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Reducing uncertainties in the assessment at national scale of C stock impacts of land use change

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Abstract

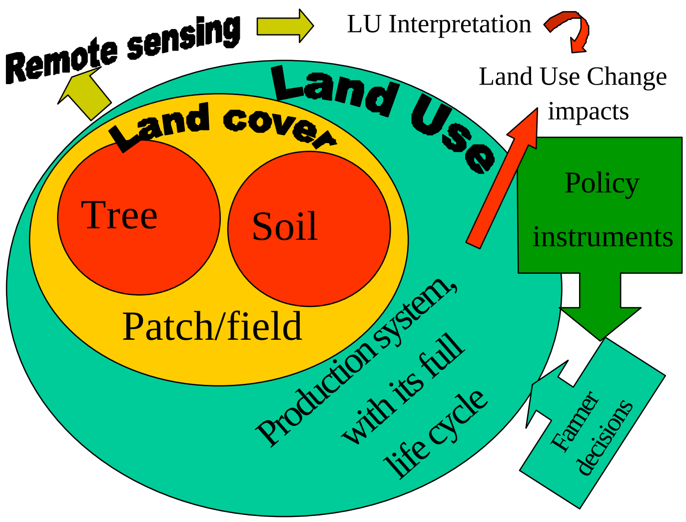
Efforts to increase terrestrial carbon stocks to slow down the rate of increase of atmospheric CO_2, can be based on generic national policies aimed at modifying land use decisions of large number of farmers, or on specific interventions at 'project' scale, with a limited spatial extent. For both type of interventions data are needed on the actual impacts of land use on C stocks, but the precision required is higher at the project scale if financial rewards are linked to actual performance. If the credibility of national assessments can be improved, countries can play a more active role in international negotiations on the credits and blame for mitigating and causing climate change.

Uncertainties in current assessment procedures are considerable, but no complete analysis has been made of how uncertainties at every step in the procedure propagate in the calculations of overall results. We review the following steps on the basis of research in Indonesia for the Alternatives to Slash and Burn project: land cover/use categories, biomass and soil C measurement in representatives of these categories, and extrapolations from land cover to time-averaged properties of a land use system.

Introduction

Considerable uncertainty remains in the humid tropics on both the rate at which land use practices change and the impacts this has on the global C balance. Here we will review a number of factors contributing to overall uncertainty of the estimates and discuss how this uncertainty can be reduced. Examples used are largely based on the 'Alternatives to Slash and Burn' project, that undertook measurements in the Amazon, the Congo basin (s.l.) and the humid lowlands of SE Asia, using and developing a common methodology (Palm et al., 1999).

Figure 1. Assessments of the impacts of land use change on C stocks involves a number of hierarchical scales:
- tree or other vegetation and soil that interact at patch or field level,
- land cover that can be observed with remote sensing tools,



- land use in the sense of a production system considered over its full life cycle,
- farmer decision making about land use (what, when, where)
- policy instruments that aim to influence farmer decisions.

The current IPCC method for national inventories of C stocks is constrained by the type of data that are generally available, and there has been no complete analysis of the uncertainties involved in every step of the procedure and the way these uncertainties propagate in the calculations to provide uncertainty in the overall result. All estimates, however, derive from assessments of the C stocks in vegetation (above- and below-ground) and soils at specific observation points.

Data on terrestrial C stocks can be used at different scales, e.g. to evaluate the prospects of specific C sequestration projects (operating over a specifically designated area, for a specified period of time), or to balance the losses and gains made at national scale to allow the country a stronger bargaining position in the international negotiations. The methods used should aim at 'whole system accounting', by targeting coverage of the total land area so that no 'leakage' (negative impacts outside of the target project area) can go unnoticed.

The IPCC methodology is based on a simple concept, namely that the total terrestrial C stock at any time t is equal to the product of the area fraction under each of a set of mutually exclusive 'land uses' and a typical C stock value associated with that land use at time *t*. It may help to write this down formally, so we are aware of the assumptions and simplifications made. Let

$$A_t = \sum_{i=1}^{n} A_{i,t} \qquad (1)$$

be the total area of a unit of land (e.g. a country or part there-off), which is allocated to *n* different land uses, that are mutually exclusive. We can define area fractions a_{it} as:

$$a_{i,t} = A_{i,t} / A_t \qquad (2)$$

The total C stock at time *t* is now defined as:

$$C_t = \sum_{i=1}^{n} A_{i,t} C_{i,t} = A_t \sum_{i=1}^{n} a_{i,t} C_{i,t} \qquad (3)$$

where $C_{i,t}$ is the C stock per unit area under land use *i* at time *t,* and the change in C

$$\Delta C_{t->t+1} = A_{t+1} \sum_{i=1}^{n} a_{i,t+1} C_{i,t+1} - A_t \sum_{i=1}^{n} a_i C_{i,t} \qquad (4)$$

stock over an interval *t -> t+1* as:

