Status of current research

In the tropical rainforest most of the nutrients (more than 85 %) are tied up in the natural vegetation (Uexküll & Bosshart 1989). When the forest is slashed and burned, the nutrient cycle is broken and soil fertility is rapidly decreased through the export of nutrients out of the system with the crop harvest and through erosion and leaching. The important factors which lead to a decrease in productivity of cultivated land with increased cropping intensity after forest conversion include (1) the erosion of top soil, (2) degradation of soil physical, chemical and micro-biological conditions, (3) increasing weed growth and (4) rising infestation with pests and diseases (Ahn 1993). Sloping land in the tropical uplands, into which future expansion of the cultivated area will largely occur, are particularly vulnerable to erosion once their vegetative forest cover has been removed (Theng 1991).

Shifting cultivation was the most practical approach evolved by farmers to escape weed problems and a decline in soil fertility after a period of cropping. The land user shifts his fields when labor demand for weeding exceeds that for clearing a new area (Greenland 1970). Furthermore, clearing a new site permits a better distribution of labor avoiding the peak labor requirements for weeding (Shenk 1983). Main causes for the change of the vegetation composition in cropping systems after slash-and-burn are the repeated soil cultivation which suppresses typical fallow species and favors the growth of adapted arable weed species (Schmid 1987). The effectiveness of fallowing to suppress troublesome weeds is directly related to the length of the fallow period and contributes especially to the reduction of annual species (Moody 1975). Additionally, in authochthonous production systems of the Tropics and Subtropics indicator plants (e.g. the parasitic weed *Striga hermonthica*, Kroschel 1998) has been used in slash-and-burn systems to indicate the restoration of soil fertility after fallowing or the soil degradation in the course of the cultivation of crops (Pülschen 1997).

Maintaining and increasing soil organic matter levels is of major importance in the development of more sustainable land use (Brown et al. 1994). Van Noordwijk et al. (1997a) note that a considerable part of agricultural productivity is based on nutrients mineralized from the labile soil organic matter fraction, especially under low external input farming prominent in the humid tropics. Aside from the nutrients released by mineralization, organic matter may improve the availability or solubility of inorganic nutrients (Hafner et al. 1993; Schwertmann 1993).

Improved cropping systems aimed at sustaining soil fertility include any or a combination of the following management strategies: inclusion of deep-rooted companion crops, trees and/or symbiotic legumes, effective residue management, erosion control and improved tillage practices. The replacement of lost nutrients with fertilizers and practices which optimize the efficiency of applied fertilizers need attention (Woomer et al. 1994).

The benefits of using legumes as cover and green manure crops can be high. Measurements in the humid tropics have shown that green manure legumes can accumulate 100 - 200 kg N ha^{-1} in 100 - 150 days (Giller & Wilson 1991). Further benefits are the improvement of soil fertility through the increase of the organic matter content (Hairiah et al. 1992) and the reduction of the need of weeding (Bunch 1990).

Agroforestry systems which imitate in part the structure and processes of natural forest vegetation have high potentials for increasing the productivity of fallow farming systems and for sustaining continuous crop production. Biologically enriched fallows, designed to enhance and accelerate the vegetative regeneration of soil fertility and to control weeds through the selective use of fallow species such as leguminous trees and/or herbaceous cover crops, take into account that the restoration of soil fertility during the fallow phase through the build-up of organic matter is greatest in the first few years (Raintree & Warner 1986). Apart from herbaceous cover crops, trees which decisively favor soil improvement can be used; ideally, they should have the following attributes: high biomass production, biological nitrogen fixation, deep rooting system, high nutrient content in their biomass, fast or moderate rates of litter decay and absence of toxic substances in foliage and root exudates (Young 1989).

Contour hedgerow intercropping, i.e. the installation of narrow tree hedges along the contours within cultivated fields, has become a popular recommendation to permit sustained continuous farming on sloping lands. In spite of its documented effects on the reduction of soil loss (Sajjapongse & Seyers 1991; Young 1989), typically by 50 to 95 % (Garrity 1995) and in spite of its contribution to the maintenance of soil fertility levels (Young 1989) and its relative advantage in small-scale farming compared to mechanical techniques (e.g. terracing) (Sukmana & Suwardjo 1991), significant problems have been associated with the adoption of tree hedgerows by smallholders. They include high establishment and management costs, competition effects between tree and crop components, and insecurity of land tenure or rights over trees (Carter 1996).

A possible alternative is the use of narrow grass strips grown along the contour as a source of fodder and mulch material. More recently research has begun to focus on natural vegetative filter strips (NVS), left unplowed during land preparation and vegetated mainly with local grass species, as a low-cost and more readily adoptable technique to reduce soil erosion (Garrity et al.

1993). The use of NVS and grass strips is a traditional soil conservation technique in some parts of the world (National Research Council 1993), but it also seems to be more recently applied or rediscovered in response to rising population pressure on land and consequent reduction of fallow periods together with the increasing cultivation of marginal sloping land (Kemper et al. 1992).

In growing crops of different species together or in sequence, the objective is to profit from a positive interaction among the system components, above as well as below ground. Deep rooting species may have a nutrient "pumping" effect (mainly for cations) from deep soil layers and some companion or cover crops may be able to solubilize sparingly soluble nutrients, especially P, making them also available to the main crop. The nutrient "pumping" effect is derived from the observation that prunings from hedgerow trees for example increased the soil pH and base saturation and decreased the Al saturation (Wong et al. 1997). To which extent the supplied bases actually came from deep soil layers (pumping effect) was not shown and research on this aspect is still needed (Garrity & Craswell 1995). Roots of trees are reaching into the subsoil if grown with other crops (Williams et al. 1997), but will absorb appreciable amounts of nutrients from the subsoil only if the upper soil is low in these nutrients. The role of trees as nutrient pumps in agroforestry systems has been generally overestimated (Traeger 1995). However, the higher total root length density acts as a safety net and reduces the amounts of nutrients being lost through leaching which can improve the nutrient use efficiency of the land use system as a whole.

