Towards improving natural resources use in Eastern Amazonia through a modified sequential agroforestry system

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Slash-and-burn agriculture, the most widely spread sequential agroforestry system in the tropics, is also the most common land use in most regions of Eastern Amazonia where, similar to other tropical regions of the world, agricultural productivity is declining as a result of progressive loss of nutrients by successive burning and cropping activities and by the shortening of fallow periods due to demographic pressure. Another concern about this system refers to burning as a land preparation means, which has been reported to be the cause for many accidental fires in rural areas, and is being accused to harm the environment.

Any modification to this sequential system, aiming to attenuate or even eliminate the present constraints, involves the consideration and the management of the fallow vegetation (*capoeira*) as an important component of this system.

Recognizing the role of the *capoeira* to the smallholder's agriculture in Eastern Amazonia, a Brazilian-German cooperative project[4] started in 1991, centered in the municipality of Igarapé-Açu, in the Bragantina region (Northeastern Pará State). In a first step the following questions were focused on (Denich and Kanashiro 1998):

- Which are the effects of different agricultural activities on the floristic composition and the development of secondary vegetation?
- What is the function of the secondary vegetation for the sustainability and productivity of the smallholder's land-use system?
- Which are the mechanisms of regeneration and possibilities for the advance of tree and shrub secondary vegetation into abandoned areas?
- Which are the possibilities for the modification of the traditional land-use techniques, taking advantage of the positive effects of the fallow system?

Out of the several studies carried out during this phase (1992 to 1995), the most outstanding results provided a base of knowledge mainly on aspects related to the function of the *capoeira* to the most common sequential agroforestry system under adoption in this region, the slash-and-burn agriculture:

- In spite of over a century of slash-and-burn agriculture, and of the progressive reduction of fallow periods, the results of studies carried out using a false chronosequence approach on floristic composition (Baar 1997) and on phytomass and nutrient stocks (Hondermann 1995) have shown that the *capoeiras* exhibit yet a considerable functional biodiversity, confirming the findings by Denich (1991) and Vieira (1996), which enables this secondary vegetation to provide nutrients for subsequent cropping periods;
- Fallow vegetation after slash-and-burn cycles regenerates mainly vegetatively from roots, shoots and rhizomes of trees and shrubs which survive throughout the cropping period, different from the *capoeiras* associated to systems with mechanized land preparation (e.g. black pepper cultivation), where land preparation destroys great parts of the root system of trees and shrub species, promoting the development of grasses and herbs which increase the weed problem in the subsequent cropping period (Denich and Kanashiro 1998);
- Land-use systems with extended fallow periods slow down soil carbon losses and maintain soil carbon stocks to levels comparable to a primary forest. This is different in semi permanent land-uses

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systems (e.g. passion fruit and black pepper) where a rapid decrease of soil carbon is found in the upper soil layers (Denich et al. 1998a).

- In a false time series approach the nutrient budget for an entire slash-and-burn land-use cycle of 9 years with NPK fertilization was estimated as follows: the net losses during the cropping phase were 75kg K ha^{-1}, 125 kg Ca ha^{-1}, 16 kg Mg ha^{-1}, 285 kg N ha^{-1} and 13 kg S ha^{-1}, while Na (-86 kg ha^{-1}) and P (-11 kg ha^{-1}) were accumulated. The most important flux for K (61%) and P (62%) export was by the harvest. The element transfer during the fire caused the main losses of N (60%), S (65%), Ca (58%) and Mg (41%), while the most important path of Na losses was leaching (92%). Comparing the stocks of nutrients in the soil and in the above-ground biomass the losses of K are considered dramatic (Hölscher et al. 1997a);
- A young *capoeira* (2 to 3 years under fallow) is able to evaporate an important proportion of the rainfall input, in spite of the marked seasonal rainfall distribution found in the study area. An average of 79% of the net radiation is converted into latent heat flux. The values lie in the range of values estimated for primary forests in the Amazon, which suggests that possible changes in the regional climate due to deforestation may be less severe where sequential agricultural systems with substantial fallow periods play an important role (Hölscher et al. 1996). The diverse nature of water relations and stomatal conductance behavior found in common species of this vegetation, with relatively high values of stomatal conductance found in some species with high frequency during the first phases of the succession, and an apparent mechanism of maintaining relatively high water potential values under low soil water availability (Sá et al. 1995), are associated to the evaporation pattern of this vegetation;
- Rainfall partitioning into throughfall, stemflow and interception in *capoeiras* is strongly influenced by the floristic composition of the vegetation and its dynamics. Some common species (the Strelitziaceae *Phenakospermum guyannense*, and the Flacourtiaceae *Banara guianensis*) exhibit very high stemflow values. The hydrochemical fluxes and their changes after passage through the canopy do not differ much of those found in primary forests for most elements. A relatively high enrichment of K in both throughfall and stemflow may be associated to relatively high K concentrations of this element in leaf tissue of many species (Hölscher et al. 1998); and
- Results of a study correlating the activity of the enzyme acid phosphatase in the soil, pH and the available phosphorus suggest that the activity of this enzyme could be a suitable indicator for evaluating the impact of agricultural activities towards degradation in the soil.

