DISCUSSION

The history of the policy on transmigration in Indonesia dates back to the era of Dutch rule, when it was small in scale and called "colonization." The policy was taken over by the government of Republic of Indonesia as a major issue in the Five-year Plan until now. The Five-year Plan started in 1969 and is now in the sixth phase.

Transmigration in Indonesia aims at transferring people living in the densely populated islands, mainly in Java Island, to sparsely populated islands. About 130 thousand families had migrated in the1970s, when Sumatra Island received 43% of them. Lampung Province alone received 15% of them during this period, as it is located in the southern arm of Sumatra and near densely populated West Java. Transmigration in Indonesia recorded a peak of about 400,000 families in 1980–1984 and 1985–1989. Sumatra Island received an additional 316,000 families, and Lampung Province, 68 thousand families during 1980 and 1989 (Hirose 1993). The above figures correspond to the number of people who migrates under government control. Many spontaneous transmigrants, though there is no statistical record, also played a significant role in the increase of the population. It is considered that the virgin forests were cleared for agriculture mainly by spontaneous transmigrants.

Transmigration, which led to the increase of the population, was the major driving force for the land use changes in Lampung Province. In the 1970s, two remarkable land use changes were recognized, one was the change from dense forests (mostly primary forests) to grasslands and the other was the emergence of plantation lands (Fig. 4). The former was derived from the repeated use of forests for shifting cultivation with a cycle to short for regeneration, leaving vast areas of infertile grasslands. The land under plantations was mainly derived from dense forests and upland areas including upland area under shifting cultivation in the 1970s. The national policy aiming at obtaining foreign currency led to the increase of agricultural product for international market.

During 1978 and 1984, when transmigration recorded a peak in Sumatra and in Lampung Province, the land area under plantations increased drastically from 159 to 311 km^2, mainly from grasslands (59 km^2), dense forests (41 km^2), and underbrush forests (40 km^2; Table 3). Total upland area including upland area under shifting cultivation and upland field growing crops and vegetables with fruit trees decreased from 100 km^2 in a total of 486 km^2 in 1970, 51 km^2 in a total of 729 km^2 in 1978, to 10 km^2 in a total of 729 km^2 in 1984 (Tables 2 and 3). This decrease clearly indicated the establishment of plantation agriculture, mainly coffee plantations, in the hilly areas, and the transfer of areas for crop and vegetable production from this area to the middle terraces in Lampung Province.

The land use change from land under monoculture plantations to mixed plantations was noticeable during 1984 and 1990 (Table 4, Fig. 4). The areas showing this change were those where plantations were introduced first in the area, presumably because the leading farmers in these areas aimed at a stable and higher income. At same time, the land use change from plantations to underbrush forests was also recognized (Fig. 4).

In conclusion, the land use and land cover in the study site changed drastically in the past 20 y from 1970 to 1990, due to the transmigration policy and the agro-economical circumstances. As mentioned above, the actual land use change was far more complex than the apparent change estimated from the change in areas under respective land use forms. In the past studies on land use and cover change, limited attention had been paid to the properties of soils in the study area. The dominant soils in Indonesia as well as in the

Southeast Asian countries are Acrisols and Ferralsols (Ultisols) which are generally infertile and prone to erosion under careless management of lands (FAO/UNESCO 1979). As the impact of human activities associated with the increase in population and industrialization is likely to lead to the intensification of land/soil use in the near future, the rational plans for future land use forms are urgently needed to harmonize with the national economic development in the Southeast Asian countries.

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peri-od	Brawijaya University (Malang, Indonesia)	ICRAF - SE Asia	ASB - Indonesia consortium
'84 - '91	Nitrogen utilization in traditional and improved systems of rainfed food crop production in the humid tropics -- EU funded (TSD-A-113 & TS2-0069-Nl) with IB-DLO, Haren, NL; 1987 Symposium Malang		
'91 - '92	Initial on farm trials (Dutch government sponsored) with IB-DLO; PhD research Kurniatun Hairiah (Univ. of Groningen) Al tolerance of *Mucuna pruriens utilis*		
'92 - '93	National funding sources: comparison of rice and maize varieties; PhD research Eko Handayanto (Wye College) Role of polyphenolics in decomposition		
'93 - '94	Tree - soil - crop interaction research in long term hedgerow intercropping trial; survey of tree roots		
'94 - '97	Biological Management of Soil Fertility (BMSF) -- EU funded (TSD ...) with AB-DLO, Haren (NL), Wye College (UK), Khon Kaen University (Thailand); 1997 Symposium Malang		Phase 1: characterization of benchmark; PhD research Beckey Elmhirst and Remi Gauthier (Wye College)
'96 - '99	Al detoxification by organic matter (URGE)	Shading requirements for *Imperata* control	Phase 2: survey of above- and belowground biodiversity + C stocks
	Test of tree safety net hypothesis -- DFID (=ODA) agroforestry modelling project (UK), with Wye College; PhD research Edwin Rowe and Didik Suprayogo		Follow up research Beckey Elmhirst
'99 -->	?	?	**Imperata rehabilitation // GEF proposal ?**

Publications from BMSF project

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CONTENTS:

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Tree-Soil-Crop Interactions in Sequential and Simultaneous Agroforestry Systems

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Introduction

Perpetuum mobiles, or machines which will keep going without inputs of external energy, have been a long-time dream of humankind. Over the centuries, an immeasurable amount of time and energy has been spent on the systems improvement of 'promising' technologies, which did not yet fully meet the target, but were considered to be at least halfway. Formulation of the second law of thermodynamics, which states that perpetuum mobiles cannot exist, has slowed down the efforts and has led to a situation where every 'discoverer' of a perpetuum mobile is met with a weary smile rather than excitement. Maybe recognition of the laws of thermodynamics has therefore reduced the progress in increasing the energy use efficiency of machines which were halfway meeting their target.

Similarly, agroforestry has often been expected to provide land-use systems which allow sustainable outputs of high value without requiring external inputs of nutrients. Here, too, considerable efforts have been made on systems improvement of 'promising' technologies. The generalizations which can be made in ecology are not as strong as those in physics, and we do not yet have the direct equivalent of the laws of thermodynamics. Agroforestry research is largely confined to conclusions about specific systems, at specific times and locations, partly by choice (every farmer will need his/her own agroforestry system), partly by lack of understanding of underlying principles. Yet we know that there is no free lunch in resource sharing between crops and trees and that nutrient exports in harvestable

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products will have to be replenished from somewhere outside the land-use unit for the system to be called truly sustainable. An apparent exception to this is nitrogen (N), where atmospheric molecular N (N_2) fixation can give land-use systems the appearance of perpetuum mobiles, even if they lead to marketable yield products, which mean both money in farmers' pockets and nutrient exports. However, the increased N availability to crops will directly increase the mining of other nutrients from the soil and will aggravate problems in the medium and longer term, unless it is part of an integrated nutrient-management scheme. The more realistic, down-sized expectations of agroforestry which have developed over the last decade (Buresh, 1995; Sanchez, 1995; van Noordwijk and Garrity, 1995) now lead to weary smiles in response to many agroforestry development proposals; at least, they should - it takes time for the message to get through. Yet it should not prevent us from making efforts to increase the nutrient-use efficiency of land-use systems on the basis of agroforestry systems, provided that they are based on the strategic use of external nutrient inputs, on a proper assessment of the biophysical resource (water, nutrients) base of plant production and on an understanding of resource sharing (competition) between the multiple components of an agroforestry system. Researchers can help farmers in analysing how 'promising' technologies can be improved, which tree and crop characteristics may be used to select appropriate component species and to what extent management choices should depend on climate and soil factors.

In this review of concepts and methods for studying tree–soil–crop interactions, we shall discuss an empirical approach to separate positive from negative interactions and obtain a process-level understanding of the components, and describe a framework for the synthesis of component knowledge. The final outcome of an agroforestry system for a specific farmer depends both on the nature (inherent plant qualities) and the nurture (effects of the abiotic and biotic environment, farmer management) of the system.

Simultaneous and Sequential Systems

If we ignore animal-production aspects for the time being, we can focus a discussion of agroforestry on the interactions between trees, soils and crops. None of these elements is specific for agroforestry, but their interactions as part of a land-use system are. The same components can be used in systems which have very different properties. A major distinction is between simultaneous and sequential systems (Sanchez, 1995; van Noordwijk and Purnomosidhi, 1995). In simultaneous systems, the interactions are both spatial and temporal, while those in sequential systems are only temporal: the tree and the crop communicate via the soil only (Fig. 13.1).

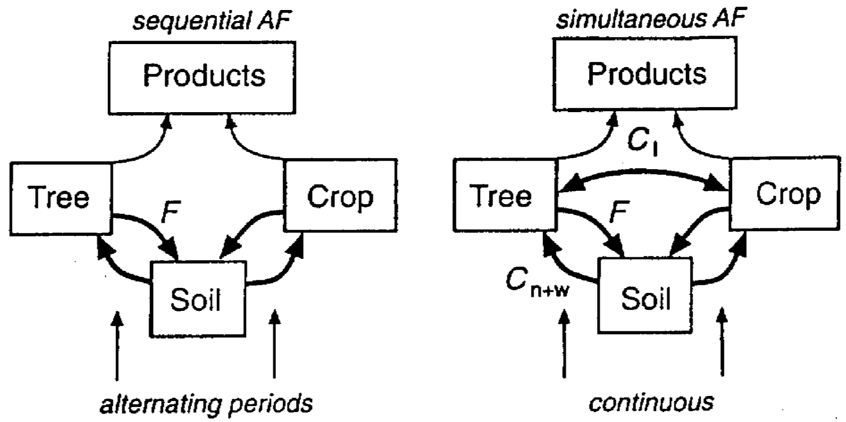


Fig. 13.1. Tree–soil–crop interactions in sequential and simultaneous agroforestry systems; *F*, effect on soil fertility; C_{n+w}, competition for nutrients and water; C_l, competition for light.

Direct empirical tests of improved fallow would consider a tree germplasm–soil combination as input and crop yield as output. The reason for looking at intermediate steps, such as tree biomass development, litter fall and build-up of soil organic-matter pools, is that we hope to find useful indicators of the effectiveness of the fallows, which can be used for evaluating a larger number of sites and/or fallow germplasm sources. A key aspect of the sequential systems is the potential build-up of soil organic-matter levels during the tree fallow without direct competition between tree and crop. Total organic-matter content is not a very sensitive indicator, as it changes relatively slowly under different management regimes and often has a high spatial variability, linked to variability of soil texture. Physical fractionation procedures, based on particle size and density (Christensen, 1992), allow the distinction of pools with different degrees of physical protection from decomposers. During decomposition, plant litter with an initial physical density around 1.0 g cm^{-3} becomes more intimately associated with mineral particles with a physical density of around 2.5 g cm^{-3}. A fractionation procedure developed by Meijboom *et al.* (1995) on the basis of colloidal silica suspensions (Ludox) has been successfully applied by Barrios *et al.* (1996a, b) in the analysis of sequential agroforestry systems. The light and intermediate fractions obtained with this method appear to be the most important ones for the N mineralization in the first year after the fallow. The hypothesis that the heavy fractions are directly related with soil structure and architecture (Kooistra and van Noordwijk,

1995) and soil-water retention is speculative as yet. A possible direct role of decaying tree roots in facilitating crop root development after improved fallows was discussed by Torquebiau and Kwesiga (1996). Evidence for this is far from conclusive.

Tree-soil-crop interactions in simultaneous systems are based on the same soil fertility effect as in sequential systems, but, in addition to that, involve competition for light, water and nutrients.