Chemical mobilization (solubilization of nutrients by root exudates) may be an important factor in P acquisition by plants. Plants differ in their ability to do so because of the amount and the kind of exudates (Ae et al. 1990; Dinkelacker et al. 1989). On the other hand, e. g. peanut (*Arachis hypogaea*), even with very little root exudation, is very efficient in P uptake apparently due to a solubilizing agent bound to the cell wall of the root (Ae and Otani 1997). Research results clearly show that in some cases a direct synergistic effect of one species on the P acquisition of another exists, but in other cases the positive effect on the lesser P efficient species will only be significant after crop residues of the P efficient species have decomposed.

A sustainable land use system not only conserves the soil but the entire range of bio-physical resources on which agricultural production depends. It is also acceptable and stable in the given social, socio-economic, socio-cultural and infrastructural environment but requires the adaptation of innovations when extrapolated to different locations. Participatory methods of technology development have a comparative advantage in the identification and modification of appropriate technologies as they help provide environmentally sound, site-specific solutions. Research has shown that farmers are by-and-large rational decision makers with extensive practical knowledge of their environment and traditional technologies. This knowledge is based on a long history of trial-and-error and normally well-adapted to site-specific conditions. The fact, however, that conditions are rapidly changing today makes the adaptation of present land use systems and the introduction of new technologies with the help of outsiders (researchers/extension workers) inevitable (Raintree 1983).

During the 1980s, when agroforestry research and development expanded, researchers realized that the complexity of agroforestry land use requires research in farmers' fields (on-farm research) probably more than in other agricultural research areas (Scherr 1991). For increasing the adoptability of agroforestry innovations and agricultural technology in general, the development of such technology should be based either on existing systems or on latent potentials in the farming system in question. Technical innovations which build on existing land use systems are not only more compatible with the existing practices and their relative advantages are more easily perceived, they are also more likely to be technically appropriate, to be more easily submitted to farmer trial and their effects to be more readily observed and understood by the farmer (Raintree & Warner 1986). To ensure that appropriate technologies for location-specific needs will be developed, participatory, analytical and multidisciplinary approaches are a prerequisite, especially in the process of diagnosis and design (Sanchez 1997).

The diagnosis of land user problems and the identification of potential (agroforestry) solutions should be based on participatory rural appraisals (PRA) conducted by an interdisciplinary team of locals and outsiders concerned with rural development in a specific area. This includes a number of participatory methods, such as informal qualitative interviews and group discussions, drawing of (historical) maps and transects, ranking and scoring, etc. (Waters-Bayer 1989). The participatory aspect of rural appraisal has been emphasized, by more rigorously shifting power over the design and implementation process to the local community with outsiders focusing on their role as facilitators (Pratt & Loizos 1992).

Past experiences have shown that there is more to a participatory research approach than just involving rural people as workers and informants in research programmes defined by outsiders (Rocheleau 1991) or using on-farm research to validate and demonstrate new technologies which have previously been developed elsewhere under controlled experimental conditions (Sumberg & Okali 1991). Participation is a two-way process: both scientists and local people have unique areas of expertise which collectively provide a better basis for development than either alone (Fujisaka 1989). Participatory Technology Development (PTD) is aimed at helping farmers become more effective technology developers themselves in a self-sustaining development process, by linking the power and capacities of agricultural science to the priorities and capacities of farming communities (Reijntjes et al., 1992). It is only when farmers actively take part in developing technologies to improve their current practice of farming, from diagnosis and design to on-farm validation and adaptation (re-diagnosis and re-design) of improved farming practices, that the sustained use of innovations and their (no-cost or low-cost) dissemination through farmer-to-farmer communication can be achieved. Of foremost importance in the PTD process is the active involvement of farmers as co-researcher and co-extension workers in the process of developing and improving agricultural technologies, in the sense of Participatory Action Research (PAR). Methods of PAR still need to be more rigorously applied in rural research and development programmes (Neubert & Hagmann 1997).

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Researchers' expertise

Research carried out by J. Kroschel has focussed on Integrated Pest Management with special emphasis on population dynamics of pests, host-parasite interactions and on biological control of insect pests and parasitic weeds (Kroschel & Koch 1994; Kroschel 1995; Kroschel et al. 1996a, b; Kroschel et al. 1996; Kroschel & Klein 1998; Klein et al. 1998). Furthermore, site factors decisive for the occurrence of parasitic weeds have been analysed with special regard to nitrogen, organic matter content of soils and their microbial activity (Kroschel 1989; Kranz et al. 1997; Kroschel 1998). Two reviews have been prepared on underrated methods of weed control in developing countries and on biological weed control (Sauerborn & Kroschel 1996; Sauerborn & Kroschel 1996).

Experiences have been also gained in the development of continous cropping systems using intercrops, cover crops and managed fallows with agroforestry components in semi-arid and sub-humid regions (Oswald et al. 1996; Jost et al. 1996; PhD dissertation of Jost 1998). A crop weed competition model was developed to simulate the effect of the parasitic weed *Orobanche crenata* on growth and yield loss of faba bean. This model is able to simulate faba bean phenology, leaf area, biomass accumulation in host and parasite, root-length density and pod yield using available weather and soil data (Manschadi et al. 1997; Manschadi et al. 1998). Further research focused on socio-economic studies and gender aspects applying conventional (interviews) and participatory methods (PRA, action research) in different countries of Africa (Bourarach et al. 1999; Runge-Metzger et al. 1997; Kroschel et al. 1996; PhD dissertation of Fischer 1999).