Based on these results and on those raised from pilot experiments considering fallow vegetation management, which were carried out during that period (Denich and Kanashiro 1998), two lines of research and management alternatives have been formulated for a second phase of the project, aiming at increasing the utilization of available resources (atmospheric nitrogen and water and nutrients from deep soil layers) and avoiding the loss of them, mainly nutrients (by atmospheric losses during burning and by drainage to deep layers) (Vielhauer et al. 1998):

- Fire-free land preparation by slashing and mulching, trying to reduce physical, chemical and biological soil degradation; and
- Fallow improvement by nitrogen fixing leguminous tree enrichment, with the aim to shorten the fallow period and to increase crop productivity per unit time and area.

The slash and mulch technology consists of cutting and chopping the fallow vegetation with a tractor driven mobile bush chopper, TRITUCAP, developed by this project (Denich et al. 1998b). A number of research activities have been completed or are underway trying to implement and to improve this technology, including:

- Fertilizer input trials in the non burning system as compared to the traditional one, involving studies of nitrogen and phosphorus dynamics, (Kato et al. submitted), and a pilot study on fertilizer response (N, P, K) , showing that phosphate deficiency is the limiting factor to such an extent, that high fertilizer inputs of N and K without P come close to no fertilization at all (Bünemann et al. 1998);
- Screening of crop varieties of rice, maize, cowpea and cassava adapted to the new conditions of slash-and-mulch (Kato et al. 1998);

• Water and nutrient dynamics in fire-free land preparation as compared to slash-and-burn conditions (Sommer et al. 1998, Vielhauer et al. 1998);
• Experimental trials towards flexibilization of planting date and period, considering that in the fire-free approach land preparation can be disconnected from the dry season, which permits the choice of a more adequate planting date with respect to agronomic objectives, to labor distribution over time, and to market demand (Vielhauer et al. 1998);
• Soil faunal activity following fire-free land preparation as compared to slash-and-burn land preparation (Leitão et al. 1998);
• Estimate of energy requirements of the non-burning to the traditional burning system (Jönsson et al. 1998);
• Characterization of size class distribution and quality of the chopped material, because decomposition rates are strongly influenced by size classes of the chips and the degree of tearing of them, revealing that more than 50% of the material chopped by the bush chopper "TRITUCAP", is smaller than 4cm, and exhibits very intensive tearing, exposing a substantial total surface to the attack by microorganisms (Denich et al. 1998b);

The enrichment technology, applied to improve the fallow vegetation is being realized by planting fast growing- (quick biomass accumulation) tree- (deep roots for water and nutrient recycling) legumes (biological nitrogen fixation) into the *capoeira*, before harvesting the last crop (Silva Jr. et al. 1998, Brienza Jr. et al.1998).

This research line started with a pilot experiment with enrichment plantings utilizing the fast growing leguminous tree *Acacia auriculiformis*, planted in two densities (2m x 2m, 2500 trees ha^{-1} and 1m x 1m 10000 trees ha^{-1}) in mixed-cropped plots of maize and cassava after the maize was harvested. The plots were left to fallow after the cassava harvest (8 months later) and the leguminous trees developed with a slight advantage to the spontaneous fallow vegetation. After 21 months of fallow (29 months after the planting of the trees) the enriched plots had 2-3 fold higher above-ground carbon stock than a non-enriched fallow of the same age and contribution to the total carbon stocks by *A. auriculiformis* was 57% (2m x 2m) and 72% (1m x 1m), respectively. The root-carbon stocks were higher in the enriched vegetation than in the non enriched one, particularly in soil layers between 0.4m and 2m. Up to 2m soil depth they reached values of 4.2 t ha^{-1} in enriched and 2.5 t ha^{-1} in non enriched vegetation (Denich, submitted; Kanashiro et al. submitted). By the end of the enrichment phase, burning and non-burning (mulching) treatments were imposed and maize and cassava were planted again. Maize was harvested in the same year while cassava was due only in the following year. After cassava harvest, both crops were planted once more to run through a second cropping cycle without fallow in between (Silva et al. 1998a). The results of this experiment are reported in this volume (Silva et al.1998b).

