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Alternatives to slash-and-burn agriculture: a research approach for the development of a chop-and-mulch system

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Abstract
The introduction of research-based innovations into traditional land-use systems is difficult, as examples from agroforestry have shown. It can take years to decades until a new agricultural practice has been adopted by the farmers and often the innovations are not very well aligned with the problems and concerns of the farmers. Therefore, in our search for alternatives to the traditional slash-and-burn land preparation (in the context of the SHIFT project "Secondary forests and fallow vegetation in the agricultural landscape of the Eastern Amazon region") we opted for field experiments carried out on small-farmers' land in an old agricultural landscape of the Amazon region. To achieve our objective we follow a phased plan: (i) exploratory research (ii) technology development and prototype evaluation and (iii) adoption-oriented research. During the exploratory project phase we identified the critical needs for improvement, focusing on nutrient dynamics, fallow regeneration, and the replacement of burning during land preparation. Then, instead of designing a completely new land-use system, we aimed at modifying those components of the traditional system which cause degradation processes due to intensified land use or introducing new components which have the potential to prevent these. Alternative technologies were developed as a set of modules including the development of a tractor-driven bush chopper for fire-free land clearing and mulching, enrichment planting with fast-growing leguminous trees to improve the biomass production of the fallow vegetation, shifts in the cropping sequence as well as the screening of modern low-input crop varieties under mulch conditions. Adoption of these modules is flexible, leaving the farmer in control of the innovation process. The adoption-oriented research phase is currently underway and assesses the willingness of the farmers to adopt the farming system improvements. Participatory on-farm research facilitates the adoption process.

Introduction
In the land use on small farms of Eastern Amazonia, fallowing plays a key role in maintaining the system's productivity. Traditionally, the fallow system in the Bragantina region of the Eastern Amazon consists of a 2-year cropping period followed by a fallow period of 3 to 7 years. Land preparation prior to cropping is done by slashing and burning the fallow vegetation. The link between fallow and cropping

period is the land preparation process which on its part directly or indirectly affects soil productivity.

In fallow systems, the fallow vegetation serves different functions which we consider advantageous in the context of small-scale farming and management of agricultural landscapes: (i) accumulating biomass and nutrients on which the productivity of the following cropping period is based, (ii) suppressing weeds which invade the field during the cropping period, (iii) pumping nutrients from deep soil layers upwards (Sommer 2000), (iv) controlling erosion, and (v) maintaining biodiversity in the agricultural landscape.

Growing demographic pressure on land as well as intensification of land use in fallow systems translate into the introduction of mechanization, extension of the cropping period or shortening of the fallow period. This leads to the degradation of the land and, thus, to higher demands for inputs such as fertilizers, pesticides or improved crop varieties. Approaches to further develop the fallow system have to consider cropping and fallow period, and raise the productivity of the land without degradation of resources.

Based on the above aspects, in our research we opted for field experiments carried out on farmers' fields, but managed by the researchers (researcher-managed and controlled on-farm research). This approach has the advantage that precise field experiments can be carried out under ecologically realistic conditions whilst the farmers can become familiar with the pros and cons of the new farming technologies.

The research activities follow a three-phased plan beginning with exploratory research followed by solution-oriented research. We are at present in the final implementation-oriented research phase. This concept implies the gradual change from researcher-managed to farmer-managed on-farm research.

The study region: The Bragantina region in the northeast of Pará state

In the Eastern Amazon, the Bragantina region, located east of the state's capital Belém, covers approximately 23,000 km^2. The region was settled more than 120 years ago and small-farmer agriculture has been practiced there since then. Although covering not more than 2 % of the state's area (IBGE 1996), the Bragantina region contributes considerably to the state's agricultural production (21% of the value of all agricultural production). Crop rotation includes the staple crops maize, upland rice, cowpea and cassava as well as the semi-permanent cash crops passion fruit and, increasingly, black pepper. The region is characterized by a mean annual temperature of around 25 °C, and an annual precipitation of 2,000-2,500 mm. The climate is humid with a dry spell from September to November. The predominant soils are Ultisols. Seventy-five percent of the landscape is covered by secondary vegetation.

Exploratory research

The productivity of the traditional fallow system depends largely on fallow period and fallow vegetation. Therefore, the exploratory research provides, amongst others, details on (i) the biomass and nutrient stocks of the fallow vegetation, (ii) the regeneration of the fallow vegetation after the field has been abandoned, and (iii) the nutrient balance of the entire land-use system, including cropping and fallow periods.