The postdoc (M. Stark) has been involved in the activities of the ICRAF-led Global Alternatives to Slash-and-Burn Initiative in the Philippines since 1994. He has gathered experience in approaches of biological soil resource conservation (natural vegetative contour strip concept) (PhD dissertation Mr. Stark). Of particular value for the Special Research Programme suggested here is thereby the experience with farmer-led research direction in the sense of Participatory Action Research. This research approach which in essence is also adopted here, provides the basis for guiding the scientific process towards highest possible relevance while safeguarding its freedom of decision.

Research at the Institute of Agricultural Chemistry of the University of Göttingen has concentrated on applied research on sustainable P and K fertilization and on basic research focusing on processes in the rhizosphere. Long term fertilizer experiments in the field have been carried out of up to 20 years. They were designed to show the relationship between soil test and optimum fertilizer rate for a long term, sustainable use of soils at a high yield level (Wendt et al. 1996; Wulff et al. 1998). Research on the rhizosphere has shown that nutrient uptake from soil may be sufficient even though soil test values are low. This is because roots can decrease soil solution concentration at the root surface to very low values and furthermore because root exudates can solubilize sparingly soluble nutrient components (Claassen 1990; Gahoonia et al. 1992; Hoffmann et al. 1994; Jungk & Claassen 1997).

Basic processes related to nutrient uptake from soil are the nutrient release from the soil solid phase, their transport to the root surface by mass flow and diffusion and the subsequent uptake into the root, usually following Michaelis-

Menten kinetics. These processes follow well established laws that can be described mathematically and thereby the process of nutrient uptake from the soil can be simulated. The simulation models used help to understand, even in a quantitative way, whether our understanding of the functioning of the soil-root system is sufficient and at which point research has to be emphasized (Föhse et al. 1991; Jungk & Claassen 1997; Syring & Claassen 1995). Further work focused on root growth (Stoffel et al. 1995) and root phosphatase activity and its implications for the P nutrition of crops (Firsching & Claassen 1996).

Nutrient depletion in the rhizosphere is characterized by the degree of concentration decrease at the root surface and by the extension of the depletion zone (Claassen 1990; Gahoonia et al. 1992). The latter is dependent on the mobility of the ion in soil and it is of significance for complex cropping systems, i.e. because of low mobility of P in soil there is almost no interroot competition for this nutrient in multicrop systems while for K sometimes and for N (NO_3^-) always crops compete for the available nutrient. This conclusion results from measurements and model calculations as well (Claassen & Steingrobe 1999; Syring & Claassen 1995).

Our Indonesian partners:

The performance of the different research areas within project D2 will be scientifically supported by scientists of the Department of Agronomy and the Department of Soil Science of the Institut Pertanian Bogor. Research of these Departments has focussed on inter-cropping and multistorey cropping systems, on different aspects of the improvement of cropping systems (Yulia & Mugnisjah 1999; Nazuradin & Mugnisjah 1997; Akbari & Mugnisjah 1997), on the biology, ecology and control of Alang-alang (*Imperata cylindrica*) and other cyperaceous weeds (Yakup et al. 1993; Chozin 1997; Chozin et al. 1994), as well as on different aspects related to soil micro-organisms (microbial activity, microbial biomass and diversity in different land use systems).

The research of potential participants of the Tadulako University focussed on the evaluation of the productivity of inter-cropping systems in relation to planting space and fertilizer applications (Mahfudz & Muhardir 1999; Mahfudz 1994), on studies related to the water use efficiency of crops and on the characterization of shifting cultivation systems in the northern part of Central Sulawesi using questionnaires and participatory methods.

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Objectives, methods, working programme and project schedule

Objectives and methods

Within the research work under project D2 two objectives are defined, a general objective and the objective which is envisaged in phase I of the project.

General objective: To develop sustainable land use systems.

Objective of phase I: To study the processes of soil fertility losses, weed infestation dynamics and nutrient efficiency and transfer among plants in existing land use systems and test first methods for the conservation and improvement of their productivity.

In the project, the use of low-cost techniques is being emphasized to minimize dependence of local land users on farm-external resources.

The proposed study area displays a wide range of stages of forest conversion in relation to the dynamics and the extent of the conversion process. This allows an investigation of the whole range of land use systems, from traditional slash-and-burn with fallow of different length, simple coffee and cacao agroforestry systems, mixed vegetable and tree gardens on sloping lands, to monocropping of annual crops (maize, beans, upland rice) on newly cleared 1111forest land and lowland rice in the valley bottoms.

Project D2 will be involved or totally responsible for the following objectives of phase I of the Collaborative Research Centre (see also operational planning matrix (chapter 3.7.3):

(1) Characterize existing land use systems and document local knowledge on soil conservation and soil fertility maintenance with special consideration of existing agroforestry land use systems.

(2) Study the dynamics of soil fertility development after slash-and-burn and in land use systems of different intensity.

(3) Analyze the dynamics of soil fertility development in cacao agroforestry systems of different age-groups.

(4) Investigate the dynamics of weed infestation after slash-and-burn and in land use systems of different intensity.

(5) Evaluate different combinations of maize with leguminous field and cover crops with and without phosphorous application with regard to N and P dynamics and the overall system productivity.

(6) Investigate the mechanisms of P mobilization through mixed cropping partners and the transfer to the main crop.

(7) Study P sorption characteristics of soils as affected by crops and soil management.

(8) Assess N_2 fixation by leguminous crops and transfer of N to non-leguminous crops.

