BIOLOGICAL MANAGEMENT OF SOIL FERTILITY FOR SUSTAINABLE AGRICULTURE ON ACID UPLAND SOILS IN LAMPUNG (SUMATRA)

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ABSTRACT

At the start of the Biological Management of Soil Fertility (BMSF) project in Lampung a set of principles was formulated for dealing with 'Mother Soil', to avoid soil degradation. These principles can be tested separately in specific hypotheses or in more integrated form in long term experiments with a range of cropping systems of different land use intensity.

A dilemma, however, exists as it appears that what is needed to sustain soil fertility does not give sufficient financial returns, while what still gives reasonable returns (low input cropping systems based on cassava) is not sustainable. A way out of this dilemma may exist by introducing tree-based agroforestry systems. We discuss whether acid upland soils should be primarily used for food crops or for income-generating tree crops, and how bottlenecks for a tree-based intensification can be overcome.

INTRODUCTION

Indonesia's population in the next century will need food as well as income. Enormous gains in the productivity of wetland (sawah) rice in the past decades during the Bimas program ('green revolution') have made Indonesia self sufficient in its staple food, apart from years with erratic rainy seasons. There has been no equivalent progress yet in the attempts to increase annual food crop production on 'upland' soils. Large areas of acid upland soils are still seen as a major potential for agricultural expansion, but often this has led to soil degradation rather than sustainable development.

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

Forests have been and are opened for food crop production in Indonesia and are often abandoned to *Imperata* fallow vegetation within a few years, after reaping the initial soil fertility of the converted forest soil (Nye and Greenland, 1960). People may then move on and create new forest frontiers elsewhere, leaving the grasslands behind as under-utilized resource and contributing to the deforestation process. A first issue in this process of land use change is whether the initial degradation into *Imperata* can be slowed down or avoided within the context of food-crop based production systems (Suryatna and McIntosh, 1982), or only by systems with a considerable tree and/or animal component as well. A second issue is how and under which conditions the grasslands can be reclaimed and used more intensively (Van Noordwijk *et al.*, 1997).

Based on general sustainability criteria (Van der Heide *et al.*, 1992) the following issues appear to be crucial for sustainable crop production on acid upland soils:

- avoiding (re-) infestation by *Imperata* and/or the ability to control spread of the grass or to reclaim infested fields;
- maintaining soil organic matter and soil structure, avoiding erosion,
- maintaining the nutrient balance, compensating for nutrient exports with farm products plus unavoidable losses,
- achieving a reasonable yield per unit labour and external inputs.

The classical agronomic view on intensification of upland cropping systems is that a higher output per ha, and therefore a higher human 'carrying capacity', can be obtained by increasing the cropping intensity, from 'shifting cultivation' via 'fallow rotation' to 'permanent agriculture' (Fig. 1). As X-axis we use the Ruthenberg (1976) R value, the fraction of time (or land) used for annual food crops as part of the total cropping cycle (area). In practice there is a danger of 'over-intensification' leading to degradation. *Imperata* fallows may on one hand prevent complete soil degradation, but they are not productive and do little to restore soil fertility (Fig. 1, trend towards lower left corner).

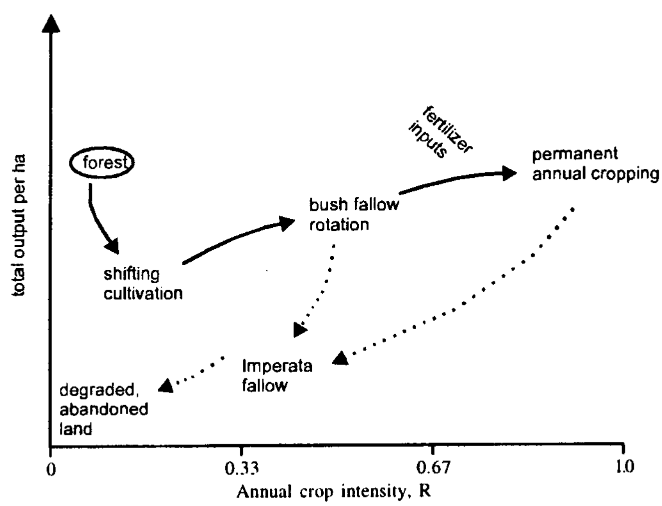

Figure 1. Total output per ha as a function of annual cropping intensity, R (the ratio of cropped and total land area). More intensive use of the soil can increase the total output per ha from shifting cultivation to permanent cropping with annual food crops, but there may be diminishing returns to labour. Intensification can also lead to land degradation and abandonment as indicated by the interrupted arrows.