Biomass and nutrient stocks of fallow vegetation

Due to the predominance of the fallow system, most of the small-farmer land is covered with a low (2 to 5 m high), dense woody fallow vegetation. The fallow vegetation following annual crops differs from the stands developing after cultivation of semiperennial crops such as passion fruit and black pepper. The emerging fallow vegetation after prolonged cropping periods shows a very heterogeneous structure and consists of a mosaic of tree and shrub islands with grassy patches. The same can be observed when the field has been plowed and harrowed after clearing.

The vitality of the fallow vegetation is expressed as biomass accumulation per time unit. The average above-ground biomass stocks on fallowed land subsequent to annual crops only differ slightly from those on land cultivated semi-permanently with pepper. In both cases, biomass stocks amount to around 10 and 90 t ha^{-1} in 1 and 10-year-old fallows, respectively. However, the variability of the biomass stocks differs significantly: the variances (s^2) of the biomass means of fallow vegetation following black pepper are about 2 to 6 times higher than those of the fallow biomass following annual crops.

According to analyses of the above-ground biomass, the above-ground nitrogen, calcium and magnesium stocks of the fallow vegetation do not differ significantly. Differences were observed for phosphorus and potassium, the stocks of which were up to 4 times higher in the above-ground biomass of abandoned pepper fields than in annually cropped fields. This can be attributed to the widespread use of NPK fertilizer during black pepper cultivation and the absorption of the residual nutrients by the fallow vegetation. There was no increase in N uptake, since this element does not accumulate to a larger extent in the upper soil layers, possibly due to N losses by denitrification and perhaps nitrate leaching.

Regeneration of the fallow vegetation

The regeneration of woody species from seeds was rarely observed in the field and tree individuals deriving from seeds play no marked role in the structural composition of the fallow vegetation. Practically all tree, shrub and woody vine species as well as herbaceous perennials regenerate vegetatively by resprouting from roots or rhizomes which have survived the cropping period (Clausing 1994, Jacobi 1997).

The woody vegetation in abandoned fields which had been cultivated traditionally without any tillage were similar in their regeneration behavior to fields where the stumps of trees and shrubs had been removed but the roots left untouched. Plowing and harrowing, however, destroy the root system in the topsoil thus impairing the regrowth and biomass accumulation of the woody species, but not affecting the herbaceous seed-born species. Similarly, prolonged cultivation with repeated weeding, as is the practice in passion fruit and black pepper plantations, exhausts the root systems and reduces the vitality of the fallow vegetation growing after field abandonment. In both cases, the woody fallow vegetation loses its regeneration potential and particularly grasses will spread on the respective fields.

Nutrient balance of the fallow system

The nutrient balance of a land-use system is a quantifiable measure for the sustainability of the use of its natural resources. The nutrient balance over a 2-year cropping and a 7-year fallow period shows that the heaviest nutrient losses on the field occur through burning and harvesting. Leaching only leads to minor losses. The most important nutrient gains to the agroecosystem are atmospheric inputs via biological nitrogen fixation as well as through rain and dust and the use of fertilizers.

When considering a 2-year cropping and 7-year fallow period, it can be seen that the nutrient losses exceed the gains. The overall nutrient balances are, therefore, negative. In spite of fertilization, nitrogen, potassium, calcium and magnesium show a deficit of 175 kg ha^{-1}, 75 kg ha^{-1}, 125 kg ha^{-1} and 16 kg ha^{-1}, respectively, in the course of the 9-

year land-use cycle (Hölscher 1995). Only phosphorus shows a positive balance of 11 kg ha^{-1}, due to the application of fertilizer.

Solution-oriented research

The following conclusions of the exploratory phase appear relevant: (i) In the fallow system of the study region, the nutrient resources are not sustainably used due to short fallow periods. The negative nutrient balance can, however, be improved by the replacement of slash burning during land preparation through alternative fire-free practices. Furthermore, the fallow vegetation in a fire-free system would be a source of organic matter biomass for improving the soil properties. Fire-free land preparation and management of soil organic matter can be combined in a mulch approach. (ii) Degraded fallow vegetation due to prolonged cropping periods or tillage is characterized by spatially heterogeneous patterns of biomass distribution as well as the extensive occurrence of herbs and grasses. During the subsequent cropping period, this leads to heterogeneous soil productivity due to the heterogeneous organic matter and nutrient input. Furthermore, herbs and grasses make later maintenance work more difficult. Both problems might be overcome by planting evenly distributed fast-growing trees during the fallow period.

Based on these conclusions, we decided to continue with two main research lines: (i) fire-free land preparation as a means of more sustainable resource use, including mulch technology, screening of cultivars suitable for mulch systems and developing a chopping implement to produce mulch, and (ii) enrichment plantings to improve the vitality and structural homogeneity of the fallow vegetation.