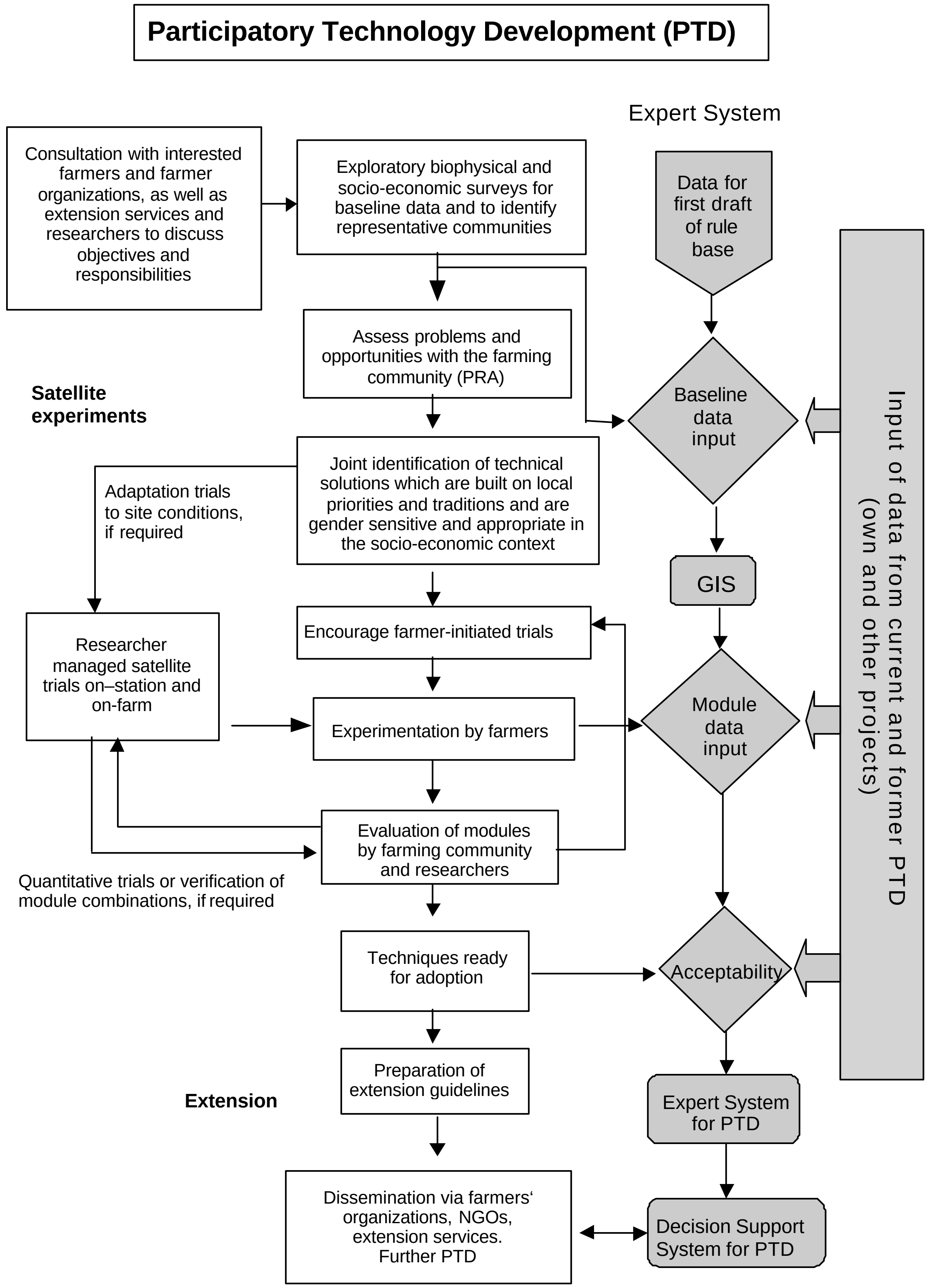
(9) Evaluate the efficiency of different hedgerow species in soil stabilization on sloping lands.

A system approach will be applied in order to assure that identified or developed land use systems are not only ecologically stable and economically profitable, but also acceptable by the involved local land users. Participatory research methods will build the basis for the inventory and assessment of existing slash-and-burn practices and agroforestry land use systems, as well as for the evaluation of newly-formulated improved land use strategies for the project area.

The initial assessment and definition of existing slash-and-burn practices, agroforestry systems in sloping lands, and the in-depth assessment of existing cacao agroforestry systems will be planned and performed in close collaboration with projects A2 and A4 using a mixture of methods: (1) participatory approaches such as Participatory Rural Appraisal, and in-depth surveys among local land users with questionnaires, together with acquiring information (2) from key-informants and local stake-holders (village officials, district agricultural officers, NGO staff, etc.) and (3) from existing documents (reports, publications) (see objective 1 in the project schedule).

Experimental research during the initial three year phase will focus on two major research topics: (1) slash-and-burn systems, and (2) continuous cropping alternatives including cacao agroforestry systems. Research sites and participating farmers will be identified during the initial (pre-project) survey. All research - except for pot experiments - will be carried out on-farm, i.e. using existing farms, to ensure maxi-mum interaction between participating researchers and farmers, and relevance of research findings in the local context. Such a research programme requires a flexible planning, considering results of surveys and contributions of involved land users.

On the basis of results of the first project phase, in the second phase a preliminary expert system will be developed (see figure).