If the total area does not change (so $A_t = A_{t+1}$) and the land use classification is the same,

$$\Delta C_{t->t+1} = A_t \left(\sum_{i=1}^{n} (a_{i,t+1} C_{i,t+1} - a_{i,t} C_{i,t}) \right)$$

this means that the net C sequestration or emission is defined as:

(5)

This equation can be re-written to separate a term indicating change in average C stocks per unit area within the class *i*, and a term reflecting the change in area of class *i*:

change in average C-stock in class *i* | change in area for class *i*

$$\Delta C_{t->t+1} = A_t \left(\sum_{i=1}^{n} (a_{i,t} (C_{i,t+1} - C_{i,t}) + (a_{i,t+1} - a_{i,t}) C_{i,t}) \right) \qquad (6)$$

The current IPCC methodology is based on equation (6) and includes estimates of increments of average C stock within a land use class. Much of the uncertainty of current national inventories derives from the assumptions made about these increments. There is a tendency of counting the increments but ignoring the losses. The C term really refers to the average current C stock across a land cover type and real increments are only to be expected if the average age of trees or forests within a class increases.

To simplify the accounting procedure it may be preferable to 'package' specific sequences of C stocks (such as in shifting cultivation, sustainable selective logging or crop-fallow rotations) into 'land use systems', with a 'time-averaged C stock'. If one makes the further assumption that the typical C stock per land use class C_i is time independent, equation (6)

$$\Delta C_{t->t+1} = A_t \left(\sum_{i=1}^{n} C_i (a_{i,t+1} - a_{i,t}) \right)$$

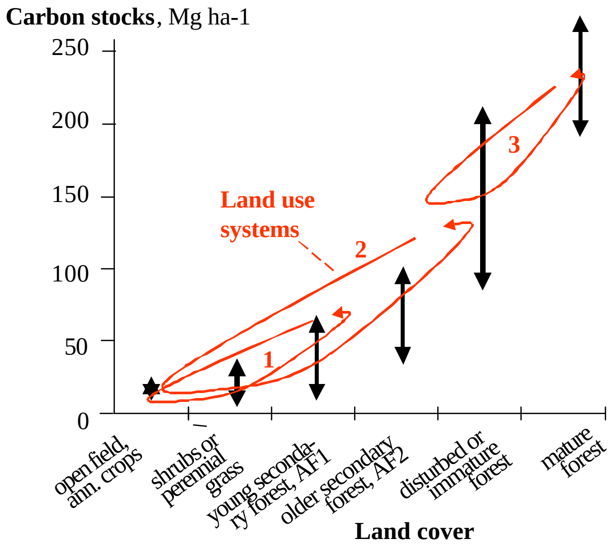
simplifies to:

(7)

This means that the change in C stock can be assessed from the change in the area fraction of the various land use practices, multiplied with a time-averaged C stock for each of these classes. For assessments at national scale the assumption that the va stages of a land use system will 'average out' may be acceptable, while at project scale the age-specific C stocks of land use systems promoted will have to be considered. There is a still a tendency, though, to count the increments of C stocks during aggrading phases, but ignore the C losses at harvesting or rejuvenation.

We will here review the uncertainties involved in following steps:
- establishing a system of n mutually exclusive land cover/use categories that allows data collection on the area fractions a_i,
- estimating the typical biomass and soil C stocks of these categories at time t, $C_{i,t}$ and extrapolations from land cover to 'time-averaged' properties of a land use system, C_i.

Figure 2. Relationships between land cover, land use systems (that contain various land covers in different parts of their life cycle) and C stocks; land use system 2 and 1 reflect long and short fallow rotation systems, 3 selective low-impact logging; AF1 = simple agroforestry systems, AF2 = complex agroforests



Land cover/ land use terminology

The issue: The Kyoto protocol only refers explicitly to two types of land cover: 'forest' and 'non-forest'. Although attractive for its simplicity and general appeal, this dichotomy does not stand to scrutiny when terrestrial C stocks are to be quantified, as the aboveground C stock in forest can range from 20 to 400 Mg C^{-1} ha^{-1}, even if we exclude the pathological cases of a cassava field that could legally classify as 'forest' because a cassava plant meets the minimum requirements of 'tree'. Clearly, if we are concerned about the storage of C in terrestrial ecosystems we will have to collect data for land cover classes that are more homogenous than 'forest'. Natural forest vegetation differs in typical C stock with climate and soil, and thus with elevation and latitude. In almost every zone a 'forest degradation' series can be found, with increasing intensity of harvesting of forest products and reduced C stock. Changes in intensity of use, without changes in forest cover per se, can have a substantial impact on C stocks.