Tree–Soil–Crop Interaction Equation

Akyeampong *et al.* (1995) developed a simple equation for quantifying tree-soil-crop interactions (I), distinguishing between positive effects of trees on crop growth via soil fertility improvement (F) and negative effects via competition (C) for light, water and nutrients. In its most basic form:

$$I = F - C \tag{13.1}$$

Soil fertility here incorporates chemical, physical and biological aspects of the soil, in as far as they are relevant for crop growth. The interaction term is positive and the combined system is advantageous for crop production if $F > C$, and not if $F < C$. Van Noordwijk (1996) described a model which links both the mulch production underlying F and the shading, which is an important part of C, to the biomass production of the tree. The model, which assumes water not to be a limiting factor for crop growth, leads to a simple mulch/shade ratio as a basis for comparing tree species. The model also predicts that at low soil fertility, where the F factor can be pronounced, there is more chance that an agroforestry system improves crop yields than at higher fertility, where the C factor will dominate. This prediction is in agreement with the conclusion of Woomer *et al.* (1995) that the crop response to alley cropping in African network sites is negatively correlated with total soil N in the 0–15 cm layer, but positively correlated with an extractable phosphorus (P) fraction (Bray II). The tree mulch, whether from N_2-fixing or N-scavenging trees, primarily contributes to the N and not to the P nutrition of the crop (Palm, 1995), and both the N_2 fixation by the trees and the N utilization of the crop are likely to be increased at better P supply. The suggestion of Sanchez (1995) that alley cropping is most likely to work where 'soils are fertile without major nutrient limitations' contrasts with this model. On soils without major nutrient limitations, the F term would be small (there is hardly a problem of plant nutrition to be addressed) and, although the impact of nutrient competition on the crop will be small as well, the negative effects of competition for water and light will remain on the negative side of the balance. To a certain extent, nutrient constraints on tree growth may differ from those on crop growth (especially where one of the components can fix atmospheric N_2 and the other not), and the best effects may be expected on

soils which are fertile without major nutrient constraints from a tree perspective, but with constraints for crop growth, which can be overcome by the tree mulches as organic source.

Cannell *et al.* (1996) attempted to clarify the resource base of the production by both the crop and the tree. Part of the positive fertility effect of the tree is based on light, water and nutrient resources which the tree acquired in competition with the crop (F_{comp}); another part may have been obtained in complement to resources available for the crop ($F_{non\text{-}comp}$) (Table 13.1). Similarly, part of the resources acquired by the tree in competition with the crop are recycled within the system and may thus be used by a future crop (C_{recycl}). Tree products which are not recycled may have direct value for the farmer ($C_{non\text{-}recycl}$). One may argue that F_{comp} is based on the same resources as C_{recycl}. The equation then becomes:

$$I = F_{non\text{-}comp} - C_{non\text{-}recycl} \tag{13.2}$$

The question whether or not a tree–crop combination gives yield benefits then depends on:

- the complementarity of the resource use (the distinction between the columns in Table 13.1);
- the value of direct tree products (the distinction between the rows in Table 13.1), specifically those obtained in competition ($C_{non\text{-}recycl}$) relative to the value of crop products which could have been produced with these resources;
- the efficiency of recycling tree resources into crop products, specifically for the resources obtained in competition with the crop (C_{recycl}).

The efficiency of recycling will depend on the degree of synchrony between mineralization from these organic residues and crop-nutrient demand, as well as on the residence time of mineral nutrients in the crop root zone under the site-specific climate and soil conditions (de Willigen and van Noordwijk, 1989; Myers *et al.*, 1994, 1997).

Table 13.1. Interplay of F (fertility) and C (competition) effects of the general tree–crop interaction equation.

	Resource base for tree growth	
Valuation of tree products	Competition with crop	Complementary to crop
Direct	$C_{non\text{-}recycled}$	–
Indirect (recycled)	$F_{competitive}$ $C_{recycled}$	$F_{non\text{-}competitive}$

If tree products have no direct value, agroforestry systems may only be justified if $F_{non\text{-}comp} > C_{non\text{-}recycl}$. With increasing direct value of the tree products, the requirements for complementarity decrease. Complementarity of resource use can be based on a difference in timing of tree and crop resource demand. If the tree picks up the leftovers from the cropping period, as occurs with water in the *Grevillea*-maize systems in Kenya (C.K. Ong, personal communication), and transforms these resources into valuable products, a considerable degree of competition during the temporal overlap may be acceptable to the farmer. As light is not stored in ecosystems, complementarity in light use is easy to measure. For water and nutrients, complementarity has to consider time-scales linked to the residence times of the resources in the ecosystem; residence times tend to increase from water, via N and potassium (K), to P. For P resources used by the tree, it will be difficult to measure whether or not this P might have become available to the crop in the absence of trees. Indications of complementarity in below-ground resource use can be obtained by observing the root distribution of both components. Actual uptake of resources will, however, depend on resource and root distribution, as well as demand factors, and thus the degree of overlap in root distribution *per se* is not sufficient to predict competition.

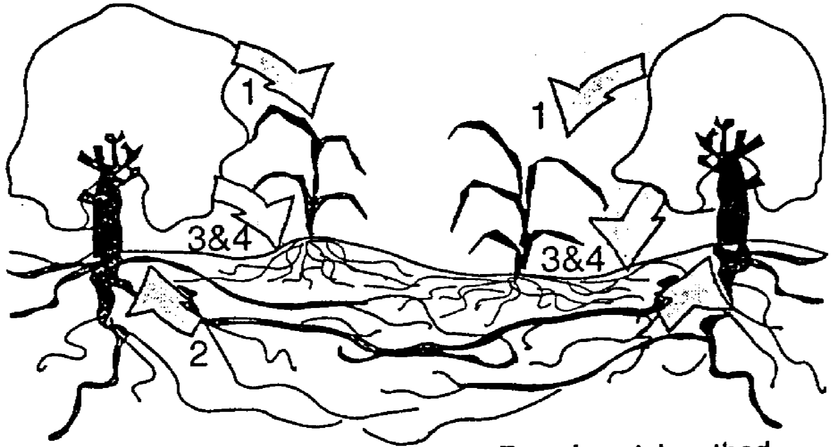
The tree-soil-crop interaction equation can be further analysed by differentiating between short- and long-term fertility effects (F_1 and F_w, respectively), and by separating the competition term into an above-ground (light) and a below-ground (nutrients plus water) component (C_l and C_{n+w}, respectively).

Experimental Approach

Empirical interaction effects

A long-term hedgerow intercropping trial in Lampung, Indonesia (annual rainfall 2.0–2.5 m year^{-1}; grossarenic kandiudult soil; P and K fertilizer used in the trials) was used to quantify, understand and predict the terms of the interaction equation (Fig. 13.2). As indicated in Table 13.2, an attempt was made to separate the various positive and negative interaction terms directly and to develop a process-based model, which can be used to understand and thus extrapolate the results. In the following presentation, we shall discuss the methods used to quantify each of the terms.

Results for the overall interaction term (Table 13.3) show that the best overall effect was obtained with a tree with a moderately positive *F* term and a small negative *C* term. The two trees with the highest *F* term also had the strongest negative *C* term. The overall *I* term does not follow the classical preference for fast-growing trees as the basis for agroforestry systems. Maize yields in the alley-cropping system exceeded that in the



Interaction term	Experimental method
1 Shading	– tree removal vs. complete
2 Comp. for H_2O & N,P,K	– root barriers
3 Mulch – direct N,P,K	+ mulch transfer
4 Mulch – long term	+ tree removal vs. control

Fig. 13.2. Schematic relations of tree–soil–crop interactions in a simultaneous agroforestry system and experimental method to quantify these.

control only where the local tree *Peltophorum dasyrachis* was used (van Noordwijk *et al.*, 1995). For this specific site, process-level research can focus on the question, 'Why is *Peltophorum* so much better than the other tree species?' Explanations can be based on its relatively deep root distribution, the compact hedgerows with a high mulch/shade ratio, an appropriate timing of its nutrient mineralization, specific effects on aluminium (Al) detoxification or a combination of all these factors.

Direct fertility effect

Tests of the direct fertility value (F_1) of the mulch are based on a mulch transfer experiment. Table 13.4 gives data on the response of a maize and rice test crop to four types of tree mulch and the relative efficiency of the crop in utilizing the N contained in these mulches. Direct mulch effects can be based on nutrient mineralization from the mulch material itself, as well as on changes in (surface) soil characteristics, such as temperature, and hence mineralization of soil organic matter. The four pruning materials are

Table 13.3. Terms of the tree–soil–crop equation for maize in the seventh year of a hedgerow intercropping experiment in Lampung (Indonesia). Data are expressed as percentage of monoculture crop yield (2.6 Mg ha^{-1} of grain); the values for *Flemingia* are based on plots where *Flemingia* replaced *Erythrina orientalis* in the fifth year of the trial.

	F (%)	*C* (%)	*I* (%)
Leucaena leucocephala	152	−159	−7
Calliandra calothyrsus	120	−115	+5
Peltophorum dasyrrachis	58	−26	+32
Flemingia congesta	37	−89	−52
Gliricidia sepium	19	−60	−41

F, fertility effect; *C*, competition effect; *I*, overall interaction ($I = F + C$).

Table 13.4. Nitrogen (N) uptake and apparent recovery (uptake as fraction of input) by maize and upland rice in response to mulch transfer of tree prunings.

	Pruning dry weight (Mg ha^{-1})	N content prunings (kg ha^{-1})	Crop N uptake (kg ha^{-1})	Apparent N recovery (kg kg^{-1})	Urea fertilizer equivalent (kg ha^{-1})	Relative N efficiency of mulch (kg kg^{-1})
Maize						
Control	–	–	45.7	–	–	–
Gliricidia	7.13	145	48.4	0.02	8	0.06
Calliandra	6.45	145	66.9	0.15	63	0.43
Flemingia	8.63	165	33.9	−0.08	−35	−0.24
Peltophorum	8.97	168	41.9	−0.02	−11	−0.07
Rice						
Control	–	–	112.6	–	–	–
Gliricidia	7.13	145	122.8	0.07	42	0.29
Calliandra	6.45	145	132.1	0.13	80	0.55
Flemingia	8.63	165	136.7	0.15	99	0.60
Peltophorum	8.97	168	116.7	0.02	17	0.10

The urea fertilizer equivalent is calculated as the amount of urea required to achieve the N uptake obtained in response to mulch; the response to urea fertilizer (50% at planting, 50% after 1 month; range: 0–135 kg N ha^{-1}) on plots without mulch was for maize: $N_{uptake} = 45.7 + 0.338\ N_{fertilizer}$; for rice: $N_{uptake} = 112.6 + 0.243\ N_{fertilizer}$. The last column gives the recovery of N (output per unit input) from prunings relative to that in urea fertilizer.

Table 13.2. Three-step approach to analysis and synthesis of tree–soil–crop interactions in simultaneous agroforestry systems. A direct experimental separation of the terms in the equation is combined with quantification of key processes and followed by model synthesis to explore management options and system–site matching.

