The ASB project can contribute to this for the (humid) tropics. For the time being, the main reason to study soil C pools in more detail is their link with agricultural productivity and intensification of land use.

2.3 SEAMEO-BIOTROP studies of vegetation and land use changes in Sumatra

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2.3.1 Introduction

BIOTROP is a Regional Centre for Tropical Biology under the South East Asian Ministries of Education Organization (SEAMEO). One of the main activities in the TFB (Tropical Forest Biology) Programme is to develop the Tropical Forest Information System by linking the various fields of Forest Ecology (including forest productivity, forest biodiversity, and forest ecosystem functioning) to compose a Tropical Forest Ecosystem Database. Remote Sensing is used to compose a bio-geographical database. A number of GIS software packages are used, including ILWIS and ERDAS, to evaluate small and large scale land use change, ecosystem dynamics, forest productivity etc. One of the activities closely related to the ASB project is an evaluation of tropical deforestation and land use change in Jambi Province by comparing recent satellite images with the vegetation map made in the seventies. Such a comparison is called a multi-date procedure (Gastellu-Etchegorry *et al.*, 1993).

Remote sensing techniques offer the potential of continuously viewing large segment of the earth's surface, thus documenting the changes that are occurring. There are various types of remote sensing products available and used at BIOTROP, such as aerial photograph, multi-spectral satellite imageries. Each of these products provides advantages and disadvantages concerning their resolutions which can complementary be applied through multi-stage sampling designs. Low resolution satellite data (NOAA, LANDSAT-MSS) are used at the first or global level and high resolution remote sensing data (LANDSAT-TM, SPOT, aerial photograph) at the second or local level. After documenting global change, we also have to try to understand the significance of these changes for the biosphere.

The coupling of satellite data and forest ecosystem models has been a great scientific interest in forestry science and ecology (Running, 1986). Tropical forests are difficult targets for remote sensing, however, at least if one wants to discriminate between primary, secondary and logged-over forest types and the man-made 'agroforests'. Uncertainties are also due to variations in inventory methods between studies with different objectives and methods. Rates of deforestation can be change rapidly. Therefore satellite data which give a quick assessment of green leaf biomass or Normalized Difference Vegetation Index; NDVI (Tucker, 1979), mean surface temperature, albedo, precipitation and several atmospheric gases indicative of biological activities (NASA, 1987) will also be utilized in the future.

2.3.2. Land use change in Jambi

Land use change is one of the important elements of global change. It has direct effects on terrestrial ecosystems, such as alteration of land cover, carbon release and the capability of the terrestrial ecosystem in fixing atmospheric carbon. Changes in temperature and water availability, and net release of soil carbon or respiration due to increased temperature may be considered as its indirect effects. The effects would initially induce changes in function and structure of terrestrial ecosystems that are expected to feedback to the atmosphere and geosphere. Land use change in many developing countries like Indonesia is usually associated with removal of forests and development of agricultural lands. According to Houghton (1992), carbon release from change in land use has increased continuously, from 0.6 - 2.5 Gt (1 Gt = 1 gigaton = 10^9 ton) for 1980, and to 1.1 - 3.6 Gt for 1990, almost entirely from the tropics. The imbalance in the global carbon cycle (the so-called missing carbon) represents an accumulation of carbon on land. The magnitude of imbalance due to land use change is determined by environmental variables affecting metabolism, decomposition and mineralization.

Deforestation, therefore has to be understood as changes in ecosystem structure and carbon balance. When clear cutting is practiced, two important processes are to follow : reduction of land cover or forested area, and reduction of Net Primary Production (NPP). A third process occurs when selective cutting is applied and the forest gets a chance to recover. It is always difficult, therefore to answer the question of whether forests globally are accumulating or loosing carbon (Fig. 2.3.1).