Table 1. Principles for biological management of soil fertility on acid soils in the humid tropics to maintain ***mother soil***

M	aintain biodiversity of soil organisms
O	ptimize biological N_2 fixation
T	une demand for and supply of N to minimize losses and need for fertilizer
H	ave deep-rooted components included as 'safety-nets' for leach ing nutrients
E	ffective acid-soil tolerant germplasm and Al-detoxification by organic matter
R	eplace P and cations exported in harvested products
S	upply permanent soil cover
O	mit or minimize soil tillage
I	ntegrate 'service' components (cover crops, trees) into the crop ping system
L	et excessive rainfall escape via by-pass flow channels

As a framework for hypotheses and experiments the following 'principles' were formulated for dealing with 'Mother Soil' (Table 1). The first set of principles ('mother') deals with organic matter and nutrient supply, the second ('soil') is focussed on soil physical aspects. In nutrient supply, nitrogen plays a special role as biological N_2 fixation (Giller and Wilson, 1991) potentially can supply sufficient quantities to off-set moderate exports in crop yields, but the mobility of nitrate under high rainfall conditions can lead to low efficiencies of N use, both for organic sources and for mineral N fertilizer (Van Noordwijk *et al.*, 1992). Although the principle of *synchrony* has been formulated as desirable in the past decade, practical applications of such fine tuning of demand and supply are still scarce (Myers *et al.* 1997). The N use efficiency which can be obtained in practical cropping systems with incomplete synchrony depends on rooting depth of component crops or crop-tree combinations (De Willigen and Van Noordwijk, 1989). Acid tolerant germplasm is needed, as lime will not easily reach the subsoil, unless deep tillage is used. Organic matter can help to detoxify aluminium (Hairiah *et al.*, *this issue*), but as for lime, such effects are largely confined to the topsoil. For nutrients other than N some form of replacement of the nutrients exported in harvested products is needed. Interactions in the Al - P - organic matter complex are discussed by Setijono (*this issue*). On the soil physical side, soil management should aim at maintaining high infiltration rates to reduce surface runoff because of its erosion risk. A near-permanent soil cover by mulch is desirable, and maintaining crop residues in the field may not be enough to achieve this. Or-

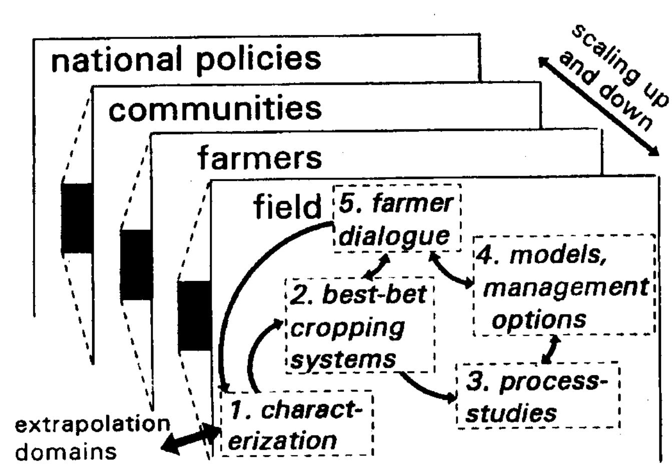

Figure 2. The biological management of soil fertility (BMSF) project is focussed on the field scale, but the objectives also require links with other levels of integration, up to national policies affecting farmer decision making.

ganic material of low 'quality' and hence slow decomposition functions better as mulch than material of high 'quality', which is a better nutrient source (at least in the short term). By-pass flow is a favourable characteristic, as it can help reduce losses by N leaching, provided the N is well incorporated into the soil matrix micropore system. Old tree root channels of the original forest vegetation (Van Noordwijk *et al.*, 1991) play a role in this by-pass flow, as long as their continuity to the topsoil is maintained by avoiding soil tillage.

The BMSF project

The Biological Management of Soil Fertility (BMSF) project in Lampung attempts to test these principles and a set of hypotheses derived from them. The project includes the following activities (Fig. 2):

- Basic characterization of soil, climate, soil management and cropping systems,
- Test of 'best-bet' cropping systems based on the principles of Table 1,
- Quantification of C and N balance of these cropping systems,
- Measurements and specific experiments on key processes in the soil-crop system,
- Integration of process-knowledge in synthetic models, which allow exploration of a wide range of management options,
- Dialogue with farmers on practical implications of management options.

In this issue of AGRIVITA some of the results of the project are discussed, relating to constraints on soil management, functions and fractions of soil organic matter, management of soil organic matter and practical applications.

In experiments in North Lampung by the BMSF project, the following cropping systems are investigated:

- fallow rotations, based on *Imperata*, planted trees, *Chromolaena* and legume cover crops,
- intensive rotations of cereals and legumes,
- hedgerow intercropping ('alley cropping'),
- cassava-based intercropping systems.