Y_c Crop yield in interaction	= Y_0 Crop yield in monoculture	+ F_l Direct fertility effect	+ F_w Long term fertility effect	+ C_l Competition for light	+ C_{n+w} Competition for nutrients and water	+ M Microclimate effects
Experimental	Control plot	Mulch transfer	Residual effect	Tree removal	Root barriers	p.m.
Process-level understanding		Litter quality, mineralization rates	Functional SOM fractions (Ludox)	Canopy shape, light profiles	Root architecture (fractal branching analysis)	
Synthesis		Water, nutrient and light capture in agroforestry systems (WANULCAS)				

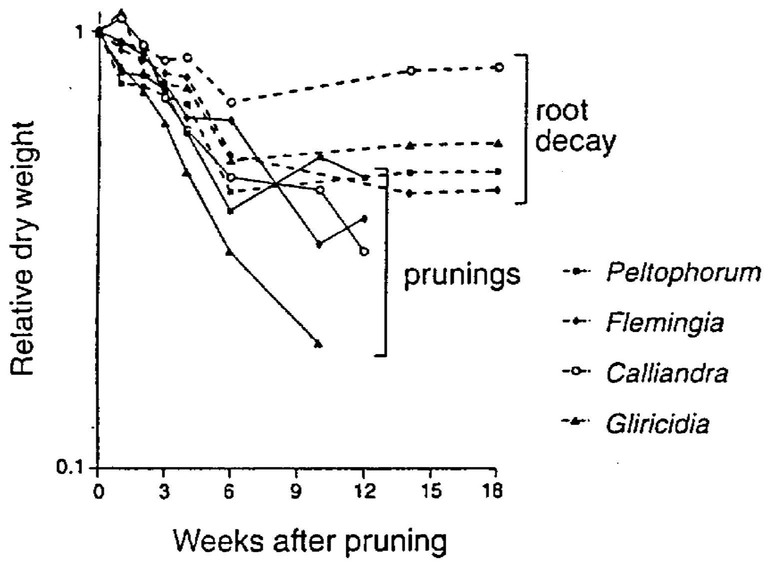


Fig. 13.3. Decomposition rate of tree prunings as surface mulch in litter bags and of root litter in ceramic pots incubated in the field.

arranged according their decomposition rate (Fig. 13.3): *Gliricidia* > *Calliandra* > *Flemingia* > *Peltophorum*. Differences in decomposition between these mulch types can be understood from their C-to-N ratios (13.5, 16, 21 and 19, respectively), lignin content (35, 28, 46 and 54%) and polyphenolic content (1.1, 2.1, 1.8 and 2.2%), although the role of the latter is relatively small under the high leaching rates found in the field (Handayanto *et al.*, 1994). For the shallow-rooted maize, the efficiency of N transfer was low (Table 13.4), with both rapidly (*Gliricidia*) and slowly (*Peltophorum*) decomposing materials. A reasonable efficiency was only obtained for mulch with an intermediate pattern of *N* release (*Calliandra*). This indicates the need for synchrony under these conditions of high rainfall and a shallow-rooted crop. For the deeper-rooted, longer-lived upland rice, the N recoveries from all mulch types was equal to or higher than that for maize. As the recovery from fertilizer N was lower for rice than it was for maize, the value of the prunings, expressed as urea fertilizer equivalent, was distinctly higher in rice than in maize. Both fast-mineralizing species can contribute (via recovery by deep rice roots) and slowly decomposing ones (because of the longer uptake period of the rice). These results are generally in line with the model of de Willigen and van Noordwijk (1989), although the difference between rice and maize in recovery of fertilizer N is unexpected.

Alternative explanations for the growth response to mulch transfer treatments exist, e.g. via their various effects on Al detoxification, rather than N supply, and we are currently testing these other possible mechanisms. Preliminary evidence indicates that *Gliricidia* may enhance soil acidification and cation leaching, possibly linked with nitrate leaching (data not shown).

Long-term fertility effect

The long-term fertility effect (F_{ω}) can be tested in the same way as in a sequential agroforestry system, by removing the trees and comparing crop yields with those in a continuously cropped control plot. A difference is that the residual or fallow effect has now been achieved during a cropping period. The first year after removing the hedgerows in the Lampung trial, the residual effect was pronounced and it formed the major part of the *F* factor, given in Table 13.3. In subsequent years, the residual effect declined, while the yields in the mulch transfer treatments increased (data not shown).

At the process level, the residual effect may be linked to changes in specific soil organic-matter fractions. Size-density fractionation (Ludox) results of soil organic matter (Fig. 13.4) show a clear difference between forest and long-term cropped soil, with intermediate results for hedgerow intercrops with various trees. The small standard error of difference (SED) values allow us to differentiate between the tree species. The trees with relatively high polyphenolic contents and slowly decomposing litters (*Calliandra* and *Peltophorum*) are better at maintaining intermediate and heavy soil fractions than *Gliricidia* and *Leucaena* (*Flemingia* was included later in the experiment, replacing *Erythrina orientalis*, so their residual effects are confounded). Barrios *et al.* (1997) also found that litter sources with low (lignin + polyphenol)-to-N ratios led to higher light fraction N contents.

We tested whether or not the fractions obtained by the Ludox method differ in turnover by analysing soil changes for an extreme form of a sequential system, formed by a chronosequence of sites where forest had been converted to sugar cane in the past 10 years (Hairiah *et al.*, 1995). Analysis of the stable carbon (C) isotope ratio ^{12}C to ^{13}C of the Ludox fractions allowed us to calculate which proportion of the organic matter in the three fractions was derived from the forest and which part from the new crop. The data (Fig. 13.5) show a clearly different turnover for the three fractions. Yet the light fraction does not get back to zero in a 10-year period, probably due to its charcoal component, derived from the slash-and-burn method of forest clearance.

Maize yield in plots where hedgerows had been removed was correlated with the various soil organic-matter fractions (Fig. 13.6), except for the

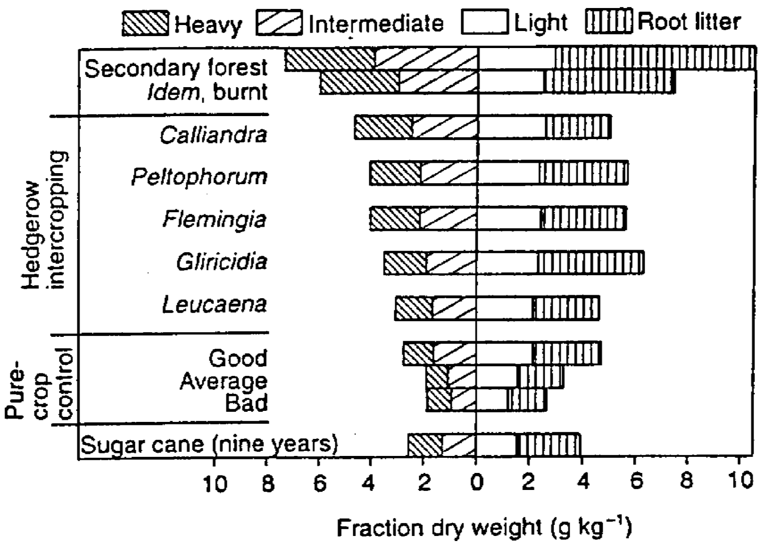


Fig. 13.4. Fractionation of soil organic matter according to size and density by the Ludox method (Meijboom *et al.*, 1995) in the eighth year of an alley-cropping experiment, its pure-crop control plot and adjacent forest and sugar-cane fields. The root litter fraction did not pass through a 2 mm sieve. The light, intermediate and heavy fractions were in the size range 150–2000 mm and were separated at physical densities of 1.13 and 1.30 g cm^{-3}. Standard errors of difference (SED) for all Ludox fractions were less than 0.4 g kg^{-1} dry weight.

Leucaena treatment. All three Ludox fractions correlate with crop yield and each other, so we cannot yet say which is the best indicator. Tree root litter did not correlate with crop yield. The *Leucaena* data are outliers deserving further attention; a relatively high N concentration in the various fractions in the *Leucaena* plots may be a partial explanation. We plan to monitor the changes in the Ludox fractions during the decline of the residual fertility effect, as well as the build-up phase, in the mulch transfer trials to obtain a more rigorous test of these fractions as predictors of crop yields.

A problem in the ongoing experiment is that the N-fertilizer treatments (urea) have acidified the soil and no longer allow us to estimate the crop N response, as they did in the first year (Table 13.4).

Competition for light

Competition for light (C_l) can be predicted from the canopy shape of the hedgerow trees, as well as measurements of the light interception by the

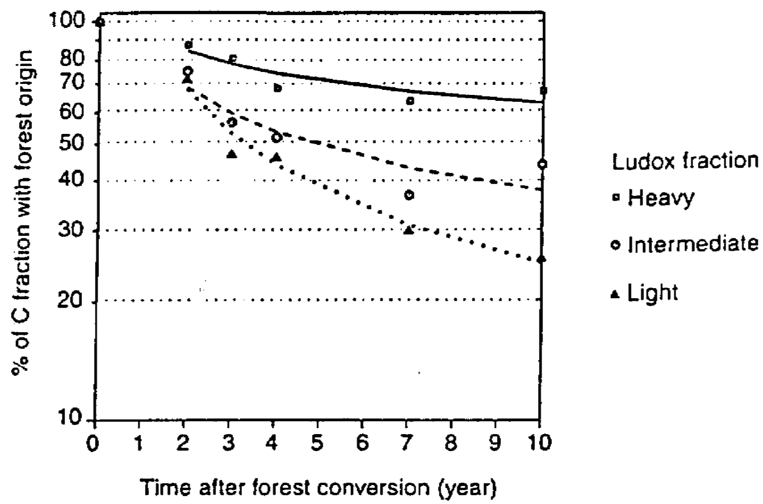


Fig. 13.5. Decomposition pattern of forest-derived organic matter in different density factions (Ludox method) after conversion of forest to sugar cane (chronosequence). Separation between forest- and sugar-cane-derived C was obtained by stable ^{13}C isotope methodology (Hairiah *et al.*, 1995).

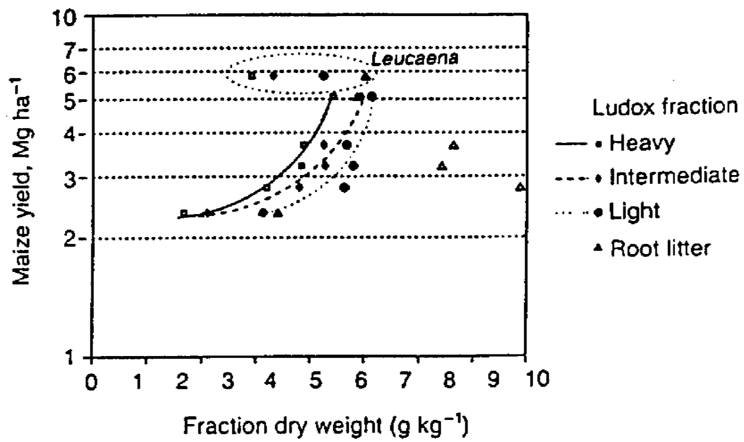


Fig. 13.6. Relationship between four organic-matter fractions (compare Fig. 13.4) and maize yield in a test of residual fertility by removing hedgerows in the seventh year of an alley-cropping trial.

canopy. Considerable differences exist between the various trees in the trial, ranging from the dense but compact canopy of *P. dasyrachis* to the extensive but open canopy of *Gliricidia sepium*. By recording light interception just before and after pruning, the light interception due to the tree canopy can be quantified in a mixed crop situation and compared with the amount of biomass pruned. Considerable differences were found in the mulch-to-shade ratio of the trees, with the highest (most favourable) results for *Peltophorum* (van Noordwijk, 1996).

Competition for nutrients and water

Competition for nutrients and water (C_{n+w}) between tree and crop depends on uptake demand of both components, as well as the relative distribution of the root system (van Noordwijk *et al.*, 1996). Fractal root-branching models hold promise of simplifying observation methods on tree-root distribution (van Noordwijk *et al.*, 1994; van Noordwijk and Purnomosidhi, 1995). Fractal branching properties of dicotyledonous trees may be based on the process of secondary growth of the transport tissue in roots in response to the degree of local branch-root development. The system in the apparent 'madness' of a root system may be a reflection of the development history of each root axis. Root diameter may therefore reflect the number of branch roots possibly connected to that axis. Root architecture may thus allow statements about the potential competition between crops and trees; actual competition estimates at any point in time will have to come from models, which include the dynamic character of resource supply during the growing season, as well as crop and tree demand factors.