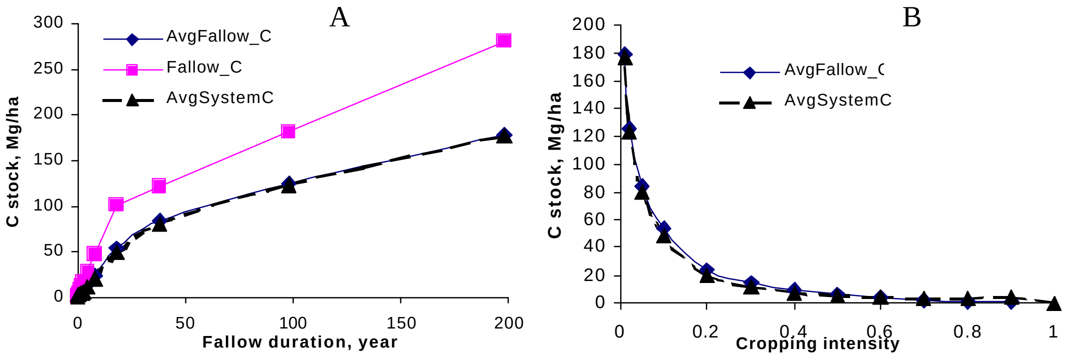


Figure 3. Time-averaged C stock of shifting cultivation and crop-fallow rotation systems, as a function of (A) fallow duration and (B) cropping intensity (= fraction of area cropped in any year), for an annual C stock increment during fallow years of 6 Mg C ha^{-1} $year^{-1}$ up to 100 Mg C ha^{-1} and
1 Mg C ha^{-1} $year^{-1}$ beyond and 2 years of cropping per cycle

Figure 2 relates a 'land cover' classification to C stocks and shows that 'land use' systems can consist of various types of cover during different phases of each cycle. The time-averaged C stock of a land use system depends on the C accumulation rates in different stages of the cycle, as well as on their duration.

For shifting cultivation of crop-fallow rotations (Fig. 3), the time-averaged C stock decreases with increasing intensity of land use. In a C accounting system based on Equation (6), 'shifting cultivation' as a land use does not lead to C sequestration or C release to the atmosphere, but 'intensification' of land use within this system would lead to net release of C, using the right-hand term of the equation.

In most existing land cover classification systems there is no place for 'agroforests' or 'complex multistrata agroforestry systems'. The IPCC methodology on soils recognizes such a class, but no national statistics exist on their area. Yet, in for example Indonesia these systems cover several M ha of land under agricultural use. If the land cover typology is only used for C stock inventories, any typology will do as long as its classes are relatively homogeneous and they can be recognized in remote sensing images covering the whole country. If, however, the assessment is to be a basis for discussing policy instruments on how to try and modify farmer decisions on the ground, then the classification system should refer to the type of livelihood farmers and other land users derive from the land.

The way the current IPCC methods are applied leaves room for considerable confusion over the role of mature and logged forest in the overall C balance. For example, the ALGAS study for Indonesia (Ghosh, this meeting) claimed that the Indonesian forest + land use change sector showed a net C sequestration, and that this more than off-set all emissions from the energy and other sectors in 1995. In view of the widespread degradation of Indonesia's forests in the 1990's this result is remarkable indeed, but it was apparently derived by correctly applying the agreed methods (Ghosh, this meeting).

Methods: Specifying major land uses on the basis of global ASB 'meta' land uses

Seven 'Meta' land uses were selected to organize the global ASB research agendas in a way that would facilitate cross-site comparisons (Table 1). Natural forests is the first point of reference, and 'Grasslands and pastures' the opposite ecological extreme. In between, a representative range of five generic upland, rainfed land use systems were selected for cross-continent comparisons of alternatives: extraction of forest products; complex multistrata agroforestry systems, also known as 'agroforests'; simple tree-crop systems, including but not limited to monoculture; crop fallow systems, which include the textbook version of 'shifting cultivation' or slash-and- burn agriculture; and continuous annual cropping systems, which may be monocultures or mixed cropping. Table 1also indicates major land uses of Sumatra's peneplains that correspond to each of the 'meta' land use systems. Not all of these categories can be distinguished in remote sensing data, but for the major ones spatial data can be collected.

Table 1. Global ASB meta land uses and corresponding land use in Sumatra (Tomich et al., 1998)

'Meta' land use	Corresponding land use in peneplains of Sumatra	Scale of operating unit
Natural forest	Natural forest	n.a.
Forest extraction	Community-based forest management	Community-level
	Commercial logging	Large-scale enterprise
Complex, multistrata agroforestry systems	Rubber agroforests	Smallholdings
Simple treecrop systems	Rubber monoculture	Smallholdings participating in a government project
	Oil palm / industrial timber monoculture	Large-scale estate enterprise
Crop / fallow systems	Upland rice / bush fallow rotation	Smallholdings
Continuous annual cropping systems	Monoculture cassava degrading to *Imperata cylindrica*	Smallholdings in a government settlement project
Grasslands / pasture	*Imperata cylindrica*	Sheet *Imperata* (>10,000 ha) used for grazing, hunting & other activities by local communities.