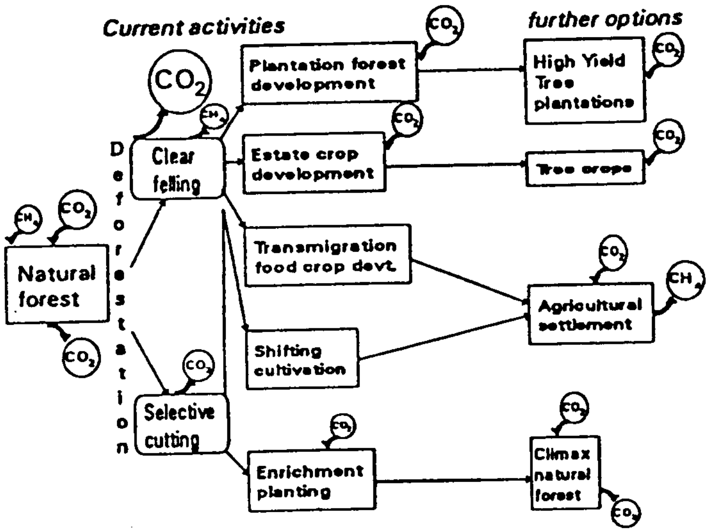

Figure 2.3.1 Land use following deforestation leading to release as well as uptake of atmospheric carbon (Murdiyarso, 1993)

Based on the identified forest types checked on the ground, there were eight classes of vegetation type obtained from NOAA image, 12 types from LANDSAT-MSS and 21 types from SPOT. SPOT and LANDSAT-TM gave almost similar results, meaning that the same objects would be classified as the same theme or unit on SPOT as well as on LANDSAT-TM data

(Djailang, 1987). However, it was obvious that multi-spectral classification on SPOT data gave better results, especially for interpreting, identifying, and delineating the secondary vegetation types.

By overlaying the digitized images from 1986 (Laumonier *et al.*, 1986) and 1992 the ILWIS software gave the change in land use in tabular form indicating the change of vegetation types and their areas. It is indicated that the most severe change from primary forests into secondary types was the change of primary limestone forest into secondary forest (92 percent), followed by lowland (13.6 percent), montane (12.3 percent), hill (9.07 percent), and submontane (6.65 percent). Minor drastic change from primary forests into cultivated types occurred in swamp (11.3 percent) and lowland (6.5 percent). As a matter of facts most cultivated areas were formed from logged-over lowland forest (22.7 percent), small portion from logged-over swamp forest (9.8 percent), while logged-over peat swamp forests remained unchanged. It is also exhibited that 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 also gave indication of the rate of deforestation in Jambi which involved 30 percent of the primary forest covering an area of about 400,000 ha. The detailed land use changes is shown in Figure 2.3.2.

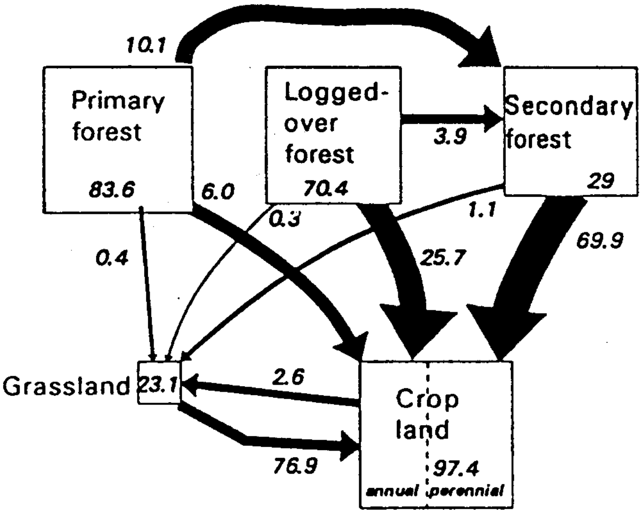

Figure 2.3.2 Land use change in Jambi Province estimated using remote sensing technique (Murdiyarso and Wasrin, 1994); the size of the boxes and arrows indicated the absolute areas, the numbers give the percentage change.

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 by ILWIS will be used to estimate the changes in the above-ground biomass per unit area. Therefore the initial vegetation types and converted or new vegetation types and their areas were tabulated. Furthermore, the amount of carbon released due to conversion of vegetation type was calculated by comparing with secondary data of above-ground biomass obtained from various sources. 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.

It is obvious that 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. The tendency of change from secondary forest are mostly into cultivated areas but grasses had also increased in this stage, probably because the shifting cultivators had worked for the second cycle on their fallows lands. The same phenomenon was observable in almost all degraded lands and cultivated types. As a results change from grassland into cultivated types was high (20 percent in dry land and 16.8 percent in wetland). Murdiyarso and Wasrin (1994) also give estimates of carbon release resulting from the changing above- ground biomass. They estimated that during a six years period the amount of carbon released from land use changes in Jambi was 176,403,000 ton or 29,400,000 ton/yr which is equal to 0.03 Gt C/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.