Mulch technology

On experimental plots, the biomass of the fallow vegetation was chopped with a stationary silage chopper or even chopped manually and then spread as mulch over the plots.

During the subsequent cropping period, rice, cowpea, and cassava yielded less in the mulched than in the burned plots, which served as control plots. If NPK fertilizer was applied, the yields in mulched and burned plots were similar. Both yields were considerably higher than the average yields in the region (Kato et al. 1999). In a second cropping period, after a 6-month fallow period, the mulched fields yielded significantly more than the burned fields, both with fertilizer application and without. This can be explained by the fact that the slowly decomposing mulch does not provide nutrients as readily in the first cropping period as the ashes of the burned vegetation. In the second cropping period, however, the mulch material is almost completely decomposed and the nutrients are released into the topsoil. An estimation based on fertilizer costs and market prices of the crops produced in the two cropping periods revealed that fertilization more than doubled the net return of the system (Kato 1998).

In the long run, fire-free land preparation would also be favorable for the management of soil organic matter. Periodic mulching would not only help to reduce nutrient losses, but also contribute to the conservation of considerable amounts of organic matter. For a sustainable land use, the improvement of the physical, chemical and biological soil properties through the addition of organic matter might even be as important as the reduction of nutrient losses by fire-free land preparation technologies.

Screening of crop cultivars

Screening experiments were conducted with a set of maize, rice, cowpea and cassava cultivars in mulched plots with and without the use of fertilizer. In the case of cassava, fertilizer means the residual fertilizer of the previous crops.

The screening results how that on mulched plots all cultivars, as expected, yielded better with the application of fertilizer. However, there appears to be some scope in overcoming the unfavorable growth conditions on mulched plots without fertilization through the use of adapted rice and cassava cultivars. The yields of the not-fertilized rice cultivars range around the local average. Yield differences between the cultivars could be found (although statistically not significant) which might be exploited through further breeding. The relatively small differences between cassava tuber yields under conditions with and without residual fertilizer also might be overcome by further selection or breeding. This does not hold true for cowpea and maize for which all tested cultivars are poorly suited to the growth conditions under mulch and, thus, require fertilizer application.

Bush chopper

For the adoption of fire-free land preparation technologies by the farmers, practical methods for the conversion of the woody fallow vegetation into mulch is of fundamental importance. As the woody plant material on fallowed fields cannot be realistically chopped by hand into manageable chips (as we did occasionally in our field experiments) the mechanization of the chopping process is a must.

Therefore, we decided to develop a chopping implement for cutting the fallow vegetation without damaging the root system of the trees and shrubs in order to ensure the vital regrowth of the woody fallow vegetation through resprouting. Cutting, chopping and spreading the plant material was to take place together.

A tractor-propelled bush chopper with a cutting width of 2 m was constructed, which can be mounted on the front power lift of the tractor. The chopper is able to cut and chop stems and branches with diameters up to 6 cm, accounting for more than 95% of the woody biomass. According to vegetation composition and structure, chopping can take from 1 to 8 hours/hectare, the average output being about 10 t chopped fresh plant material per hour.

Preliminary estimates of the costs of mechanized mulching show that the rental costs for a tractor (including driver) and the chopper for preparing one hectare of fallowed land for planting are only slightly higher than the costs of land preparation with slash-and-burn carried out by contracted fieldworkers.

Enrichment plantings

Increasing degradation of the fallow vegetation can be counteracted by enrichment plantings. Acceleration of biomass production as well as nutrient accumulation while overcoming the spatial imbalances in a relatively short fallow period are achieved by planting fast-growing, nitrogen-fixing leguminous trees on abandoned fields.

In a field experiment on small-farmer land, *Acacia auriculiformis* (Leguminosae) trees were planted at spacings of 2 m x 2 m (2,500 trees per hectare) and 1 m x 1 m (10,000 trees per hectare). Experiments followed with other leguminous trees, such as *A. angustissima, A. mangium, Clitoria racemosa* and *Inga edulis* (Brienza 1999). *Acacia auriculiformis* were planted in mixed-cropped plots of maize and cassava after the maize had been harvested. The cassava crop did not suffer any significant yield reduction due the competition by the saplings (Brienza 1999). After the cassava harvest, however, *A. auriculiformis* developed faster than the spontaneous fallow vegetation. At the age of 21 months, the enriched fallows had a 2-fold higher above-ground biomass than the fallow without enrichment planting. The total above-ground biomass of the 21-month-old enriched fallows was as high as that of 7-year-old fallow plots. The spontaneous undergrowth of the enriched plots was suppressed significantly. Furthermore, in degraded fallow vegetation, the heterogeneity of the spatial biomass distribution could be significantly reduced by the evenly growing planted legume trees. Tentatively, it was concluded that the higher cost-benefit ratio for biomass accumulation of an *Acacia-auriculiformis*-enriched fallow is found at the lower planting density.