Before measurements were made by ASB researchers, a further specification of each of these classes was made, e.g. specifying the context in the landscape mosaic (*Imperata* grasslands occur at different scales, with likely difference in fire history).

Results and discussion

The ‘stratified’ sampling approach used, with a-priori definition of the strata proved to be essential for communication in a multi-disciplinary, multi-faceted study of the trade-offs between biodiversity, C stocks an profitability of land use practices. The category ‘community-based forest management’ proved to be heterogeneous in character, spanning a wide range of intensities of use and resultant forest types. Within the ‘rubber agroforests’ we also encountered a substantial variation in biomass of stands of similar age, related to the various degrees to which secondary forest species are tolerated as part of the system. Further research into the methods of stand rejuvenation showed that there are essentially two methods: field-level renewal in rotational systems and methods based on internal rejuvenation in gaps, resulting in a wide scatter of tree ages and diameter in a single management unit. This distinction or ‘rotational’ and ‘permanent’ agroforests had not been made before, and should be considered for the global ‘meta land use’ level, as it has consequences for many system attributes, including C stocks.

Measuring C stocks in vegetation

the issue: Aboveground biomass of vegetation is usually estimated on the basis of an inventory of tree diameter and heights in sample areas, and the use of ‘allometric’ equations to derive the biomass of the trees based on their stem diameter (and/or height). Allometric equations have been established for a range of tree species grown in monocultural plantations as well as for mixed-species forests. There is no clear understanding, however, of why the parameters of these allometric equations differ between sites and species, making the choice of any equation arbitrary. We tried to assess how much uncertainty in aboveground C stock results from this, and what approaches could be suggested as alternative.

results and discussion

Ketterings et al. (1999) derived a power equation from 29 trees of 8-48 cm in diameter in Sepunggur, Jambi as follows:

$$\mathbf{AGB} = 0.0661\ \mathbf{D}^{2.59} \qquad (\text{kg.tree}^{-1}) \qquad (8)$$

where AGB = aboveground biomass and D is stem diameter measured in cm. When the equation was applied to four other sets of data compiled by Brown (1977), the estimated AGB was 23% to 50% less than the actual AGB. This suggests that the variation in AGB between trees at different sites is not mainly determined by stem diameter.

Wood density as a factor causing variation in AGB between trees was then included as a variable in the equation as follows:

$$AGB = 0.019\ (2.54)\ r\,D^{(2+0.62)} \qquad (\text{kg.tree}^{-1}) \qquad (9)$$

or $$AGB = 0.047\ r\,D^{2}H \qquad (\text{kg.tree}^{-1}) \qquad (10)$$

where H is tree height measured in m and ρ is the wood density (dry weight per unit volume). The value of 2.54 and 0.62 in the equation are the parameter values of equation for the relationship between height and diameter which are considered to be site and species specific. The above equation is similar to one developed previously by Brown et al. (1995) from data in Brazil. The inclusion of wood density (ρ) was found to reduce uncertainty in the estimated AGB by 12-19%. The error induced by model was reduced from 58-63% to 26-42% when the equation developed by Brown et al. (1995) was applied to data observed in Jambi after adjustment of wood density from 0.71 to 0.53 (Ketterings, 1999). For practical applications this means that data of wood density are needed, either through the use of databases or by measurement of the tree. A problem with the first is that the literature often gives a considerable range fort the wood density of a single species, depending on site conditions, while measurement is complex because wood density differs with position on the stem and with branch diameter.

An attempt was made to generate allometric equations on the basis of characteristics of the branching pattern. A key parameter appe ars to be the relative increase of branch (link) length with increasing diameter of a branch (Fig. 4). This parameter but itself can be visually assessed, at least for the more extreme values.

Ongoing research, however, suggests that this method of derivi ng allometric equations yields requires that input-parameters were derived from a sufficiently large data set. It may still be a considerable short cut to empirical establishment of allometric equations for each type of tree and situation.

As biomass and C stock estimates increase more then proportionally with increasing cross sectional area of the stem, a few very large trees can have a large impact on the total estimate. Forest inventory methods have to be adjusted to obtain appropriate representation of the largest trees in the sample. In the ASB protocol this meant adding a specific effort to estimate the density of trees of more than 30 cm diameter.