Participatory Technology Development (PTD)
Expert System
Consultation with interested farmers and farmer organizations, as well as extension services and researchers to discuss objectives and responsibilities
Exploratory biophysical and socio-economic surveys for baseline data and to identify representative communities
Data for first draft of rule base
Assess problems and opportunities with the farming community (PRA)
Satellite experiments
Baseline data input
Input of data from current and former PTD (own and other projects)
Joint identification of technical solutions which are built on local priorities and traditions and are gender sensitive and appropriate in the socio-economic context
Adaptation trials to site conditions, if required
GIS
Encourage farmer-initiated trials
Researcher managed satellite trials on–station and on-farm
Experimentation by farmers
Module data input
Evaluation of modules by farming community and researchers
Quantitative trials or verification of module combinations, if required
Techniques ready for adoption
Acceptability
Preparation of extension guidelines
Extension
Expert System for PTD
Dissemination via farmers' organizations, NGOs, extension services. Further PTD
Decision Support System for PTD

Research focus 1: Processes of destabilization and stabilization in slash-and-burn and cacao agroforestry systems

Objective: Assessing processes underlying soil fertility degradation after slash-and-burn and soil fertility stabilization in cacao agroforestry systems.

Research hypotheses:

(1) Soil fertility decreases after slash-and-burn because (a) rapid organic matter decomposition leading to reduced nitrogen availability and stronger sorption of phosphorus, (b) sorption of P is further enhanced due to changes of P sorbents after burning and (c) leaching of nutrient cations (Ca, Mg, K).

(2) After slash-and-burn, cacao agroforestry systems are likely to constitute an appropriate land use in sloping lands in the rainforest margins because (a) the perennial component of the system helps maintain soil fertility through nutrient cycling and (b) soil loss reduction.

Methods (see also objective 1, 2 and 3 in the project schedule):

On the basis of the results of project A3 and A4 and as a result of a joint characterisation of existing land use systems as planned by projects A2, A4 and D2 (D1, D3) and the documentation of field histories, fields will be selected to analyse the processes of destabilization in slash-and-burn systems. Investigations will focus on natural fallows at 1 to 5 and 5 to 15 years after start of the fallow cycle as well as on maize cropping systems in the first, second and third year after slash-and-burn (chronosequence studies in a false time series). Natural forest will also be included in the investigation and will serve as a reference for undisturbed soil development. It is envisaged to perform these investigations in the Kulawi and Gimpu valley.

On each plot at least 10 individual soil samples will be taken at three soil depths at random. The sub-samples will be carefully mixed into a combined sample and analyzed with regard to soil pH, organic C, nitrogen plus NH_4 and NO_3, P, K, Ca, Mg, CEC, exchangeable bases, biomass C, microbial activity (e.g. dehydrogenase activity) and other relevant soil parameters. Through destructive sampling of at least 15 square meters with at least three replications above and below ground biomass will be quantified and plant nutrient content analysed. Aspects of nutrient cycling will be assessed in depth: nutrient pumping by fallow vegetation will be studied by comparing changes of nutrient pools in soil at different depths and estimating the rate of nitrate leaching as influenced by root lenght density. These investigations will be carried out in close collaboration with project D4. Further studies will focus on the fallow vegetation, their species composition, the steadyness and the specific coverage of individual species according to Braun-Blanquet (1965)[1]. The determination of the plant species will be carried out in collaboration with project C2.

(b) Processes of stabilization in cacao agroforestry systems will be studied in cacao plantations of two different age-groups: up to 5 years and more than 10 years. All parameters described under (a) will be assessed. The biomass of cacao trees will be estimated through non-destructive methods according to Hairiah et al. (1999)[1]. This research part will also be conducted in collaboration with project D4. Project C2 will support the identification of plant species. Cacao plantations can be found in all valleys. The Napu valley is very suitable to find different age-groups of cacao agroforestry systems on sites with similar soil conditions and after slash-and-burn of primary forest.

In phase II of the SFB, cacao agrofoestry systems will be further investigated with the objective to quantify the overall functioning and productivity of such a production system as influenced by synergistic and antagonistic effects of its plant components through testing a range of leguminous cover crops in various cropping pattern arrangements (focus on plant arrangement and density). There may also be scope for the systematic incorporation of agricultural field crops in the cacao system, thus upgrading its value.

Research focus 2: Weed infestation in slash-and-burn systems

Objectives: Assessing weed infestation dynamics after slash-and-burn and in land use systems of different intensity in order to identify indicator plants.

Research hypothesis:

(1) The length of the fallow period as well as the duration of land use influence the composition of the arable weed flora. Typical fallow species will be suppressed by species which are better adapted to the cropping system and to soil cultivation methods.

(2) The decrease of soil fertility after slash-and-burn favors certain weed species better adapted to degraded soils. These weeds could serve as indicator plants for site factors on the basis of their syn-ecological behaviour.

Methods (see also objective 4 in the project schedule):

Weed surveys will be conducted in the Katu region and the Kulawi and Gimpu valley in maize fields cultivated in the first, second and third year after slash-and-burn, as well as on maize fields, which have been cleared after 1 to 3 years

[1] Braun-Blanquet, J. (1965): Plant sociology; the study of plant communities. Hafner, London, UK.

[2] Hairiah, K., van Noordwijk, M. and Palm, C. (1999): Methods for sampling above and below-ground organic pools. In: Murdiyarso, D., van Noordwijk, M. and Suyamto, D.A.: Modelling global change impact on the soil environment. IC-SEA Report No.6. Bogor, Indonesia: BIOTROP-GCTE/IC-SEA: 46-77.

and more than 3 years of fallowing. At least 10 to 15 individual fields will be selected on fertile and infertile soil locations, respectively. For the identification of individual plants we will rely on project C2. The fields surveyed will be crossed in a zigzag way in order to draw up a list of plant species. The specific coverage of each species and of vegetation groups (crops and their mix cropping partner, woody plants, weeds (dicots and grasses) will be determined according to Braun-Blanquet (1965)[1]. At each location information will be gathered on geographic location, relief (shape, slope inclination, slope direction, altitude), crop grown, frequency of ploughing, previous crops (crop rotation), frequency and time of weeding. Depending of the size of the field five to ten individual soil test portions (0-30 cm soil depth) will be collected randomly with soil augers at each location. Representative soil samples will be prepared thereafter by mixing these proportions. Samples will be air-dried, sieved and physical and chemical analysis conducted (soil texture, pH-value, organic carbon and N) with the support of central laboratory Z3.