Encouraged by the promising results of the pilot enrichment experiment, a larger experiment was started, including two exotic tree species (*A. mangium* and *A. angustissima*) and three indigenous tree species (*Inga edulis*, *Clitoria racemosa* and *Sclerolobium paniculatum*), as well as a mixed planting of these species, all treatments tested at three spacings (1m x 1m, 1m x 2m and 2m x 2m). The area was slashed and burned in November 1994. Maize and cassava were planted in January and February 1995, respectively. Trees were introduced after maize harvest, and cassava was harvested eight months later. The trees were left to grow up until December 1997/January 1998, when all plots were slashed. In four of the five blocks the biomass was chopped and in one the biomass was burned. Following land preparation, maize as planted end of January and harvested in May 1998 and cassava was planted end of February and is still in the field.

Several multidisciplinary studies (including biophysical and biogeochemical ones) were carried out or are under way in this experiment, including:
• Tree growth and biomass accumulation during fallow, including the aboveground vegetation (Brienza Jr. et al. 1998a) and the contribution by the litter (Pantoja et al. 1998). Some preliminary results are also reported into more details elsewhere in this volume (Brienza Jr. et al. 1998b);

• Spectral composition of solar energy transmitted through the enriched fallow as compared to non-enriched fallow vegetation, revealing that the strongest effect of enrichment trees upon the quality of solar energy at ground level was found in plots with *A. mangium* (Sá et al. 1997).
• Biodiversity assessment, including floral diversity of the natural fallow vegetation under enrichment treatments (Wetzel et al. 1998) and faunal diversity (Leitão et al. 1998);
• Rooting depth and root morphology of enrichment tree species (Fisher et al. 1998);
• Water relations and stomatal conductance of frequently found species of the spontaneous fallow and of the enrichment species (Sá et al. 1998); and
• Rainfall partitioning in enriched fallow vegetation as compared to the non enriched one (Möller et al. 1998).

Another relevant research being focused towards enrichment of fallow is the measurement of biological nitrogen fixation by the nitrogen fixing tree legumes. A preliminary study comparing primary forest and spontaneous fallow vegetation had formerly been carried out (Thielen-Klinge et al. 1998) and a broader and in-depth research including methodological issues (comparing the ^{15}N labeling method with the ^{15}N natural abundance method), Paparcikova (non-published data) is currently under way.

Considering that degraded pastures are a common reality in smallholder areas reducing the usable land for cropping, a pilot experiment is under way applying the enrichment technology to recuperate a degraded pasture with the goal to return to crop production under shifting cultivation (Fernandes et al. 1998a). Results from this experiment are also reported elsewhere in this volume (Fernandes and Vielhauer 1998). Furthermore, the inclusion of the animal component in the smallholder system requires in-depth research activities, which are planned to be carried out in a recently approved project "Role of cattle in the fallow systems in Eastern Amazon region" (Rischkowsky 1998).

All the major results so far obtained, have yet to be evaluated from other research angles and under different space and time scales to guarantee that the proposed technologies are actually feasible to the scenario they were proposed to and promote desirable environmental and socioeconomic impacts.

Although all research of the project has been carried out on smallholder's land, so far almost all the experiments are being conduced as researcher managed on-farm trials. A further step is to implement a stronger participatory approach to the research. A valuable tool towards improving the links of this project with the surrounding scenario is a recent conducted intensive rural appraisal in collaboration with another SHIFT project headquartered in NAEA/UFPA (Silva et al. 1998), as well as own studies of landscape structure and dynamics being carried out by using remote sensing and GIS tools (Sampaio et al. 1998, Metzger et al. 1998).

A new phase of this project is being planned, aiming at:
• Defining the policy parameters for the introduction of the mechanized slash and mulch land use system through a broad based community oriented testing of the equipment as well as the associated technology modules;
• Assessing through community based watershed studies the on-farm and off-farm benefits of the alternative land use systems in economic and ecological terms; and
• Testing with a participatory approach, multipurpose tree species aiming at enrichment of the fallow vegetation.

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