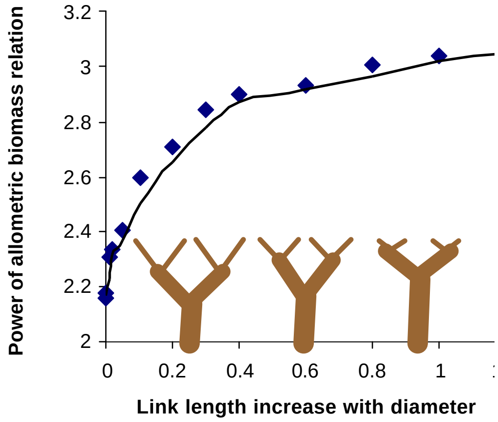


Figure 4. Relation between predicted power of the allometric equation (exponent of D) and the relative increased of link (branch) length with branch diameter, using the Functional Branch Analysis (FBA) spreadsheet module of the WaNuLCAS model

Measuring C stocks in the soil

the issue

Forest soils may loose a considerable part of their soil organic matter content after converted to agricultural land. The variation in soil organic matter content between different sites and soils is often very large, that it is not easy to find a proper point of reference, to judge whether specific values are lower tha n would be expected under 'undisturbed' forest conditions. Hassink and Whitmore (1997) proposed a dimensionless 'C saturation deficit', C_{sat}, as the difference between the current C_{org} content and a reference content, $C_{org, ref}$ which is supposed to indicate the undisturbed forest condition.

$$C_{sat} = (C_{org, ref} - C_{org}) / C_{org, ref} = 1 - (C_{org} / C_{org, ref}) \qquad (11)$$

As soil biological properties are not routinely measured, chemical and physical factors should be considered which are associated with '*protection*' of soil organic matter from microbial breakdown. The two factors are soil texture and soil pH.

Effects of land use change on soil organic carbon, however, may be difficult to quantify from limited datasets, as generally no historical data are available of C_{org} before forest conversion and one normally has to rely on 'paired' datasets, of sites still under forest and those now under other land use. Even moderate differences in soil texture and/or pH, however, can lead to changes in C_{org} of similar magnitude as those of the land use change. Van Noordwijk *et al.* (1997) suggested to use a ratio of the measured C_{org} and a reference C_{org} value for forest (top) soils of the same texture and pH as a 'sustainability indicator'.

The equation for $C_{org,ref}$ in the upper 15 cm of mineral soil from Sumatra under forest cover is :

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

An issue that is still open to debate is whether or not we should try to we include the subsoil (at least the first m) into the assessments, as it may represents a considerable amount of C. The debate focuses on the degree to which subsoil and topsoil C are related across sites, and the degree to which subsoil C responds to a change in land use practices.

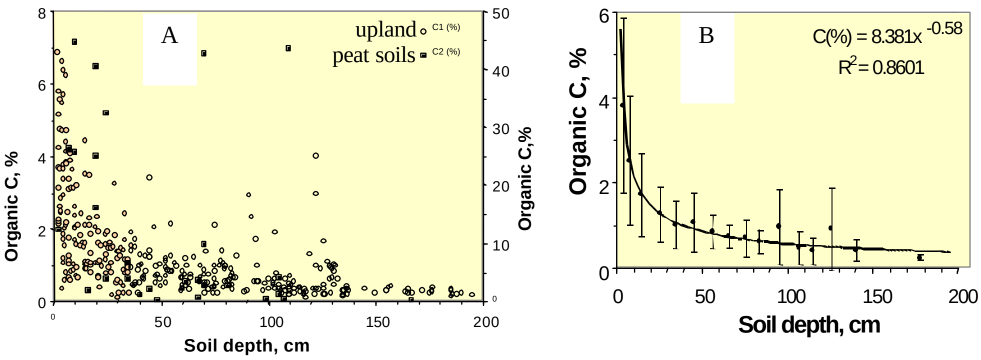


Figure 5. Relationship between C_{org} content of soils and depth for upland soils (open symbols in figure A and all data in Figure B) and peat soils, with various thickness of peat layers; data for Jambi province (central Sumatra) collected as part of national soil survey and analyzed by Hairiah and Sitompul (2000)

results and discussion

Data on C_{org} content in Jambi's upland soils (Fig. 5A) show a decrease with depth, as expected. The variation in subsoil C contents is considerable, however, and its relative magnitude does not differ between top- and subsoil. It is difficult, however, to attribute part of this variation to land use practices. The filled squares in Fig 5A refer to peat soils show that there is much variation in the depth of the peat layer, and hence the C stock of these soils. In view of the total C stocks concerned, a better representation of these peat soils should get priority, as they are clearly susceptible to impacts of land use change. For example, for oil palm plantations on peat soils in Malaysia a subsidence of 2.5 cm per year was reported, half of which is attributed to compaction, half to decomposition/respiration. The latter translates to a C loss to the atmosphere of 10 - 20 Mg C ha^{-1} $year^{-1}$.

Use of the Carbon Saturation Deficit

A survey of the organic matter content of topsoil in the Jambi benchmark area of the ASB Project covered a wide range of land use types including: Natural forest, logged over forest, jungle rubber (rubber agroforest), woodlots and degraded land (*Imperata* grassland). Figure 6 shows the C-org of different land use types in Jambi. Measurement based on soil C-org showed a big variation among the land use types, rubber agroforest had a higher than the natural forest. The measurement on C_{-org}/C_{-ref} showed a better indicator for C-dynamics.