Research focus 3: Soil fertility, crop management and soil erosion control in improved slash-and-burn systems

Objective: Evaluating methods to reduce or eliminate fallow periods in traditional slash-and-burn systems especially on sloping land in the rainforest margin

Research hypothesis:

(1) Constant ground cover with leguminous field and cover crops in annual maize cropping increases the land equivalent ratio through complementary resource use, reduces the weed seed bank in the soil, minimizes the frequency of tillage operations, and improves soil fertility and thus crop yield, above all through nitrogen additions and increased phosphorus availability. Phosphorus availability is improved by some species (cover crops) through root exudates. This improved P availability may be useful to other crops either through direct contact between roots or after decomposition of crop residues of the cover crop.

(2) Continuous cultivation on sloping lands can be sustained through the incorporation of contour hedgerow practices using trees, grasses or natural vegetation as buffer strips to stop soil erosion, together with the maintenance of soil fertility through judicious application of mineral and organic fertilizer, green manure, lime and crop residues.

(3) Improved fallows with leguminous trees and cover crops are superior to traditional fallowing practices in terms of speed of soil fertility rehabilitation and in avoiding weed infestation, and are thus superior in economic profit-

ability.

Methods (see also objective 5, 6, 7 and 8 in the project schedule)**:**

According to the objectives outlined, treatments can be classified under three groups: (a) use of cover crops and mixed-crops in annual maize crop production, (b) buffer strips for soil conservation, and (c) improved fallow management.

Since homogeneous blocking of treatments is crucial and plots will be relatively large (up to 12 x 24 meters, with a minimum of 2 meters border around each plot) treatment groups will be tested in three separate sets of trials on different farmers' fields. The number of sites for each treatment group will be at least two (fertile and less fertile soils), the number of blocks (replications) within site not less than three. Preferably, subsets of trials shall be replicated at different elevations and/or slope positions to cover the range of bio-physical conditions in which shifting cultivation is being practiced.

(a) Trials on maintaining soil fertility in continuous cropping systems after slash-and-burn clearing will use existing maize crop production systems as the control treatment (see objective 5 in the project schedule). The trials will be established on fields selected in the Napu and Gimpu valley with approximately the same length of fallow before slash-and-burn clearing. Experimental treatments will include two cover crop species in a relay cropping system and two leguminous and one non-leguminous food crop in a mix-cropping system with maize (with two crops per year). The efficiency of treatments in reaching and maintaining complete ground cover, improving nutrient availability for the maize crop (biological N fixation and availability of P), improving soil physical and chemical conditions, and reducing the weed infestation will be assessed. Under the acid soil conditions of the study area, the application of phosphorus will be inevitable to increase the productivity of the land. Therefore, the application of superphosphate or of slow-release rock phosphate will be tested as subplot treatment in a split-plot design.

In co-operation with project D4 the quantification of nutrient flows will be investigated (see activity 8 and 9 of objective 5 in the project schedule) and the effects of the diversity of crops grown on the population dynamics of insect pests and their natural enemies will be assessed in co-operation with project C3 (see activity 7 of objective 5 in the project schedule).

In addition to the field experiments, the efficiency of cover crops to mobilize P and its transfer to the main crop will be studied in separate pot experiments (see objective 6 in the project schedule). If the main crop of maize profits directly from the P mobilized by roots of the cover crop it will grow better and, more important, its P influx will be higher in the case the two root systems are in contact with each other. Model calculations which at this moment exclude chemical mobilization will help to further assess the significance which this process may have for the P nutrition of both the main and the cover crop. The fundamental nature of chemical P mobilization will be investigated in later stages of this project. Beside chemical mobilization, an assessment of mycorrhizal infection will be done in the field and in the pot experiment.

The study of nitrogen dynamics will include changes of mineral N (N_{min}) and net N mineralization over time in different cropping systems. Net N mineralization will be studied in collaboration with project D4 by field incubation of undisturbed soil samples using pipes introduced into the upper soil layer. Because of high rainfall NO_3 may be lost from soil even when crops are growing. To which extent NO_3 is being lost and not used by crops will depend mainly on excess rain over evapotranspiration, the root length density in soil and their uptake capacity. Measurements to assess possible NO_3 losses will be useful but for a better understanding of the functioning of the system its modeling will be pursued. Therefore a mathematical model will be developed that takes into account NO_3 in soil, leaching potential, root length density and uptake kinetics of the roots. On this basis different situations will be simulated and the significance of different rain intensities, root length densities and uptake capacities will be assessed concerning NO_3 losses from soil.

(b) The third set of trials will study the effects of vegetative buffer strips with different plant species and interstrip management options, on reducing soil loss from sloping fields and maintaining soil fertility on terraces forming behind contour strips. Narrow contour strips of leguminous trees, grasses for animal fodder, or natural vegetation (of spontaneously growing local grasses and herbaceous plants) will be established at regular intervals (2 meter vertical drop) on sloping land of the Napu and Gimpu valley. The different possibilities for soil stabilization will be discussed with land users with whom the type of contour strips and the plant species will be selected. An overall precondition for this research will be the willingness of land users to test contour strips for erosion control on their fields. Apart from the analysis of soil samples for selected soil fertility parameters, sediment and nutrient loss in trials established on sloping lands will be determined through the installation of sediment traps at the bottom of experimental plots. Nutrient losses will be evaluated in collaboration with project D4.