An experimental approach to complementarity of resource use can be based on using tracers (e.g. ^{15}N) injected into the soil at different depths and recording the recovery in trees and crops. We have started such experiments, including *Peltophorum* and *Gliricidia* as well as food crops. Preliminary data show that the relatively deep rooted *Peltophorum* has higher recoveries for deeply placed ^{15}N than the other components.

Integration: the Water, Nutrient and Light Capture in Agroforestry Systems Model

Integration of the various processes into a model of tree-soil-crop interactions is attempted via the water, nutrient and light capture in agroforestry systems (WANULCAS) model (Fig. 13.7), which is still under construction. The model makes use of the STELLA II modelling environment and represents a four-layer soil profile, a water and N balance and uptake by a crop and a tree. The model allows for the evaluation of different pruning regimes, hedgerow

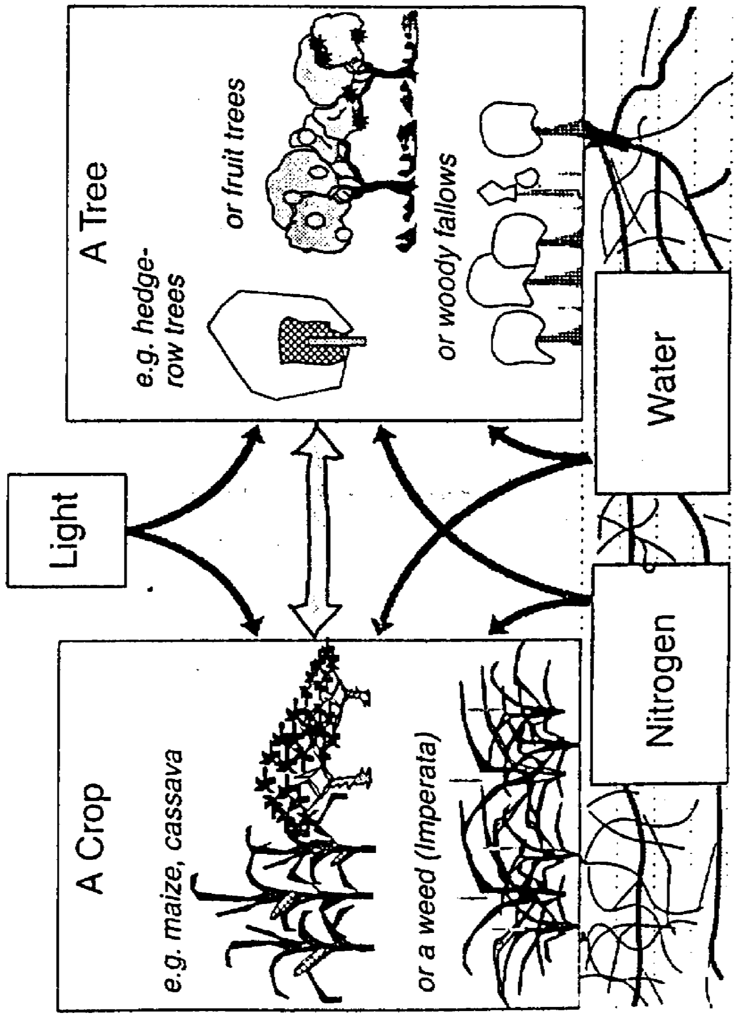


Fig. 13.7. Components of the WANULCAS model for predicting water, nutrient and light capture in agroforestry systems.

spacings and fertilizer application rates. A key feature of the model is the description of uptake of water and nutrients (at this stage, only N) on the basis of root-length densities of both the tree and the crop, plant demand factors and the effective supply by diffusion at a given soil water content. Underlying principles were described by de Willigen and van Noordwijk (1989) and van Noordwijk and van de Geijn (1996).

The model can be used for both simultaneous and sequential agroforestry systems and may help to understand the continuum of options, ranging from improved fallow via relay planting of tree fallows to rotational and simultaneous forms of hedgerow intercropping. The model explicitly incorporates management options such as tree spacing, pruning regime and choice of species or provenance. It includes various tree characteristics, such as root distribution, canopy shape, litter quality, maximum growth rate and speed of recovery after pruning. The model will first be tested on the basis of the Lampung data set.

Indirectly, the model demonstrates that process-based research can be done in the context of systems-improvement experiments, but that it should not be restricted to any one system or ecoregion only. Ideas about priority systems and regions will change faster than our understanding of these systems. The processes and interactions studied are inherently more generic than the systems and they can thus provide part of the glue which holds a large number of farmer-based agroforestry efforts together. A major challenge now is to extend this framework to systems where tree products dominate the value of the system as a whole.

Acknowledgements

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Shade-based *Imperata* control in the establishment of agroforestry systems

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In the establishment of tree-based production systems *Imperata* control in the first one or two years can be facilitated by intercropping with food crops, as the 'weed control' labour costs can be born by the crop and the crop cover reduces *Imperata* regrowth. There is a transition period, however, where the tree cover becomes too high for intercropping and not high enough for *Imperata* control. Bagnell-Oakley *et al.* (1997) indicated that this transition is a major risk period where *Imperata* can get the upper hand again by its competitive strength and/or by causing the rapid of fires, which kill the trees.

To get a better quantification of these issues we performed an experiment at the BASF research station with various levels of artificial shade, to establish interactions of duration and intensity of shade on Imperata biomass decline and ont its ability to regrow from rhizomes after the biomass is removed (e.g. by handweeding). The results (Fig. 1) show that even if light levels are reduced to about 10% of full sunlight, a well-established Imperata stand will only gradually decline, and a 50% shade for up to 8 months had little effect.

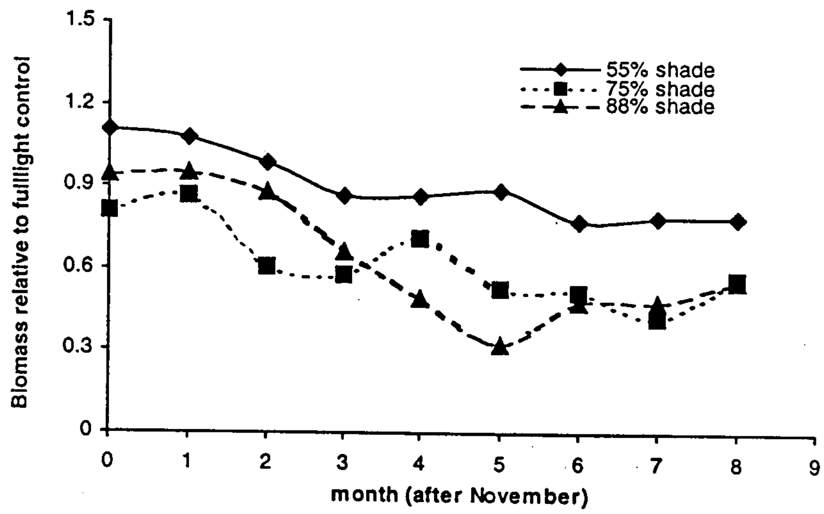

Figure 1. Aboveground biomass of Imperata , relative to a full-sunlight control, as affected by shade intensity and duration (BMSF experiment 22: November 1995 – July 1996)

In the experiment we also followed the regrowth after removing all aboveground biomass (Fig. 2). A 50% shade had no effect on the ability of Imperata rhizomes to resprout; a 75% shade decreased the viability of rhizomes, but did not give full control. and at least 3 months of 90% shade is required for full control, after a single hand-weeding to remove current aboveground biomass.

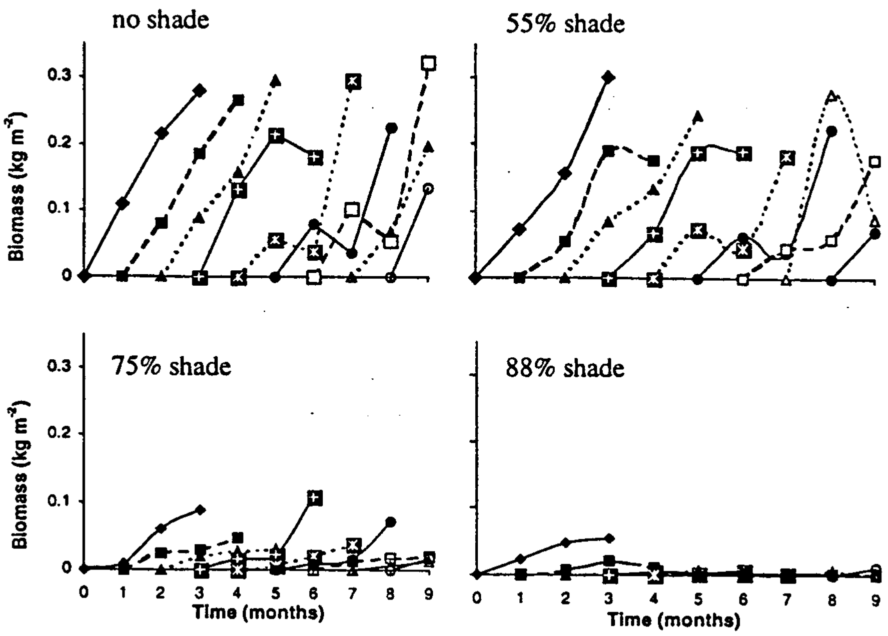

Figure 2. Regrowth potential of Imperata after exposure to shade for different periods of time (BMSF experiment 22)....

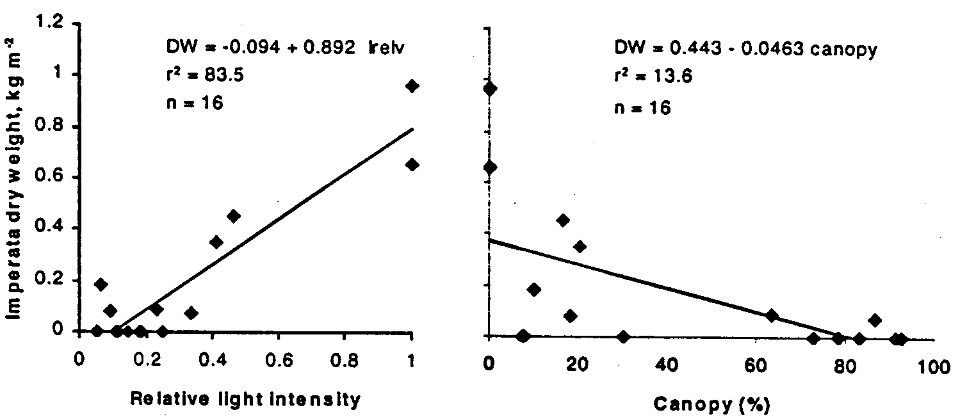

Figure 3. Relationship between *Imperata* biomass and **A.** light intensity (relative to full sunlight, measured with a PAR sensor) and **B**.tree canopy cover estimated with a 'densimeter' in various young agroforestry systems in Lampung; the data include pepper/coffee gardens of 4 – 8 years old, 7 year old rubber, 3 - year old *Acacia mangium,* 9 year-old oil palm and 8?-year old mixed fruit tree agroforest

These results can now be compared with results of a survey of Imperata occurrence in agroforestry systems of 2-8 years old in the ASB North Lampung benchmark area. A relationship was indeed found between light levels below the tree canopy and Imperata biomass (Fig. 3 A).

The relationship with tree canopy estimated with a simple mirror ('densimeter') was less impressive (Fig. 3 B)

The intercept of the regression line in Fig. 2A agrees with a critical shade level of around 10%, although in some plots with this type of shade *Imperata* still occurs; this may be caused by seasonal variation in light levels and the very slow deacy of existing biomass after shade intensifies.