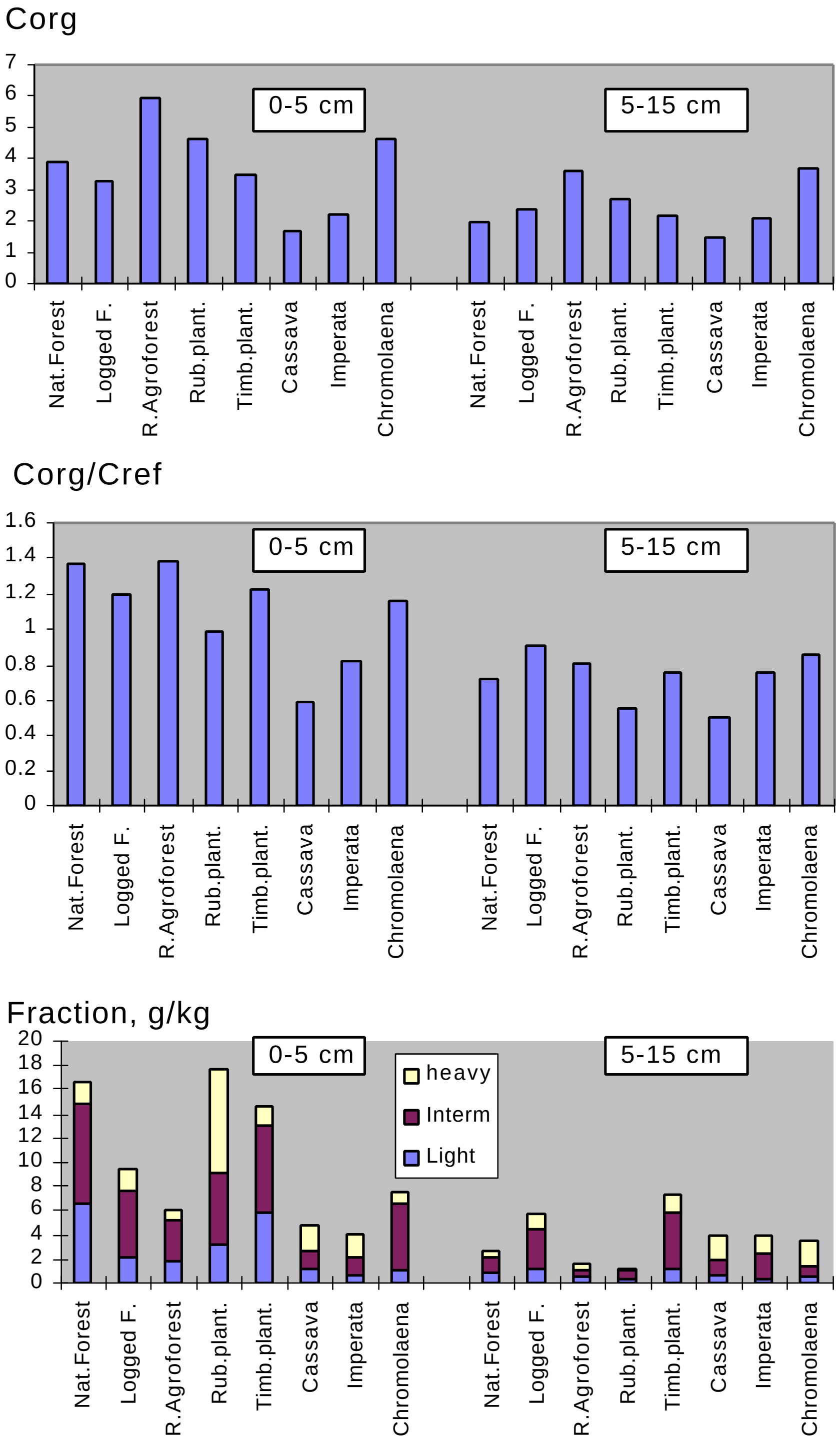


Figure 6. Measurements of C_{org}, C_{org}/ C_{ref} and SOM fractions (Ludox) at 0-5 cm and 5-15 cm soil depth of different land use types in Jambi (Van Noordwijk et al., 1998)

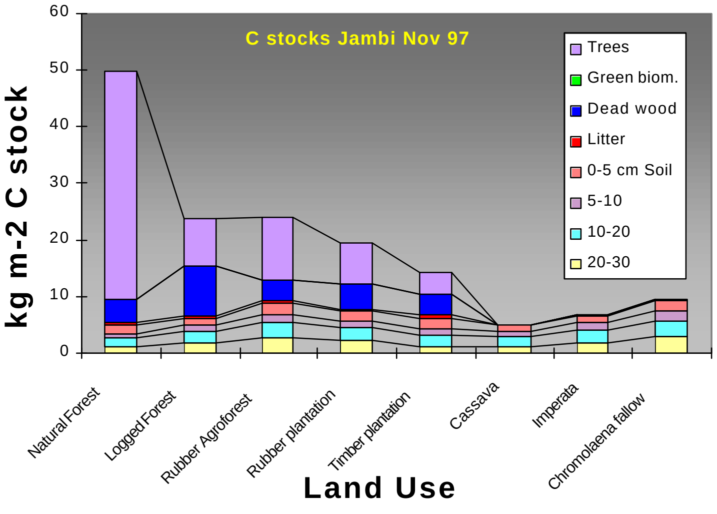


Figure 7 Carbon stocks in a range of land uses in Jambi (Sumatra, Indonesia)