For further studies it is thought to relate the above-ground biomass and NPP because NPP has now become readily assessable using remote sensing technique (Running et al, 1989). The necessity to quantify global terrestrial vegetation changes should be related not only to the structural changes but also the functional properties of the vegetation, especially within the framework of climate change. The carbon budget will be more relevant to be discussed when the functioning of each vegetation type is understood. More specifically, NPP shows the capability of vegetation types in fixing atmospheric carbon and thus forms an important ecosystem function.

NPP may be estimated from ecosystem models or using a recent approach which employs remote sensing techniques. An explicit formulation of NPP is based on NDVI, a dimensionless index given by combining high resolution radiometric satellite sensors, as given by Running (1989). For the case of NOAA-AVHRR NDVI is the algebraic combination of surface radiance in the red (R: 0.56 to 0.68 μm) and near-infrared (NIR: 0.75 to 1.1 μm), given as:

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

In order to reduce ambiguities of the estimated NDVI, regional-scale derived from local area coverage (LAC) raw data having 1.1x1.1 km^2 resolution may be used.

2.4 Research programs of CIFOR and ICRAF related to the ASB project

2.4.1 Geographic Information System at CIFOR

CIFOR was established in 1993 as part of the CGIAR (Consultative group of Agricultural Research) network, to stimulate and coordinate research on sustainable management of tropical forests, improve the livelihoods of 'forest people' and conserve biodiversity.

CIFOR will officially join in the ASB project in Phase II and is thus interested in the characterization and diagnosis work in Phase I. The exact nature of CIFOR's involvement is still open for discussion.

Dr. Andy Gillison and bu Ati introduced us to the Geographic Information System (GIS) which CIFOR is developing. As example they digitized a map of part of the Kerinci Seblat National Park. Based on a digital elevation model a more precise interpolation of climatic data can be made then is so far available and this can help in predicting more accurately the potential range of plant or animal species, based on limited survey data. If the survey data are obtained in a transect spanning the major environmental gradients, a cost-efficient method of biological survey's is possible.

Dr. Gillison also introduced the concept of 'plant functional attributes' (pfa's) as a scheme to describe and analyze ecological similarities across taxonomic groups. This system would be useful, e.g. in comparing the fallow vegetation in the three continents where ASB is involved.

2.4.2 Agroforestry Research in Southeast Asia by ICRAF

ICRAF's S.E. Asia Research Programme was initiated in 1992. ICRAF's overall objective '...helping to mitigate tropical deforestation, land depletion and rural poverty through improved agroforestry systems' is translated into a division for research and a division for training, information and dissemination. The research is organized in four programs:

1. *Characterization and Impact* - studying existing agroforestry systems in their interaction with factors such as climate, soils, markets and government policies.

2. *Multipurpose Tree Improvement* - looking at the prospects and methods for improving the tree germplasm used in agroforestry systems.

3. *Component Interactions* - focussing on the tree-soil-crop interactions in various agroforestry systems.

4. *Systems Improvement* - comparing existing and 'improved' versions of agroforestry systems and through a process of on farm testing feeding them into the 'real world' as studied in program 1.

In the integration between the four programs the 'Diagnosis and Design' procedure developed by ICRAF is used to identify constraints and exploit opportunities.

For the Southeast Asia program, three priority ecosystems have been identified:

A. Forest margins or zones of current forest conversion; here we focus on 'complex agroforests' as sustainable alternative to destructive slash-and-burn systems based on annual food crops only.

B. *Imperata* grasslands, where small-scale agroforestry methods can contribute to reclamation of currently underutilized land, and

C. Hill slopes, where naturally vegetated strips and contour hedgerows can intercept eroding material and contribute to erosion control.