Considerable differences were found between the different types of tree crops under current farmer's practice in and around the ASB benchmark area (the survey included some of the better soils with pepper/coffee gardens):

- *Acacia mangium* is a rapid grower and a 3-year old stand only allowed 6-9%light to penetrate,
- *Paraserianthes falcataria* has an open canopy and 4 – 8 year old stand allowed 18 – 25% light through,
- Rubber development is slow and a 7 year old stand allowed 25 – 46% light through, leading to substantial *Imperata* problems
- A 9-year old oil palm stand (smallholder management) still allowed 34% light through and was not out of the *Imperata*/fire risk zone,
- In 4-8 year old pepper gardens the shade trees (most often *Gliricidia*) were managed to let 10 – 18% light through, as the pepper vines need light as well; in mixed pepper/coffee systems, a denser shade is maintained
- In 7-9 year old mixed fruit tree gardens, especially those with cacao, low light levels (5 - 12%) prevail and *Imperata* is no problem.

In **conclusion,** the data obtained so far suggest that complete shade-based control of *Imperta* requires a persistent tree canopy which only allows 10% light to reach the herb layer. After 2 or 3 months of such shade, a single handweeding round might be effective in obtaining full control. Our data confirm that there is a considerable gap between tree canopy densities which still allow intercropping of annual food crops (say up to 50% light penetration) and the density required for *Imperata* control. Managing tree crops should aim at making this transition period as short as possible to reduce risks of fire and weed damage to tree crops. Short-lived cover crops (such as *Mucuna pruriens utilis*) which can develop a good cover but die back after 3-4 months, can not be expected to provide adequate control (as was noted by Hairiah *et al.,* 1993).

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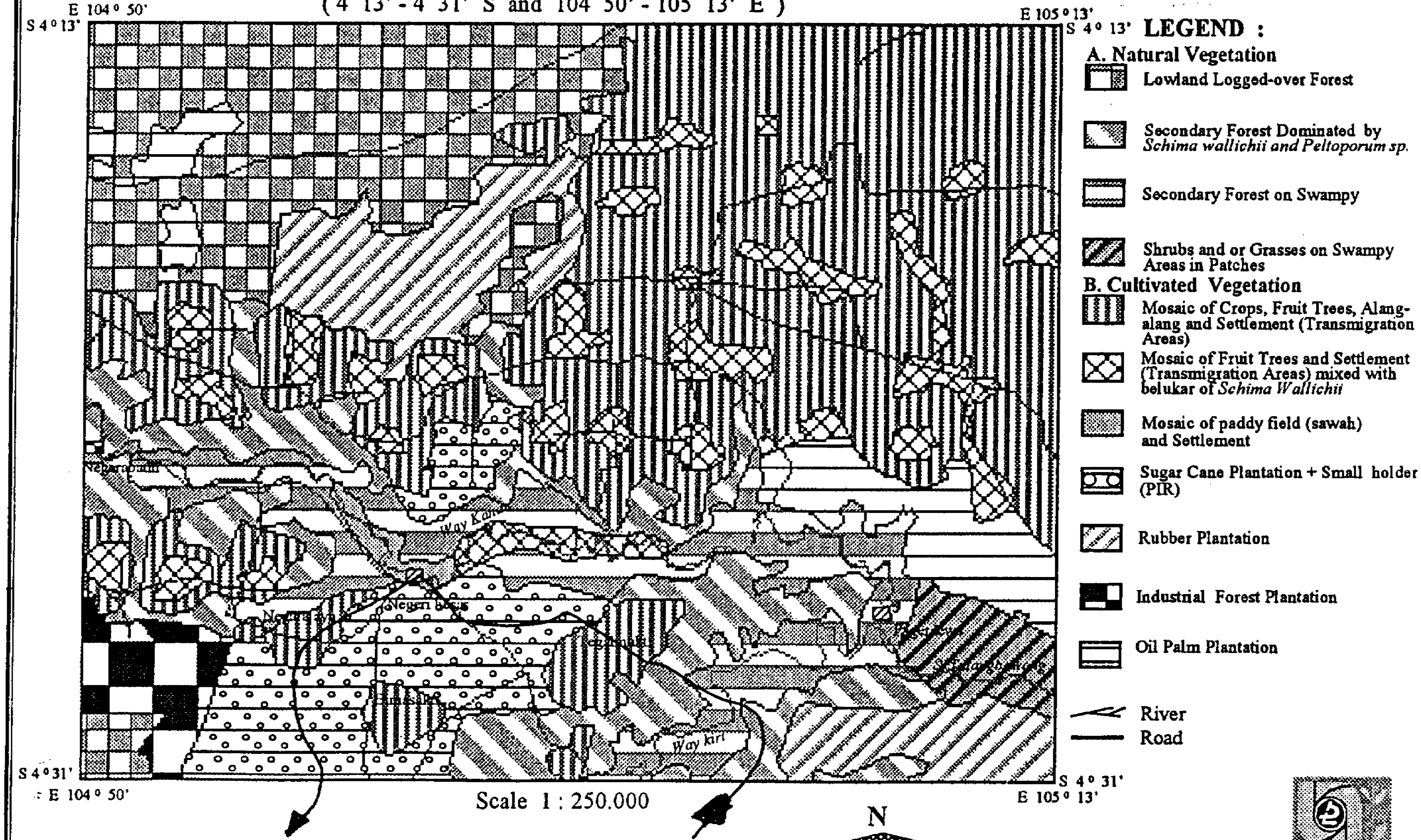
LAND COVER 1994
NORTH LAMPUNG - ASB BENCHMARK AREA
(4 13' - 4 31' S and 104 50' - 105 13' E)



Scale 1 : 250.000

SOURCE :
Landsat -TM FCC; Scale 1 : 250.000; P/R 124/ 063; May 1994.

Designed by Aep Hidayat

Published by SEAMEO - BIOTROP, 1997.

Table.3. Land use and cover changes on North Lampung Bencmark area in 1988-1992-1994-1996

No.	Land Cover	1994		1996	
		Ha	%	Ha	%
1	Lowland Logged-over Forest	20965.91	14.8	12702.47	9.0
2	Secondary Forest Dominated by *Schima wallichii* and *Peltoporum* sp.	15635.79	11.0	15049.02	10.6
3	Secondary Forest on Swampy	12470.82	8.8	12475.70	8.8
4	Shrubs and or Grasses on Swampy Areas in Patches	2720.98	1.9	501.86	0.4
5	Mosaic of Crops, Fruit Trees, Alang-alang and Settlement (Transmigration Areas)	49048.27	34.6	46248.31	32.6
6	Mosaic of Fruit Trees, and Settlement (Transmigration Areas)	10053.04	7.1	12301.79	8.7
	mixed with belukar of Schima wallichii.				
7	Mosaic of Paddy field (sawah) and Settlement	710.82	0.5	711.12	0.5
8	Sugar Cane Plantation + Small holder (PIR).	11040.64	7.8	9206.89	6.5
9	Rubber Plantation	9903.86	7.0	15221.70	10.7
10	Industrial Forest Plantation	3065.37	2.2	3942.65	2.8
11	Oil Palm Plantation	6076.50	4.3	12215.51	8.6
12	Bare land (Ladang)	0.00	0.0	1114.97	0.8
	Total	141692.00	100.0	141692.00	100.0