Time-averaged C stocks of a land use system

the issue Averaging the C stock over the life span of a system gives a simple measure of its role in the global C balance, as long as different stages of the system may be expected to occur in roughly proportional areas at any point in time. To estimate the time-averaged C stock of the range of land use systems evaluated as 'alternatives to slash and burn', we need the following information:

- Is it a rotational system where periodically whole fields are cleared of vegetation to start a new cycle, or is it managed under permanent vegetation cover?
- What is the length of a single rotation cycle?
- What is the rate of C sequestration per year during the various stages of the cycle (e.g. during periods where annual food crops are grown and during periods of fallow regrowth)?
- Does the C stock reach a maximum at which annual C sequestration levels off?

The land use systems chosen for evaluation by ASB all are rotational in nature, except for the community managed forest with extraction of non-timber forest products. Commercial logging (officially) consists of logging episodes and periods where the forest can recover. All other land use systems involve field clearing at the start of a new cycle, mostly using slash-and-burn techniques of land clearing. Some of the rubber agroforests may evolve into a stage of gap-level rejuvenation instead of field level clearing, but the form initially chosen for evaluation by ASB is a rotational form.
The main uncertainty is the annual rate of C sequestration. The measurements of standing C stock in a range of land uses at different ages since land clearing by slash-and-burn can be used to estimate an average rate of C sequestration (Fig. 7). In the figure three groups of land use are distinguished:

- logged-over forests; we have to make a rather arbitrary decision on the effective age of the natural forest and the line connecting the points of logged forest with natural forest may overestimate C sequestration if logging has done near-permanent damage to part of the system (such a logging ramps and trails, see chapter III),
- natural fallows (secondary forests), agroforests and more intensive tree-crop production systems, which apparently accumulate at a rate of about 2.5 Mg C ha^{-1} yr^{-1}

- cassava/*Imperata* systems where there is a negligible rate of C accumulation with age, presumably because annual fires prevent the build up of C stocks in vegetation.

On the basis of these results time-averaged C stocks were assigned to the land use types chosen for evaluation (Table 2).

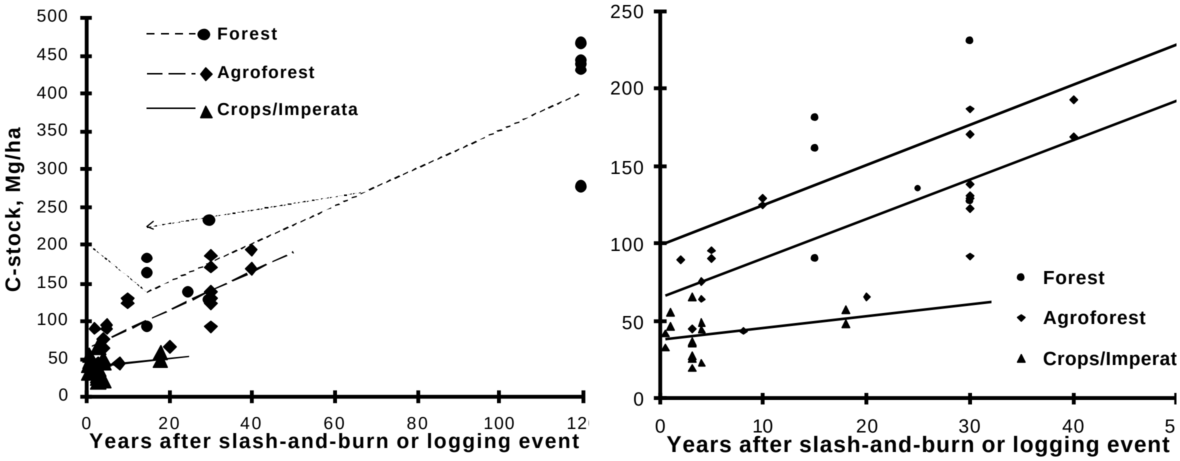


Figure 8 *Carbon stock in aboveground biomass, surface litter and top 30 cm of the soil, as a function of time since forest clearing (slash-and-burn) or logging (left: whole ASB data set, right: excluding the natural forest plots) (source: Tomich et al., 1998)*

Table 2 *Time-averaged carbon stocks for land uses of the lowland peneplain; three regression lines were used for the calculations (1 for forest, 2 for agroforest and tree-crop plantations, 3 for cassava-imperata) (Tomich et al., 1998)*

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

Refining categories within 'rubber agroforest'

The 'rubber agroforestry' category used so far embraces a range of land use practices, and we may have to split it into more than one category. For example, within the rotational forms the common land clearing practice at the start of a new cycle is to slash and burn the previous vegetation. Part of the farmers, however, uses a slash-and-mulch technique for replanting, that maintains higher C stocks in the initial years. A third group uses the 'sisipan' method of interplanting new rubber into gaps in existing stands. Current estimates are that these 'permanent' rubber agroforests may have a 20 - 30 Mg ha^{-1} higher time-averaged C stock than the values derived in Table 2.