These systems represent various stages in an agronomic intensification pathway, represented in figure 1 as a trend towards the upper right corner.

The project site is at Karta (4° 30'S, 104° 98'E), about 50 km N of Kotabumi inside the sugar cane plantation Bunga Mayang (PTP VII) in Sungkai Selatan district (Ketapang), Kabupaten Kotabumi. The project is located in a patch of secondary forest surrounded by sugar cane fields. The area is a moderately dissected undulating to rolling plain, containing acid tuffs and coarse felsic sedimentary rocks, with slopes of 3 - 15%. Accelerated erosion is common and the drainage pattern is dendritic. The convex crests and upper slopes (slope 0-8%) are classified according to the USDA system of soil classification (Soil Survey Staff, 1987) as Kandiudults, the middle and lower slopes (slope 3 - 15%) as Hapludox. Both soil types are well drained, (very) low in CEC and exchangeable K, low in available (Bray-I) P and very low in total K and total P. A low pH and (very) high Al saturation lead to Al-toxicity as a major constraint to crop production. Typical soil organic matter contents in the topsoil are 1.7 - 1.9 %, root development is possible till 120 cm. Annual rainfall is 2000-2500 mm. Further descriptions of site and climate were given in Van der Heide *et al.* (1992) and Van Noordwijk *et al.* (1992).

A major objective of the research project in N. Lampung is to quantify both the direct crop nutrition effects of organic inputs and their contribution to long term maintenance of soil organic matter, as criterion for sustainability. This quantification should lead to the establishment of criteria and guidelines of wider applicability. By inclusion of cover crops or hedgerow trees into the cropping system, sufficient aboveground plant residue can be produced to maintain soil organic matter at a desirable level. Weed infestation can be prevented by maintaining a continuous soil cover, by including winding leguminous cover crops in the rotation or by periods with heavy shading by hedgerow trees. Although biologically possible, such systems however, have found little farmer application, probably because the direct returns to labour are not sufficient.

The productivity-sustainability dilemma

As a short cut to a full financial evaluation, Van der Heide *et al.* (1992) introduced a 'production index' which can be used to add the yields of the various components of multiple cropping systems and allow a (rough) comparison of the overall performance. The index is similar to a 'land equivalent ratio' (LER), but uses 'target' yields to scale the actual yields of each crop, rather than the actual yields obtained in a monoculture. The 'target yields' are chosen so as to reflect yield levels which, given the farm size, make farming worthwhile. They do not necessarily coincide with maximum attainable yields. Between the various crops the target yields approximate equal net financial returns to labour and land. The definition of the 'production index' I_p is:

$$I_p = \sum_{i=1}^{n} Y_i / T_i$$

where Y_i and T_i are actual and target yields of crop i, and n in the number of products obtained from a unit of land. Based on approximate price levels in North Lampung, Van der Heide *et al.* used a tentative target yield for cassava tuber fresh weight of 25 Mg ha^{-1}, a maize grain yield of 5 Mg ha^{-1}, a rice grain yield of 2.5 Mg ha^{-1} and a cowpea yield of 2 Mg ha^{-1}. I_p values above 1.0 indicate cropping systems which have acceptable yields. Systems which meet this target, however, will export 30 - 80 kg of N ha^{-1} yr^{-1} from the field (lower part of this range for cassava and upland rice, the higher part for maize; the export of the grain legumes depends on how effective their N_2 fixation is), 6 - 12 kg of P ha^{-1} yr^{-1} (the higher values for maize and soybean) and 5 - 90 kg of K ha^{-1} yr^{-1} (the lower values for rice and maize, the higher ones for cassava) (Van der Heide *et al.*, 1992).

Most alley-cropping research has focussed on the soil fertility aspects; the N contribution of tree prunings rarely exceeds the equivalent of 60 kg N as urea per crop (two pruning cycles per crop, two crops per year) (Van Noordwijk *et al.*, 1995a). If we take a conservative estimate of the labour costs of pruning as 20 man days per ha per pruning cycle, the rewards for this labour are only 1.5 kg Urea N per day of work or, at current fertilizer prices, 870 rupiah per day, less than a third of the official minimum wage in Indonesia.