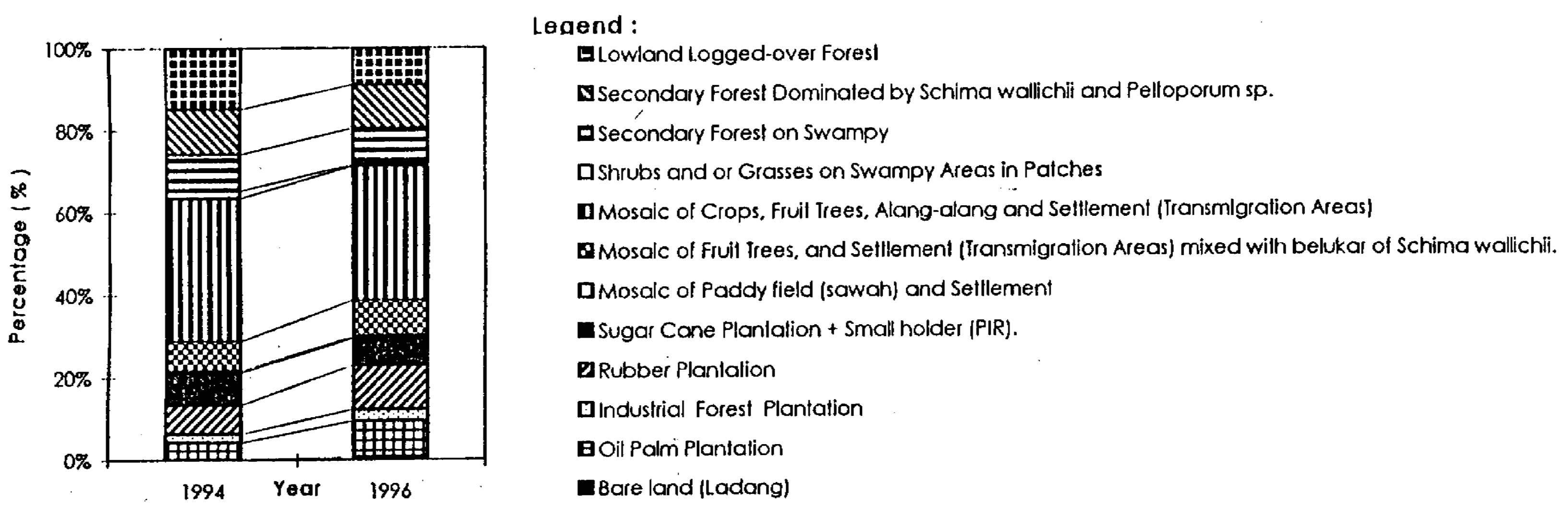
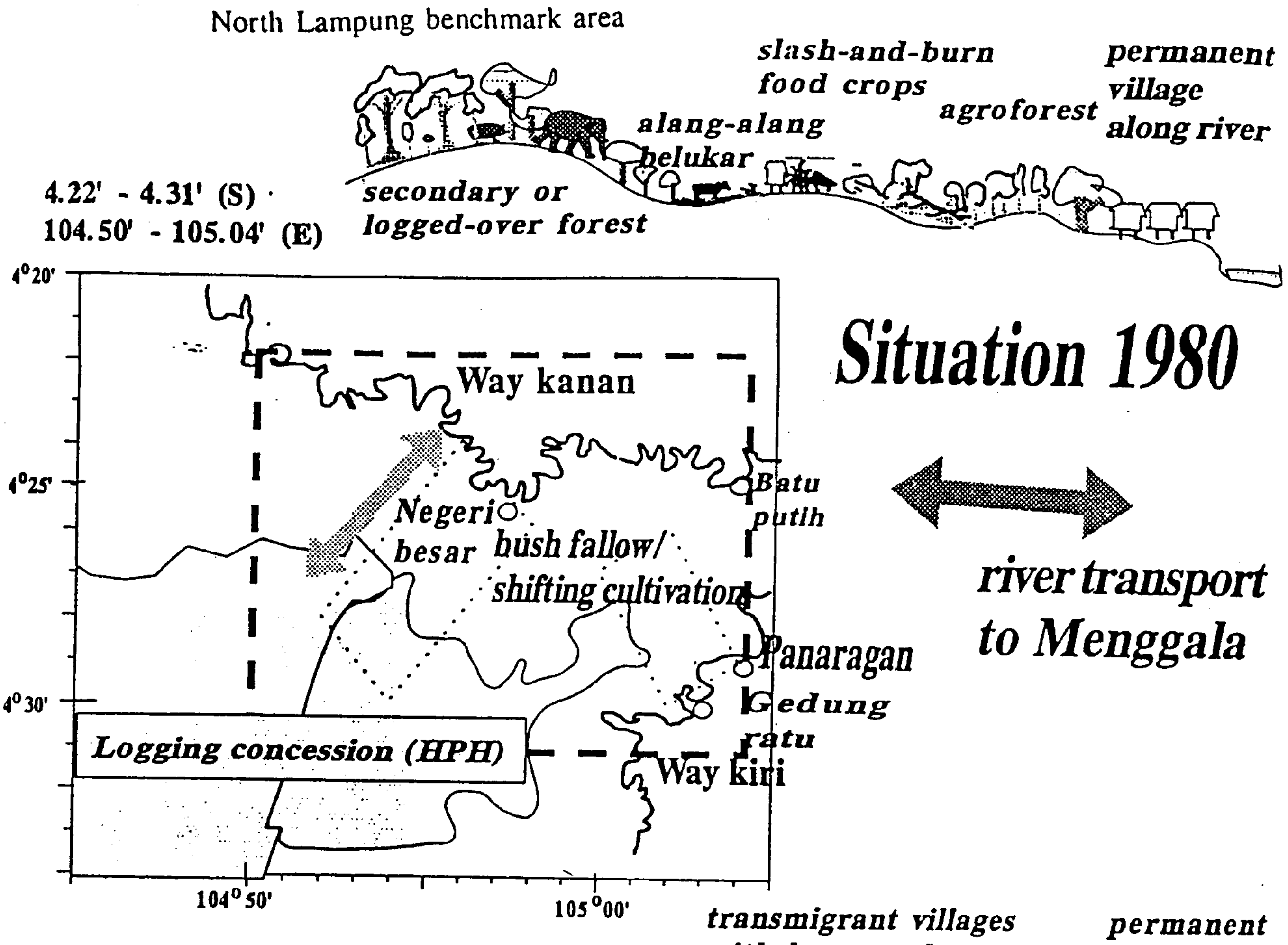
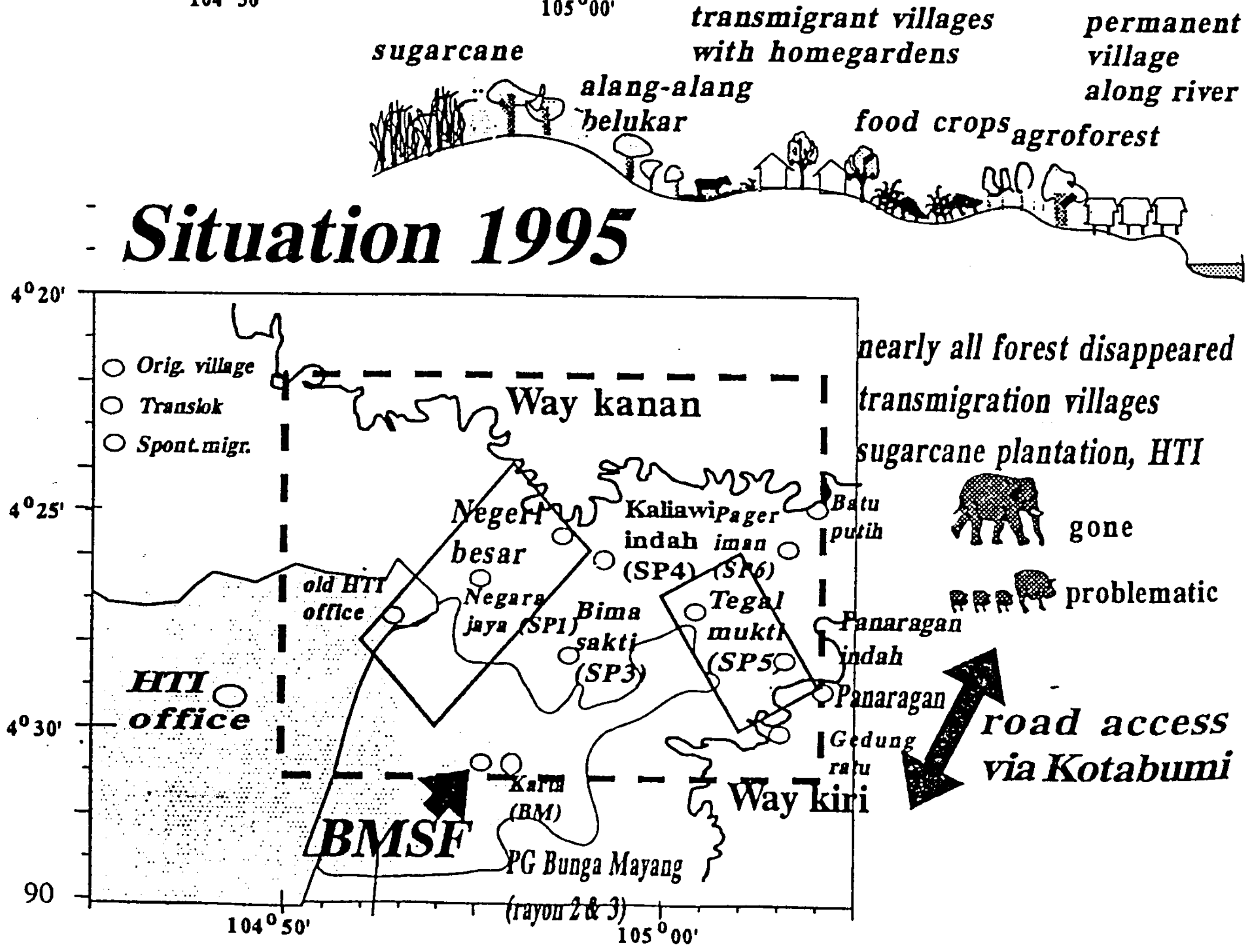


Fig.3. Graphic of the percentage of land use change and land cover area from 1994 to 1996 in North Lampung Benchmark area.


North Lampung benchmark area
slash-and-burn food crops
permanent village along river
alang-alang belukar
agroforest
4.22' - 4.31' (S)
104.50' - 105.04' (E)
secondary or logged-over forest
Situation 1980
4°20'
4°25'
4°30'
Way kanan
Batu putih
Negeri besar
bush fallow/ shifting cultivation
river transport to Menggala
Panaragan
Gedung ratu
Logging concession (HPH)
Way kiri
104°50'
105°00'


sugarcane
transmigrant villages with homegardens
permanent village along river
alang-alang belukar
food crops
agroforest
Situation 1995
4°20'
4°25'
4°30'
Orig. village
Translok
Spont. migr.
Way kanan
nearly all forest disappeared
transmigration villages
sugarcane plantation, HTI
gone
problematic
Negeri besar
Kaliawi indah (SP4)
Pager iman (SP6)
Batu putih
old HTI office
Negara jaya (SP1)
Bima sakti (SP3)
Tegal mukti (SP5)
Panaragan indah
HTI office
Panaragan
Gedung ratu
road access via Kotabumi
Karta (BM)
Way kiri
BMSF
PG Bunga Mayang (rayon 2 & 3)
90
104°50'
105°00'

SOIL AND OTHER CONSTRAINTS TO AGRICULTURAL PRODUCTION WITH OR WITHOUT TREES IN THE NORTH LAMPUNG BENCHMARK AREA OF THE 'ALTERNATIVES TO SLASH AND BURN' PROJECT

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ABSTRACT

In the context of the 'Alternatives to Slash and Burn' project an area in North Lampung was characterized at community and household level to identify the main land use strategies and constraints. Three stata were considered: the local Lampungese, the government sponsored transmigrants and spontaneous migrants, representing the latest arrivals. Whereas the Lampungese focus their farming on the river banks and floodplain, the other two groups farm on the poorer upland soils. Apart from soil fertility constraints, vertebrate pests (esp. pigs and rats) are identified as major determinant of farming success. Tree crops play a relatively small role in the current farming system, but they are perceived as a way to improve the current situation.

INTRODUCTION

Sumatra was chosen as first study area in the humid forest zone of S.E. Asia during the first phase of the global 'Alternatives to Slash and Burn' (ASB) project. Slash-and-burn farming systems exploit the forest for its soil fertility effects and generally have a low productivity relative to the amount of damage they do to forest resources (Sanchez *et al.*, 1990; Brady, 1996). The global project on 'Alternatives to Slash-and-Burn' (ASB) is built on the hypothesis that: 'Intensifying land use as alternative to slash-and-burn farming can help to reduce deforestation, conserve biodiversity, reduce net emission of greenhouse gasses and alleviate poverty'. The hypothesis thus implies (semi)permanent activities on a small area as alternative to extensive slash-and-burn activities on a large area.

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

In the first phase of the ASB project a broad ranging 'characterization and diagnosis' activity was initiated in Brazil, Cameroon and Indonesia to collect baseline data on the nature of current slash-and-burn conversion of tropical forests in the three continents and judge the relevance of this intensification hypothesis in the local context of farmers, other users of forest resources and government institutions. Guidelines and procedures were developed for 'Characterization and Diagnosis' for the global project (Izac and Palm, 1994).

Sumatra, the land of gold, is the westernmost part of the Indonesian archipelago and strategically located on the major access routes, from mainland S.E. Asia and by sea from India (Reid, 1995). Yet, the interior of the island was not very attractive and was bypassed by human settlers, travellers and traders, who focussed on the more fertile soils of Java. People lived in the northern and western coastal strip, in the relatively fertile piedmont transition between the mountain range and the peneplain of poor soils and along the rivers in that zone. Marsden (1811) described swidden practices in Sumatra. His contemporary sources in Sumatra were well aware of the importance of soil organic matter as the source of soil fertility in the few years after opening a piece of forest by slash-and-burn methods and the fact that depletion of this fertility necessitated abandoning the plot to a period of fallow regrowth. But land was plentifull and the fallows could be long enough.

Since the beginning of 20th Century, population density in Sumatra increased also in this peneplain by migration from Java both spontaneously and sponsored by the government in the transmigration program. A clear gradient in population density exists from the South (Lampung) to the middle (Jambi, Riau) of the island. Although the major part of the land in Sumatra is considered to be government forest land, a substantial part of this land is no longer under forest cover.

Four 'benchmark areas' were characterized in Sumatra for the ASB project. The North Lampung benchmark area was chosen to represent the peneplain zone of Sumatra with a high population pressure, compared to the peneplain site in Jambi. Lampung has received large numbers of spontaneous and trans-migrants from Java in the past decades, but is now a source area of migration into the remaining forest margins of Sumatra. Sustainable development and intensification of land use here may help to reduce the pressure on forests elsewhere.

We will review results of the characterization and diagnosis for the North Lampung site here and discuss the links with the research on biological management of soil fertility in the BMSF project on the edge of the benchmark area.

MATERIAL AND METHODS

Methods

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

Five institutions in the ASB-consortium collaborated with ICRAF staff to adapt the ASB global characterization guidelines for research in Sumatra. This process yielded two instruments for fieldwork on land use and socioeconomic characterization. One is a structured questionnaire for use in a stratified random-sample survey of households. The three strata are: local farmers, spontaneous migrants, and government-sponsored transmigrants. The other instrument is an informal checklist for open-ended discussions as part of community-level appraisal.

Community-level characterization activities are developing a holistic picture of prevailing land use patterns at the forest margins, including forest concessions, industrial forest plantations, tree-crop estates, and large-scale absentee owners as well as smallholders. Similarly, the household-level characterization covers the range of smallholder farming systems, not just shifting cultivation.

The household-level questionnaire for Indonesia is built around sets of systematic questions for different land use categories, including wet rice fields (*sawah*), home gardens (*pekarangan*), upland fields (*ladang*), perennial plots, including agroforests (*kebun*), bush fallow (*belukar*), grasslands (*padang pengembalaan*) and forests (*hutan*). Developing a valid sample frame for spontaneous migrants proved especially challenging since these households typically are unreported or under-reported.

Household-level characterization was completed in May 1995. Initial reports for the various strata were presented by Gintings *et al.* (1995), Hadi *et al.* (1995) and Saleh *et al.* (1995). Data of all sites and strata were jointly analyzed and are presented here.