(c) Research with regard to improved fallow management will be carried out in phase II of the project. The trial will be laid out as randomized complete block design. The experimental treatments will be applied to fields which are about to be fallowed after the usual cropping cycle in the traditional shifting cultivation system. Together with land users plants for improved fallows will be selected. These will include the broadcast sowing of two different tree legumes for which seeds are easily accessible for farmers in the area and herbaceous legume cover crops. Additionally, native leguminous and non-leguminous fallow plants will be selected and investigated for their suitability to improve fallows. Traditional natural fallows at one, two and five years after start of the fallow cycle will be used as the control in a false time series. Soil fertility rehabilitation (soil pH, soil organic matter, P availability, cation and other nutrient 'pumping' effect of deep rooting plants) will be assessed through destructive subsampling of above- and belowground biomass with quantification of the component species and their specific coverage, and the analysis of plant and soil samples at half-yearly intervals. Nutrient pumping by fallow vegetation will be assessed by comparing changes of nutrient pools in soil at different depths with nutrient uptake.

Working programme

In conducting the proposed research activities, the Tropical Crop Production Department of Kassel University and the Institute of Agricultural Chemistry of Göttingen University will work in close collaboration with the relevant departments of the Institut Pertanian Bogor and the Tadulako University of Palu. For initial assessment of existing land use practices and for implementing the participatory research approach the collaboration with scientists of sub-programme A will be essential. The initial baseline survey of existing slash-and-burn practices and cacao agroforestry systems will be conducted during the first six months of the Collaborative Research Centre (SFB). The postdoc (University of Kassel) will be responsible supervising and monitoring the study. He will also analyse final data and document survey results.

During the initial survey, potential sites and participating farmers for the subsequent in-depth assessment of existing slash-and-burn fallow systems (Napu valley, Kulawi and Gimpu valley), cacao agroforestry systems (Napu valley) and improved options for sustained continuous production in the rainforest margins (Napu and Gimpu valley) will have been identified. Further screening of potential sites will follow if needed.

Further, the postdoc will be reponsible for the research on the productivity and sustainability of traditional and improved shifting cultivation systems, including basic monitoring, data collection and research work in the experimental investigation of systems improvements. Through the integration of results of other projects the overall goal of his research will be the design of sustainable land use systems. Investigations of the mechanisms of P mobilization through mixed cropping partners and the transfer to the main crop will be implemented by the Ph.D. student from Göttingen University. Studies for the determination of species composition, steadiness and specific coverage of the fallow vegetation in slash-and-burn systems will be supported by J. Kroschel through a short-term consultation.

Our partners from the Tadulako University will support the research project in different aspects. Mr. Wahuddy will study the P sorption characteristics of soils as affected by crops and soil management. Mr. Mafudz will focus on the cacao agroforestry systems and Mr. Abdul Hadid intends to work in maize cropping systems with regard to the modelling of the maize growth. The experience of Mr. Sangadyi will be of an advantage for the characterisation of land use systems and the selection of study sites. In depth studies will focus on weed dynamics and on fallow vegetation.

Masters students from both Germany and Indonesia will be further supporting the research programme. The Indonesian students will be supervised by the co-operating partners of the Institut Pertanian Bogor. Indonesian Ph.D. student will be co-supervised either by J. Kroschel or N. Claassen.

Farmers will be involved at all stages of the research in monitoring the land use alternatives and its components studied. The perception of participating local land users regarding tested technologies will be constantly and formally recorded. When superior technologies have been safely identified, the potential of these improved technologies will be tested under farmer management. This technology verification phase will be implemented during the second three-year project period.

Project schedule (operational planning matrix)

Project title: Designing sustainable agricultural land use systems

General objective: Develop sustainable land use systems

Objectives of first phase: Study the processes of soil fertility losses, weed infestation dynamics and nutrient efficiency and transfer among plants in existing land use systems and test first methods for the conservation and improvement of their productivity

Objectives (O.) / Activities (Act.)	*Participating projects*	*Research period 01/06/2000 to 31/05/2003*			
		2000 JASOND	2001 JFMAMJJASOND	2002 JFMAMJJASOND	2003 JFMAM
O1. Characterize existing land use systems and document local knowledge on soil conservation and soil fertility maintenance with special consideration of existing agroforestry land use systems.					
Act. 1: Socio-economic studies are conducted among landusers using conventional and participatory methods	A2, A4, D1	▬▬▬			
O2. Study the dynamics of soil fertility development after slash-and-burn and in land use systems of different intensity.					
Act. 1: Experimental sites are selected together with land users, and the history of land use is documented (Chrono-sequence studies in false time series)	D4, (A4)	▬▬▬			

Objectives (O.) / Activities (Act.)	*Participating projects*	*Research period 01/06/2000 to 31/05/2003*			
		2000 JASOND	2001 JFMAMJJASOND	2002 JFMAMJJASOND	2003 JFMAM
Act. 2: Soil samples are analyzed for selected soil fertility parameters (org. C, N, P, K, Mg, CEC, microbial activity)	Z3				
Act. 3: Above- and below-ground biomass are estimated and analyzed for their nutrient content	D4, Z3				
Act. 4: Species composition, steadyness and specific coverage of the fallow vegetation are determined	C2				
O3. Analyze the dynamics of soil fertility development in cacao agroforestry systems of different age-groups.					
Act. 1: Experimental sites are selected together with land users, and the age of cacao plantations are determined	D4				
Act. 2: Soil samples are analyzed for selected soil fertility parameters (org. C, N, P, K, Mg, CEC, microbial activity)	D2				
Act. 3: Above- and below-ground biomass are estimated and analyzed for their nutrient content	D4				
Act. 4: Species composition, steadyness and specific coverage of the weed vegetation are determined	C2				