It thus appears that what is needed to sustain soil fertility does not give sufficient financial returns, while what still gives reasonable returns (low input cropping systems based on cassava) is not sustainable. A way out of this dilemma may exist by introducing tree-based systems, which represent a trend towards the upper left

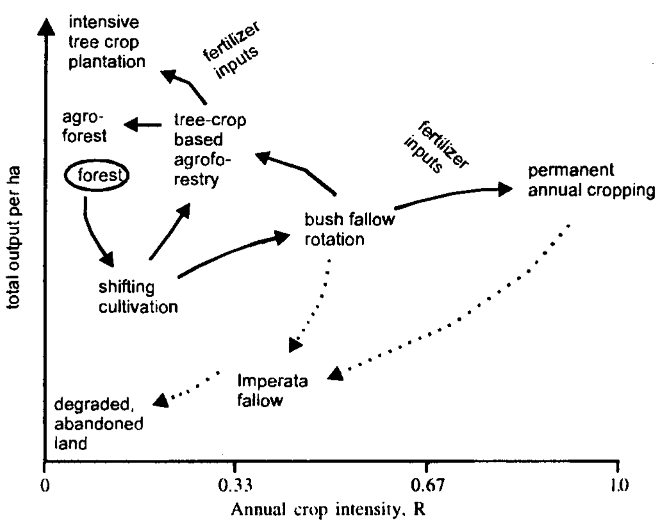

Figure 3. Agroforestry options and tree-crop-based systems can allow a high total output per ha at a low intensity of growing annual food crops (compare Fig. 1)

corner in the output - crop intensity diagram (Fig. 3): they increase total output per ha at a low annual crop intensity. The nutrient content of the exported products may be low (rubber) or the price for the products high enough (oil palm, fruits) to use mineral fertilizer where and if required. Biological management of soil fertility may play a key role in such a transition and allow food crop production in the intermediate stages.

We will conclude this general introduction by considering two further questions:

1. Should acid upland soils be primarily used for food crops or for income-generating tree crops?
2. How can we overcome bottlenecks for a tree-based intensification?

Should acid upland soils be used for food crops or for income-generating tree crops?

Three perspectives on upland farming often coexist: local farmers, transmigrants and spontaneous migrants. Their farming systems may show considerable differences, even where they use the same soil, under the same climate and under the same market conditions. Local farmers have nearly everywhere in Indonesia developed production systems for marketable products to supplement local food production, and in several cases to replace local food production and depend on markets for food (Gouyon *et al.*, 1993). Yet, the main focus of agronomic research tends to stay with the food crop component. Colfer (1991) described the change in research culture which is needed to shift from a food-crop based bias focussed on (trans)migrant farmers, to efforts to more fully exploit the opportunities of diverse, tree-based production systems. In the past, many transmigration projects were implicitly or explicitly based on the 'food crop' approach. Subsequent experience has shown that on acid upland soils tree-crop based production systems are more likely to be sustainable and attractive to farmers. Levang (1995) discussed the change in perceptions surrounding the shift of transmigration villages from 'food-crop based' to systems integrating crops, animals and rubber trees in Batumarta (S. Sumatra). Spontaneous migrants, who lack the government support initially provided to transmigrants and who often operate with less secure land tenure, appear to have adapted to local conditions more rapidly than transmigrants and may adopt rubber-based systems (Van Noordwijk *et al.*, 1995b).

Investments in tree crops are only possible if off-farm cash-earning opportunities exist during the transition period. In all these cases there is a choice between 'food' versus 'income' as main focus of agricultural activities. This is an issue at the farm-household scale, but also at the national scale. Should upland soils be developed for export-oriented tree commodities (oil palm, rubber etc.) and raw materials for agro-industries (including tapioca, pulp and paper), or for food crops? The current globalization of world trade leads to re-assessment of traditional policies based on home production as basis of national food security.

How can we overcome bottlenecks for a tree-based intensification?

A number of bottlenecks exists for tree-based development on acid upland soils, even if it offers the best long term chances of a sustainable and productive agriculture. These include:

- Requirements of adequate marketing channels and roads, allowing exchange of tree crop products for food,
- Need for investment support due to the waiting period before trees generate income,
- Insecurity of land tenure, especially for spontaneous migrants and in zones with conflicts between transmigrants and local people, due to ambiguity of past policies,
- Institutional barriers (and red tape) between food-crop based agriculture, tree crops and forestry institutions for education, research and extension, which do not correspond with the fuzzy boundaries of farmers *agroforestry*,
- Lack of adequate information due to past (and current) bias of research towards intensive, plantation-based management, in stead of diverse smallholder systems,
- Need for flexible, location-specific solutions, which complicates government approaches which traditionally have been based on 'packages' and 'blue-prints'.

These bottlenecks offer a new challenge for farmer - extension - research - private sector communication and cooperation, with the joint aim of managing upland soils for sustainable agriculture in the next century. We have to cut through the red-tape and blue-prints to achieve the maximum benefits of re-greening by farmers on their own initiative.

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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.