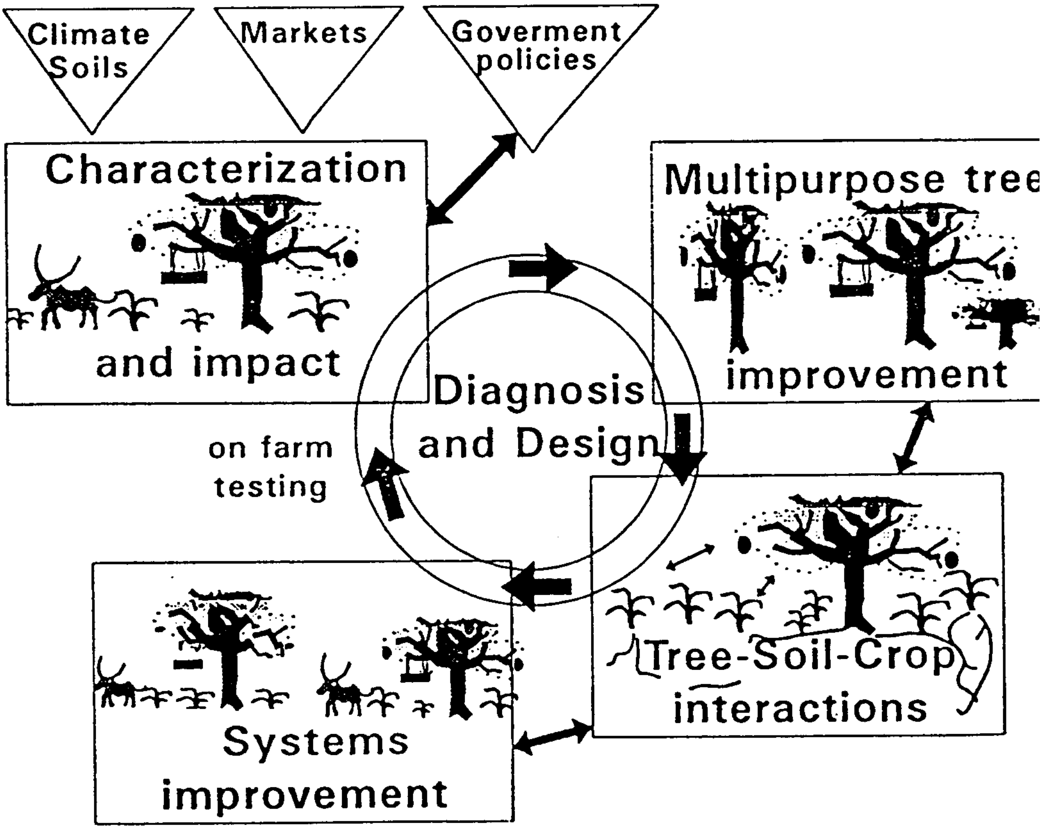

Figure 2.4.1 ICRAF research programs

3. Application of Simulation Models to Shifting Cultivation Systems

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Principle

A contribution by The Tropical Soil Biology and Fertility Programme (TSBF) to the Alternatives to Slash & Burn Consortium (S&B) is the application of simulation modelling to shifting cultivation systems. The model selected for this purpose is CENTURY ver 3.0 (Parton *et al.*, 1992). CENTURY is a general model of plant-soil ecosystems that may be used to represent many common land uses including natural and managed grasslands, natural and plantation forests and field monocrops (Parton *et al.*, 1987, 1989) and is able to move between land uses within a single simulation (Woomer, 1993a). CENTURY simulates the dynamics of carbon, nitrogen, phosphorus and sulphur within plants, residues and soils. Through the use of simulation models, it is hoped that the impacts of current shifting agricultural and alternative practices may be predicted beyond a time-frame that is possible through field observation and experimentation alone.

Strategy

TSBF Headquarters staff have previously developed the capacity to apply CENTURY to shifting cultivation systems (Woomer, 1993b) and planned changes in the soon-to-be-released CENTURY ver. 4.0 will increase that model's applicability to these systems by allowing for multiple- and intercropping. TSBF proposes the following strategy to apply simulation modelling to S&B:

1. *July 1994.* TSBF will purchase a copy of CENTURY 4.0 for distribution to collaborative institutes in Brazil, Camaroon and Indonesia. The national institutes will nominate one or more scientists to collaborate with TSBF during future activities and identify this individual to TSBF Headquarters by November 1993.
2. *July 1994.* TSBF will provide data report forms and instructions to national cooperators that allow for the construction of preliminary site data files (contained within this communication).
3. *September 1994.* The nominated national scientist(s) will complete the data report forms with the best available data based on secondary sources of information.
4. *August - November 1994.* TSBF scientists will visit the various S&B field sites, provide training on the use of CENTURY, assist in improvement of site data files and install experiments useful for model calibration and validation.
5. *December 1994 - June 1995.* The long term impacts of present and candidate land use practices will be simulated by cooperators, the stronger candidate land uses reported to the respective institutes and the overall results summarised in a publication intended for an international journal.