Objectives (O.) / Activities (Act.)	*Participating projects*	*Research period 01/06/2000 to 31/05/2003*			
		2000 JASOND	2001 JFMAMJJASOND	2002 JFMAMJJASOND	2003 JFMAM
O4. Investigate the dynamics of weed infestation after slash-and-burn and in land use systems of different intensity.					
Act. 1: Species composition of the weed flora, the steadyness and specific coverage of individual weed species in annual crops (maize) determined (determination of indicator plants)	C2	—	—		
Act. 2: Site factors of surveyed fields are determined and specific field information is gathered	Z3	—	—		
O5. Evaluate different combinations of maize with leguminous field and cover crops with and without phosphorous application with regard to the overall system productivity.					
Act. 1: Experimental sites and intercrop partners are selected together with land users	(A4)	—			
Act. 2: Soil samples are analyzed for soil fertility parameters (org. C, N, P, K, Mg, CEC, microbial activity)		—	—		
Act. 3: Growth, nutrient uptake and yield of all intercrop partners (land equivalent ratio – LER) is quantified			— —	— —	

Objectives (O.) / Activities (Act.)	Participating projects	Research period 01/06/2000 to 31/05/2003			
		2000 JASOND	2001 JFMAMJJASOND	2002 JFMAMJJASOND	2003 JFMAM
Act. 4: Root development and performance is determined					
Act. 5: Changes in mineral nitrogen (N_{min}) and net mineralization assessed	D4				
Act. 6: Weed species, their steadyness and specific coverage are determined	C2				
Act. 7: Pest and predator interactions are studied	C3				
Act. 8: Nutrient flows in the cropping system are quantified (mineral and organic fertilizer inputs, harvest exports, etc.)	D4				
Act. 9: Nutrient flows related to other processes are quantified (deposition, gaseous losses, erosion, etc.)	D4				
O6. Investigate the mechanisms of P mobilization through mixed cropping partners and the transfer to the main crop					
Act. 1-3 same as Act. 3-5 under O5					
Act. 4: Interaction between roots of intercrop partners is assessed in pot experiments					
Act. 5: P-uptake with and without chemical mobilization is evaluated by modeling					

Objectives (O.) / Activities (Act.)	*Participating projects*	*Research period 01/06/2000 to 31/05/2003*			
		2000 JASOND	2001 JFMAMJJASOND	2002 JFMAMJJASOND	2003 JFMAM
Act. 6: Intensity of mycorrhyza activity of intercrop partners is studied					
O7. Study P sorption characteristics of soils as affected by crops and soil management.					
Act. 1: P concentration in soil solution at different time periods after slash-and-burn or after growing different crops as well as P sorption curves are determined.					
O8. N_2 fixation by leguminous crops and transfer of N to non-leguminous crops is assessed.					
Act. 1: N content of crops and soils with and without legumes is measured and N_2-fixation is evaluated by simple budget.					
Act. 2: N_2-fixation is evaluated by the use of ^{15}N dilution techniques.	Special DFG-Project (Prof. Vlek)				
O9. Evaluate the efficiency of different hedgerow species in soil stabilization on sloping lands.					
Act. 1: Options for slope stabilization are discussed with land users; strategies and the selection of plants for the establishment of vegetative contour strips are agreed upon and selected	A2, A4				

Objectives (O.) / Activities (Act.)	*Participating projects*	*Research period 01/06/2000 to 31/05/2003*			
		2000 JASOND	2001 JFMAMJJASOND	2002 JFMAMJJASOND	2003 JFMAM
Act. 2: Contour strips are established and soil loss is quantified with sediment traps					
Act. 3: Growth and yield components of maize are analyzed					
Act. 4: Soil samples analyzed for selected soil fertility parameters (org. C, N, P, K, Mg, CEC, microbial activity)	D4				

Fieldwork of German participants 07/2000 - 06/2003

	Year	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Kroschel	2000												
	2001		X	X									
	2002									X			
	2003												
Claassen	2000												
	2001				X								
	2002			X									
	2003												
Postdoc	2000							X	X	X	X	X	X
	2001	X	X	X	X	X		X	X	X	X	X	X
	2002	X	X	X	X	X		X	X	X	X	X	X
	2003	X	X	X	X	X							
PhD student	2000												X
	2001	X	X	X	X	X		X	X	X	X	X	
	2002	X	X	X	X	X	X	X	X	X	X	X	X
	2003	X											

Function of the project within the SFB

The objective of this project is to develop cropping systems for the rain forest margins that are productive and stable and to understand why they are sustainable for the special conditions of the research area, i.e. low soil fertility, relatively high rainfall and often steep slopes. To obtain representative research sites sampling will be done over the whole area together with project A4. The final decision which sites will be appropriate for the investigations will be taken with project D4, which is going to measure nutrient stocks and nutrient fluxes at the same sites as D2. To include local knowledge on crop growth and fallow vegetation project A2 and A4 will supply the needed information by means of participatory research. For a better understanding of the sustainability of cropping systems the nutrient fluxes measured by D4 will be essential as well as the effects of crop and plant diversity on plant-insect interactions and the control of pests, which will be investigated in collaboration with project C3. The determination of the flora of fallows and arable land as well as the establishment of a herbarium will be carried out in collaboration with project C2. Project D2 will supply information on crops and cover crops as animal feed to project D3 and and will provide data to project A4 for economical analysis of cropping systems. D3 will provide information on manure availability on farms.

Farmers adoption of technologies developed by D2 will be studied together with projects A2 and A4. This will help to understand attitudes towards technological change and to develop methods to overcome constraints of acceptance. The inclusion of A3 related to available markets will be an important aspect.

D2 will supply data on nutrient in- and output of cropping systems to subprogramme B. D2 will use climatological data from Z2. The land use mapping of Z1 as well as the soil map will be essential to appreciate the significance of different cropping systems and for extrapolating new technologies developed in D2. The central laboratory Z3 will be needed continously for the chemical analysis of soils, plants and extracts.