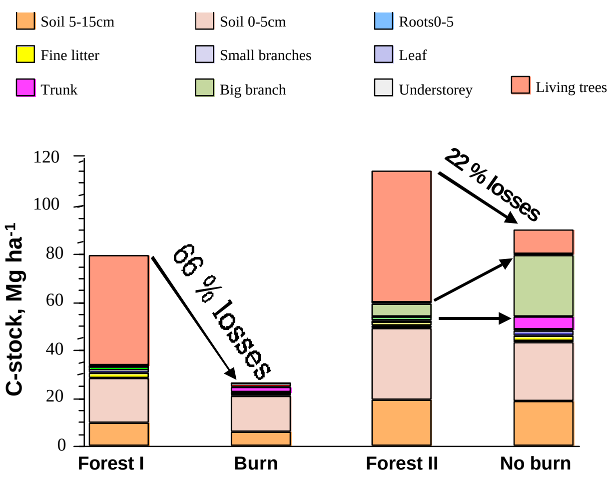


Figure 9. Changes in carbon stock during land clearing from old jungle rubber/secondary forest for replanting rubber, either using 'slash-and-burn' (left) or 'slash-and-mulch' (right) practices in Jambi (Prayogo *et al*., ***in prep***.).

Can farmers estimate C stocks on their land?

the issue If efforts to increase terrestrial C stocks by specific land use practices by other land use practices are to be implemented, it is important that farmers as the prima ry land users are aware of at least the orders of magnitude involved. If any financial compensation schemes come into practice to induce farmers to maintain higher C stocks, criteria for this should relate to farmers concepts and knowledge. As most of the C stocks are aboveground, we explored the categories farmers use to assess the size of trees.

results and discussion Informal discussions with farmers in Jambi inside their rubber agroforest made clear that they are used to assess the volume of timber in m^3 of wood (per 0.25 m^3 increment), as it is used in the market. It appeared, however, that the concept of 'volume' for them is directly linked to the commercial value. Trees without commercial wood value had no 'volume' in the farmer's language either.

Modeling tools

A range of modeling tools (Murdiyarso et al., 1999) is available for extrapolating process-level knowledge to estimates of the time-averaged C stock of a wide range of land use systems. The Century model (Parton et al., 1994; Paustian et al., 1997a,b; Woomer, 1993; Sitompul et al., 1996, 2000) remains a solid basis for long time descriptions of land use systems that are relatively homogeneous. The WaNuLCAS model (Van Noordwijk and Lusiana,, 1999) uses a similar description of belowground C stocks but allows a more detailed description of interactions between trees, crops and weeds partly sharing the same space in agroforestry systems.

In the ‘Crop down, fallow up’ or CDFU model(http://www.icsea.or.id/models/cdfu.htm) a simple description of decline and regrowth of C stocks during fallows and cropping periods description is applied at landscape scale to a mosaic of plots, to investigate the transient behaviour under non-equilibrium conditions as well as include explicit scaling rules. Depending on the amount of between-plot variation in parameter values, the trade-off between carbon stock and crop productivity can shift by a factor 2, even though both properties are directly related to area.

Discussion

Improving the quality and credibility of national inventories and assessments is important for the international negotiation process. First attempts at using the IPCC methodology for countries in SE Asia have suggested large difference between countries in the way the land use change and forestry sector is assessed, by using different sets of assumptions and parameter values. Further harmonization is needed. We propose that the evaluation be based on ‘time-averaged C stocks’ of ‘land use systems’, in stead of on the current hybrid of stock- and flow-based accounting. The results of the ASB project for land use systems in the lowland peneplains of the humid forest zone, should be expanded and replicated in other ecological zones, to obtain national coverage. The various ways forests are used for logging and other extractive activities needs further quantification.

Iterations may be required on the set of land use categories once further data on C stocks are available. For example, oil palm plantations are a rapidly expanding land use category in Sumatra, both in the lowland swamp forest zone and in the undulating lowland peneplain. The growth rates in the two zones may differ by 50% or more, so that a time-averaged C stock should differentiate between these two types of oil palm plantation, For this process of ‘splitting’ and ‘lumping’ we need to develop guidelines on how much effect a ‘split’ will have on the overall result before it is considered important enough to do it. This relative importance should be related to the uncertainty in the data set as a whole.

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