The following information is intended to brief cooperators on the hardware requirements and capabilities of the CENTURY model. More detailed information on the model will be available upon arrival of the CENTURY USERS MANUAL (Parton *et al.*, 1992). Also included are the site data report forms that, when returned to TSBF Headquarters will be used to assemble preliminary site data files for each respective institute.

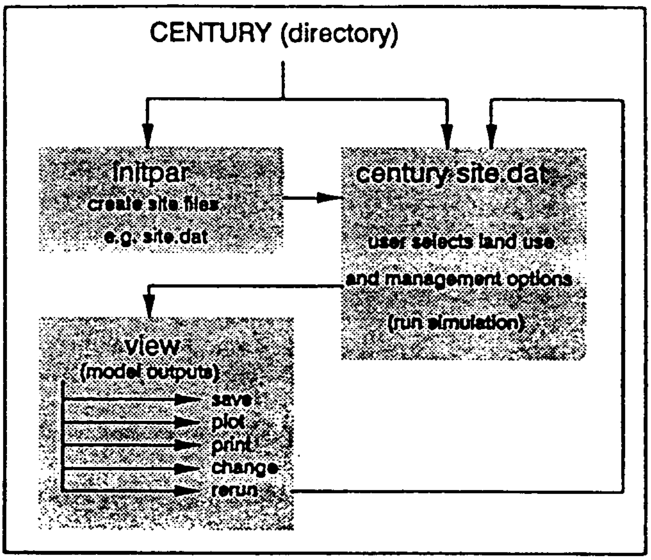

Figure 3.1. General structure of the CENTURY model. Files are constructed in INITPAR, run in CENTURY and visualised in VIEW.

Model structure and description

Parton *et al.* (1987) reported a detailed description of CENTURY; interested readers are referred to that publication. CENTURY was first developed to simulate grassland ecosystems of the Great Plains region of the US, and is currently being evaluated in many other areas of the world. Briefly, CENTURY simulates soil dynamic based on the dynamics of functional pools. These pools are differentiated on residence time in soils and the C:mineral ratios of these pools. Plant productivity is simulated via user defined (or default) algorithms appropriate to a particular ecosystem and climate.

The overall structure of CENTURY is presented in Figure 3.1. CENTURY consists of 3 major components: INITPAR, CENTURY and VIEW. INITPAR is used to develop site files that initialize the simulation. INITPAR may also be used to view model input and output definitions. The CENTURY component runs the environmental simulation; CENTURY must always be run with a data and fix file (i.e. site.DAT and site.FIX, respectively). The data file (.DAT) defines specific soil and climate attributes, the .FIX file is based on more general ecosystem attributes. CENTURY may be run for a grassland, cropland or forest, with various management options available to the user. The model output is then directed to the VIEW

Table 3.1. Minimum data requirements and selected user options to initialise a CENTURY site file as a shifting cultivation system.

Parameter
Parameters for site data files
monthly precipitation
monthly minimum temperature
monthly maximum temperature
soil pH
clay content
sand content
silt content
initial soil Active carbon
initial soil Slow carbon
initial soil Passive carbon
length of simulation (years)
forest growth season
initial large wood carbon
initial fine branch carbon
initial leaf carbon
initial coarse root carbon
initial fine root carbon
crop planting, senescence and harvest and regrowth months
crop harvest, shoot and root allocation
ash C:nutrient ratios
large wood removal during clearing
efficiency of burn
Shifting cultivation management options:
actual, long-term average or changing weather data
forest removal/return events: timing
forest removal events: biomass allocation
change in forest litter C:nutrient ratios
fertilisation timing and quantity
addition of organic residues
crop/fallow pattern
tillage pattern

component. VIEW is the output module of TIME-ZERO: an integrated modelling environment. VIEW allows for the output to be plotted, printed, or saved. VIEW also allows the user to change input parameters and to re-run the simulation without re-entering INITPAR.