Benchmark area

The North Lampung benchmark area (4 22' - 4 31' S and 104 50' - 105 04' E) covers an area of approximately 17 x 25 km^2 along the lower reaches of the Tulang Bawang river, and largely within Pakuan Ratu sub-district. Negara Jaya and Tegal Mukti were chosen to represent transmigration villages, while Tiuh Baru (one of the four sub-villages of Negeri Besar) was chosen as representative of local communities. Spontaneous migrants were interviewed in one of the sub-villages of Negara Jaya, in Kaliawi Indah and in Panaragan Indah. The latter two were established under the jurisdiction of local village leaders, on land sold to newcomers.

Soils in the benchmark area are very deep, well drained and very acid, with low soil fertility status; iron concretions are often found within the soil profiles. The major soil groups are Oxi/Ultisols, Inceptisols and Entisols, covering 64, 29 and 7% of the area, respectively. Soil erosion has occurred throughout the area with various intensities depending on land management (Rachman *et al.*, 1995).

RESULTS

Landscape ecology and history of settlement

The Tulang Bawang river originates in the forested mountains of the Bukit Barisan range and flows eastwards, via the piedmont zone with relatively fertile soils used since long for coffee and pepper based agroforestry systems, into the undulating and rolling landscape of the dissected peneplains, consisting of acid tuffaceous sediments of low fertility. The river here forms a relatively fertile valley and floodplain, which gradually transforms into the swamp and mangrove zone which forms the fuzzy eastern coastline of Sumatra. The Tulang Bawang river follows the same pattern as the smaller Sekampung and Seputih rivers to the south and a large number of rivers to the north, with the Musi, Batang Hari and Indragiri systems as the largest. All these rivers have up till recently dominated the land use patterns, as they provided the major access for human migration, trade as well as political influence. The Tulang Bawang river has for long been on the border of the Sriwijaya kingdom based in Palembang and the Lampung districts which were under the power of Banten in West Java. Menggala was a major fort controlling access to the river, while Kotabumi was a trading post, on the edge of where the (southern branch of the) river was navigable and close to the pepper production zone which for long was the major source of wealth. The village of Negeri Besar consists of fertile land banking the river, surrounded by infertile higher ground of the peneplain. Van Romburg (1900) travelled on the Tulang Bawang river and continued on horseback to Negeri Besar 'via a region which offers little variation and where extensive alang-alang fields and low forest indicate that the original rain forest was converted into upland rice fields long ago'. Van Romburg was surveying for native rubber producing plants and found little of interest around Negeri Besar and continued towards Krui (West Lampung) and then by boat to West Sumatra and Jambi. A traveller around 1920 noticed the logs and rubber transport on the Tulang Bawang river and the depleted forest on the river bank around Negeri Besar. At that time all easily accessible forests were logged for railway sleepers for the new Lampung - Palembang railway. Until 1980 these uplands were used for extensive 'shifting cultivation' or 'long rotation fallow' systems. Free roaming buffaloes grazed the area. Land close to the river was described as 'mosaic of shrub, secondary forest and *Imperata*'. Further from the river some primary forest remained, on the least accessible places (Fig. 1).

After logging concessions had depleted the forests, large areas were allocated for conversion to a sugarcane plantation and industrial timber estate (HTI). Transmigration settlements were established in the early 1980's, in the zone which had previously been used by the local population in an extensive fallow rotation or shifting cultivation system. The last remnants of 'swidden' cultivation based on temporary dwellings still existed in mid 1980's when the precursor of the BMSF project started. Thus the land use pattern as it exists now (Fig. 2) differs drastically from that around 1980.

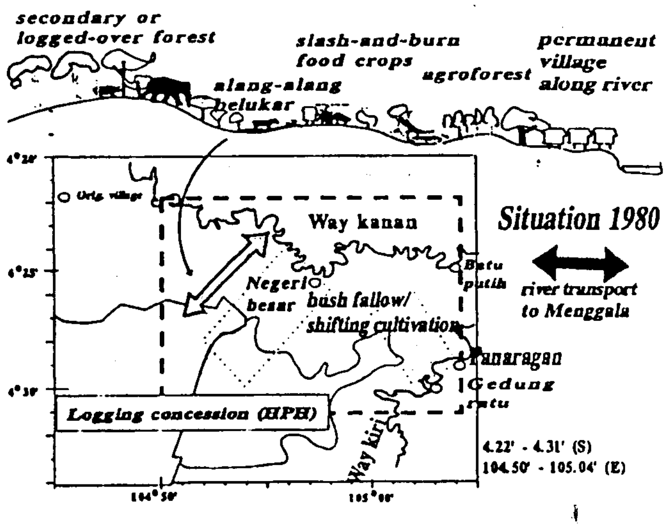

Figure 1. North Lampung benchmark area around 1980

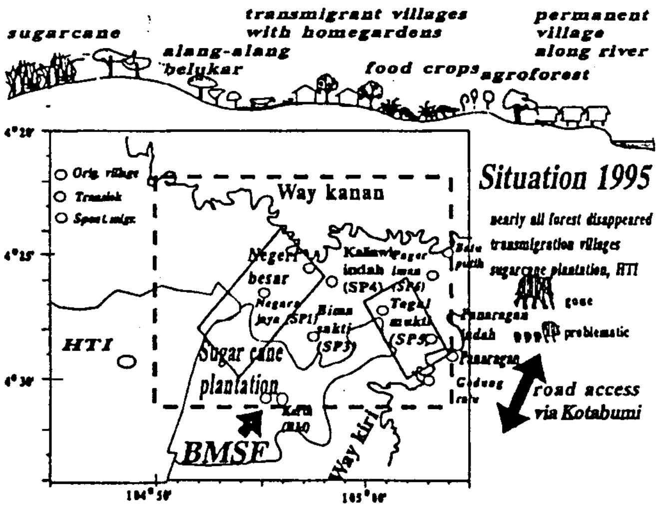

Figure 2. North Lampung benchmark area around 1995

Table 1. Population size of the benchmark areas, based on BPS Lampung (1983 and 1993)

	Pakuan Ratu (1290 km²)			Lampung Province (35377 km²)		
	1983	1993	Δ %	1983	1993	Δ %
Population (1000's)	31.4	77.0	145	4902	6173	25.9
Density, (no. km^{-2})	24	60	150	139	174	25.9
Population Growth rate (% yr^{-1}) 1983-1993			9.38			2.33
No. of Households (1000's)	7.2	17.8	147	930	1269	36.5
People/HH	4.4	4.3	-1	5.3	4.9	-7.6

Population data

The population of North Lampung has increased dramatically since the 1970s. Of the total number of migrants that went to Sumatra since the beginning of the 20'th Century, 50% settled in Lampung (RePPProt, 1988). Data for the Lampung benchmark site show that in the 1983-1993 period the population in the Pakuan Ratu sub-district doubled and the annual growth rate has been as high as 9.4%, while it was only 2.3% for Lampung as a whole (Table 1). The population density of Pakuan Ratu remains much smalller than the average for Lampung province, however.

Possible factors contributing to the high rates of migration to Lampung are: 1) Lampung is adjacent to Java and inter-island travel is easy and relatively cheap, 2) Lampung has been receiving migrants and transmigrants from Java since the beginning of this century and the cultural and family links between the two regions are by now well cemented, 3) Many (trans) migrants have been modestly successful, and the favourable reports sent to relatives and friends in the area of origin have induced them to join a new life in Lampung. The earlier (trans) migrants, however, have occupied most of the available good quality land and what remains now is the less-fertile, acid peneplain land in North Lampung, as well as the mangrove swamps. As pressure on the land increased, the land was degraded. Those who cannot survive have moved to other areas, so that the area has changed its function from a receiver to a sender of migrants. Recently, however, there is cause for some optimism that conditions in the benchmark area can improve. Improved road access and transformation of the degraded lands to productive tree crops is improving the options for local farmers.

Table 2. Food and tree crop performance in Pakuan Ratu according to available sub-district statistics (no data available on smallholder sugarcane and oil palm) (Source: BPS Lampung, 1983 and 1993)

	area (1000 ha)			production (ton/ha)		
	1983	1993	Δ %	1983	1993	Δ %
Wetland rice	0.11	0.71	545	4.4	4.2	-5
Upland rice	0.41	6.70	1,534	1.6	2.6	63
Maize	0.57	1.11	95	1.2	2.6	117
Soybean	0.04	5.90	14,650	0.7	0.8	13
Cassava	0.85	1.07	26	11.6	12.3	6
Rubber		1.00				0.11
Coconut		0.72				0.58
Clove		0.10				0.11
Coffee		0.07				0.56

If we can trust the available sub-district statistics (Table 2) there has been a dramatic increase in the area under most food crops, but especially upland rice and soybean, associated with the settlement of the transmigrants. Tree crops are a minor element in the farming system in Pakuan Ratu, according to these statistics.

Regional economics

The per capita Gross Regional Domestic Product (GRPD) of Jambi and Lampung provinces are both below the average for Sumatra and are less than nearby provinces such as S. Sumatra, Riau and West Sumatra (RePPProt, 1988). However, it should be noted that GRDP per capita is a purely statistical computation and may not reflect the actual level of welfare, especially where oil production and related industries contribute to the GRDP of several of the other provinces.

The GRDP statistics show that the industrial and manufacturing sectors have grown rapidly within the past decades, much more so than the agricultural sector. In Lampung, the manufacturing sector consists largely of agro-processing enterprises e.g., coconut oil, crumb rubber, tapioca (cassava) pelletizing (RePPProt, 1988).

The agricultural sector requires seasonal labor during the harvest period. Many transmigration sites are close to large scale plantations and thus provide a relatively cheap labour force for these plantations, as off-farm income is usually needed to supplement the on farm production. Many 'spontaneous migrants' start as seasonal labourers, who decide to stay on after observing the opportunities still available. In Lampung, migrants start by picking coffee and pepper in the better soils of the piedmont zone. The sugarcane plantation close to the ASB benchmark area brings in new groups of labourers from Java every year during the harvest period.

Village characterization

Most of the transmigrants in Negara Jaya and Tegal Mukti came to Pakuan Ratu sub-district under the 'local transmigration' scheme and were re-settled in the early 1980's from forest reserves in South and Central Lampung, where they had started as 'forest squatters' in land classified as protection forest. Many of them had coffee gardens. Negara Jaya has good infrastructure and access to off-farm employment from the Bunga Mayang sugarcane factory and plantation, and from a sawmill and industrial forest plantation (HTI) with fast growing species (*Paraserianthes falcataria* and *Acacia mangium*). Much of the *Imperata* grassland has recently been converted into sugarcane under a nucleusestate small holder scheme. Tegal Mukti was established in 1983/84 and has poorer infrastructure compared to that of Negara Jaya. The distance to the sugarcane factory is about 30 km over a road which was in bad condition until recently. A new road connection towards Menggala in the East opened in mid 1995 and has dramatically improved the accessibility of the area.

Tiuh Baru is part of Negeri Besar, a large original Lampung village, on the right bank of the Way Kanan river. Transmigration brought large changes to the area. Large tracts of land were sold by the adat leaders and used for transmigration settlements. Improved road access via Kotabumi opened new economic opportunities and exposure to the neighbouring transmigrant communities induced gradual social change in the village. Maybe the most remarkable phenomenon is that now many girls/ young women work in textile factories in Tangerang (near Jakarta) (Elmhirst, 1995).

Land use and farming systems

Most of the land used by farmers in the benchmark area is unirrigated, but roughly 10% of the area is a wetland along streams and rivers. Often such wetlands have been converted into sawah's (wet rice fields). Most of the land is used for food production and, more recently, mainly sugar cane. There has been a great increase of wetland rice production in Pakuan Ratu through conversion of marshy lands (Table 2). Cassava cultivation increased considerably in North Lampung. This may be explained by the decreasing soil fertility so that planting cassava is the logical choice (it can grow on poor soils); at the same time there are many pelletizing factories that guarantee a market for cassava tubers. Fluctuating prices cause considerable year-to-year variation in cassava area. North Lampung has various kinds of perennial crops e.g. coconut, cloves and sugarcane are grown; few tree crops are grown within the ASB benchmark, however, which occupies the Easternmost part of Pakuan Ratu sub disctrict.

The farming systems within the selected villages can be differentiated as follows:

A. Local people

Losing large parts of the adat (customary) land to the transmigration programme marked the end of shifting cultivation. Now farmers tend to intensify production on their remaining land. Planting cash crops, both annuals and perennials, indicated a movement towards commercial cultivation. Hybrid corn is the most popular annual cash crop, while coffee is the perennial choice on the small patches of suitable soil. Similarly, land tenure has been changing from communally-owned to privately-owned land. Much of the adat/customary land has been sold, but disputes over the land are common.

B. Transmigrants

Each farmer in the two transmigration villages was allotted 2 ha of land divided into homelot (0.25 ha), LU-I (0.75 ha), and LU-II (1 ha). Most of these plots are dry land. The farming system in Negara Jaya and Tegal Mukti is slightly different. The first village was reached earlier by the sugarcane smallholder scheme, but by 1994/ 1995 many farmers were disappointed with this scheme. Poor soils and logistical problems of fertilizer delivery and the pronounced dry season of 1994 caused poor crop growth (some sugarcane resembled *Imperata*) and problems with transport of the cane harvest to the factory led to financial disappointment. Many farmers could not repay their credit to the sugarcane plantation and said that when the contract to the company expired, they will not renew it. Currently, there is increased interest in growing other perennial crops: rubber (encouraged by the village head, who is of Lampung origin), oil palm (the recently improved roads allow traders from the provincial capital to operate in the area to collect the bunches) and fast growing timber (mainly *Paraserianthes)* as used by the HTI.

In Tegal Mukti cassava used to be the most important crop (heavily infested by *Imperata*). Recently sugarcane was extended to this area. A previous rubber extension project failed, but a cattle project has been (moderately) successful in this village.

Soils in both villages are poor, but Tegal Mukti is worse than Negara Jaya. The acid soils accompanied with frequent drought have made the land very susceptible to weed invasion. Farmers have to use high doses of fertilizer for planting annuals. Interruption of weeds (i.e. *Imperata*) and pests such as rats and wild pigs are a significant factor in causing poor harvests. Many farmers stated that uncertainty about planting food crops in the dry land meant that it was more worthwhile to leave it as bush or sell it, and work at off-farm opportunities. Many farmers sold their dry land to buy sawah: 1 ha of dry land is equal to 0.25 ha of sawah (Elmhirst, 1995).

From Elmhirst (1995) it appears that no one can live by agriculture alone in the transmigration settlement; those who come close are the ones who own sawah. As much as possible, farmers have tried to convert available land into sawah; share-cropping of other people's sawah is common as well. Only farmers with access to sawah can live from on-farm income. Accumulation of capital from these ventures is used for buying more land from the local people. Other livelihood strategies chosen by transmigrants include moving away to urban areas or to more fertile land in the nearby forest margins (in surrounding provinces).

Table 3. Basic demographic characteristics of three strata in the population of the ASB North Lampung benchmark area (survey April 1995 by ASB-Indonesia team)

	Local people	Trans-migrants	Spontaneous migrants
Number of respondents	37	54	22
Average household size	6.19	4.57	4.23
Age of family head (%)			
< 30 years	11	20	32
30-40	51	37	41
40-50	29	15	23
> 50	9	28	5
average	39	41	36
Education of household head (%)			
< 6 years	76	89	90
> 6 years	24	11	10
Working[1] in (%)			
agriculture	100	100	100
non-agric.	21	33	18
Years of stay of household head			
0-5 years	6	19	77
5-15	0	81	23
>15	94	0	0
Birth place of household head			
same district	100	4	0
elsewhere, Sumatra	0	13	23
elsewhere, Java	0	83	77
Primary reason to migrate			
looking for new land	-	27	45
to get a better life	-	16	23
hard life in original place	-	12	18
joining relatives	-	10	5
resettled by government	-	33	0
other reason	-	2	9

1. More then one answer possible

Results of the household survey

The household interviews first can be grouped by basic demographic characteristics (Table 3). Average size of the interviewed households was larger for the local people, than for transmigrants and spontaneous migrants. The latter had the largest share of young family heads. A larger share of the local household heads had completed more than six years of school education, than in the two other groups. About 80% of the household heads in the two migrants groups were born in Java. The primary reasons to migrate were looking for new land or better livelihood opportunities for the spontaneous migrants, while a third of the transmigrants indicated that they had been resettled by the government as the main reason for coming to the area. All the interviewed households were involved in agriculture, but many had other sources of income as well, especially in the transmigrant stratum.

Table 4. Average number of plots and total size of various land use types for three strata in the population of the ASB North Lampung benchmark area (survey April 1995 by ASB-Indonesia team); HH = household.

	Local people	Trans-migrants	Spontaneous migrants
Wet rice fields			
Fraction of HH's owning	0.43	0.24	0.36
no. of plots/owning HH	1.3	1.0	1.13
avg. size per plot (ha)	0.87	0.59	0.75
area per all HH (ha/HH)	0.49	0.14	0.31
Upland (annual) crops			
Fraction of HH's owning	0.32	0.78	0.68
no. of plots/owning HH	1.2	1.4	1.2
avg. size per plot (ha)	1.1	1.1	2.1
area per all HH (ha/HH)	0.41	1.17	1.7
Sugar cane			
Fraction of HH's owning	0	0.28	0
no. of plots/owning HH	0	1.1	0
avg. size per plot (ha)	0	1.4	0
area per all HH (ha/HH)	0	0.44	0
Tree-based systems			
Fraction of HH's owning	0.14	0.04	0
no. of plots/HH owning	1.4	2	0
avg. size per plot (ha)	0.86	0.96	0
area per all HH (ha/HH)	0.16	0.07	0
Fallow land (bush/Imperata)			
Fraction of HH's owning	0.22	0.26	0.46
no. of plots/owning HH	1.4	1.2	1.0
avg. size per plot (ha)	2.23	0.78	1.09
area per all HH (ha/HH)	0.66	0.25	0.50
Home garden			
Fraction of HH's owning	0.41	0.87	0.96
no. of plots/owning HH	1	1.0	1.0
avg. size per plot (ha)	0.07	0.26	0.29
area per all HH (ha/HH)	0.03	0.22	0.28
Total size (ha/HH)	1.75	2.29	1.97

The total farm size of the interviewed farmers (Table 4) was smallest for the local people stratum and largest for the transmigrants (2.3 ha close to the original land allocation). The transmigrants had the least access to wet rice fields ('swamp rice' along river banks and rice in non-technical irrigation) and had the largest area under upland annual crops. Only a quarter of the interviewed households in the transmigrant group participated in the sugarcane outgrower scheme, but for those who did it took nearly all their land outside the homegarden. Only small areas were under tree-based systems (mixed fruit agroforests or jungle rubber). Homegardens are only used by the transmigrants and spontaneous migrants and occupy about 0.25 ha in each case, close to the original allocation for transmigrants. Fallow land under bush or *Imperata* is only a small part of the total farm according to the data, but it is possible that this category was under reported, especially for the local people, who still have access to secondary forest or bush along the river.

Table 5. Percentage of different land types which is perceived as 'fertile' by their users for three strata in the population of the ASB North Lampung benchmark area (survey April 1995 by ASB-Indonesia team)

	Local people	Trans-migrants	Spontaneous migrants
Wet rice fields	95	85	75
Upland crops	78	34	22
Sugar cane	-	37	-
Tree-based systems	71	11	-
Fallow	58	22	27

In general the local people are a lot more positive about the fertility of the land they use (Table 5) than the migrant groups. This is in line with the soil maps. The migrant groups are only positive overall for the land which can be used for wet rice fields (sawah).

Table 6. Use of inputs as percentage of fields used by three strata in the population of the ASB North Lampung benchmark area (survey April 1995 by ASB-Indonesia team); W = wetland rice, U = upland food crops, S = sugar cane, T = tree-based systems

	Local people				Trans migrants				Spontaneous migrants			
	W	U	S	T	W	U	S	T	W	U	S	T
High yielding seed	35	4	-	0	57	9	-	17	50	43	-	-
Organic fertilizer	0	0	-	0	7	40	0	6	0	14	-	-
Inorganic fertilizer	6	13	-	33	0	63	56	6	0	79	-	-
Pesticides	35	26	-	0	36	47	17	6	75	64	-	-
Herbicides	12	0	-	0	0	9	0	0	0	7	-	-
Animal Power	12	9	-	17	0	16	6	0	0	7	-	-
Tractor	0	0	-	0	0	0	33	6	0	0	-	-
Thresher	0	0	-	0	0	2	0	0	0	0	-	-

The use of 'high yielding varieties' is largely confined to wetland rice, but the spontaneous migrants use them for their upland food crops as well. The low rating of soil fertility for especially upland food crops by the two migrant groups is consistent with a relatively large number of farmers using inorganic fertilizer on this system (Table 6). The local people use fertilizer especially for their tree crops, not for the food crops. Organic fertilizer is only recorded for the use use of cattle manure by some of the transmigrants. The data show hardly any fertilizer use on the wetland rice fields, but a relatively large use of pesticides for this crop. Herbicide use is not widespread and the degree of mechanization is very low.

Table 7. Biotic and abiotic problems as percentage of fields used by three strata in the population of the ASB North Lampung benchmark area (survey April 1995 by ASB-Indonesia team); W = wetland rice, U = upland food crops, S = sugar cane, T = tree-based systems

	Local people				Trans migrants				Spontaneous migrants			
	W	U	S	T	W	U	S	T	W	U	S	T
Elephants	19	4	-	0	0	0	0	0	0	0	-	-
Monkeys	29	52	-	13	0	2	0	0	38	6	-	-
Pigs	52	83	-	50	29	49	32	0	50	38	-	-
Rats	81	91	-	13	50	29	4	0	50	19	-	-
Planthopper	29	0	-	0	0	21	0	0	63	6	-	-
Other pests	76	57	-	0	64	59	40	4	75	31	-	-
Diseases	33	17	-	25	21	14	0	0	38	38	-	-
Imperata	19	35	-	13	0	29	0	0	0	56	-	-
Other weeds	76	30	-	13	7	12	0	0	25	31	-	-
Erosion/flood	86	61	-	38	36	10	0	0	63	38	-	-
Fire	43	9	-	63	0	2	32	12	0	13	-	-
Drought	86	35	-	0	21	10	0	0	0	13	-	-

The abiotic and biotic constraints to agricultural production again differ by land use type and farming group (Table 7). Vertebrate pests play a prominent role. Elephant problems only occur on the north side (left bank) of the Tulang Bawang river where the local people have land. Monkeys are not a problem for the transmigrants, as they farm furthest from the forest edge. Pigs and rats are a prominent problem for all food crop production, along with insect pests. *Imperata* and other weeds are less often reported as constraints than vertebrate pests. Fire is the major risk in tree crops, though, and this is linked to the *Imperata* complex. Problems with the water balance (erosion, flooding and drought) are the most important constraint for the local farmers who use the river banks and floodplain.

Figure 3 combines the data for the three strata in Table 7 and includes the assesment of soil fertility of table 5. Overall, soil fertility is seen as a major constraint for all land use systems except the sawah rice fields. Vertebrate and insect pests are a problem for all land use type, but least for the tree crops, while *Imperata* and the associated fire is a main risk for tree crops.