Implementation-oriented research

The crucial point of the research process is the adoption and application of the technology by the farmers. The task of transferring agricultural research results into practice usually falls within the scope of extension services and development agencies, but should also be supported from the research side to arouse the farmers' interest and to channel the innovation properly. Accordingly, implementation-oriented research aims at developing incentives which are coupled with the innovation to encourage the farmers to adopt the new technology. Subsequently, implementation strategies might be developed to support the efforts of wide-spread introduction of the innovation. Implementation-oriented research includes agronomic on-farm research with deliberate participation of the farmers. They will be asked to maintain labor logs, monitor weed and pest incidence, and to characterize their production over an entire cropping period.

There are basically two ways an innovation attracts farmers: it either directly improves directly their income or makes farming easier and more efficient. The following agronomic incentives might attract farmers in the Eastern Amazon to adopt the fire-free land preparation methods being tested in participatory on-farm trials:

1. Changing the cropping calendar: Cutting and chopping with the bush chopper instead of slashing and burning the fallow vegetation allows land preparation outside the dry season which the burn depends on. Thus, the farmer can extend the respective volume of work over a longer period of time. According to the changed planting time the harvest period might fall in seasons of low supply, possibly resulting in higher selling prices.
2. Re-arrangement of the crop sequence: In mulch systems, nutrients of the mulch material are slowly released by decomposition, or even temporarily immobilized, resulting in a low nutrient supply at the beginning and an increased nutrient supply later in the cropping period. Thus, the sequence of the crops within the cropping period might be changed such that a less demanding crop, e.g. cassava, is planted as a starter crop and more demanding crops, such as maize, follow later. This practice provides the farmer with further flexibility in scheduling planting and harvesting, according to food or market demands.
3. Extension of the cropping period: The extension of the cropping period beyond the common 1-2 years saves labor and money for land preparation and increases both the land-use factor R and the agricultural productivity of the land (Kato 1998). More investigations are needed, however, to evaluate the long-term effects of this practice on the vitality of the fallow vegetation.

External incentives might include subsidies from international environmental markets under the framework of the Clean Development Mechanism (CDM) (see IPCC 2000). Our own estimates revealed that mulching combined with fallow management might considerably increase the carbon stocks and carbon sequestration capacity in Amazonian fallow systems (Denich et al. 2000).

Another way to repay for the farmer's readiness to apply new environmentally sound farming practices are the certification of the farm products and their commercialization via fair trade initiatives. Certified products allow the consumers to use their purchasing power to support these approaches. In our case, the supportable attributes of the products might be: (i) produced by small farmers, (ii) produced without the application of fire, (iii) produced in systems which contribute to mitigation of the greenhouse gas problems and, (iv) free of agrochemical residues. According to FAO, the demand for products especially from organic agriculture has created new export opportunities for the developing countries.
Implementation-oriented research requires private-public partnership beyond the partnership with the farmers. We have already initiated the cooperation with a local mechanical engineering company which is involved in maintenance and repair of the bush chopper and which will construct a version of the chopper which meets Brazilian industry norms. Furthermore, a private contractor, who offers excavation and land-clearing services, attends the whole process and is prepared to put the device at the farmers‘ disposal.

Conclusion

Our approach to follow a hierarchical and phased research plan aims at the improvement of the traditional fallow system with slash burning for land preparation by replacing only those components in the traditional system recognized to be harmful to the system. Thus, the system that is well-known to the farmer is basically maintained. The approach differs in this respect from attempts to develop completely new land-use systems. Additionally, other components of the system might be modified, leading to a further improvement of the system. A set of agricultural practices can be offered to the farmer as a modular system. The modules are: (i) the mulch system including fire-free land preparation using the newly developed bush chopper, (ii) low-input crop cultivars suitable for mulch systems, (iii) re-arrangement of the crop sequence, (iv) changing the cropping calendar, and (v) extending the cropping period. Due to the modular system, the readiness of the farmer to adopt new technologies might increase, as the system can be modernized step by step, according to the farmer’s needs and ability as well as to his management capacity. In addition, the farmer can himself control the degree of risk he is prepared to take.
A great number of farmers have accompanied the project from the beginning, either as fieldworkers or as observers. It can be recognized that the close contact to the research project over several years influences the farmers’ understanding of the research activities as well as the evaluation of their own land-use behavior. However, this does not automatically mean that they adopt science-based innovations. On the other hand, the agricultural sector of the Bragantina region is highly dynamic, and as the small farmers increasingly produce for the market they continuously innovate their production methods according to market demands. They also have to search for fire-free land preparation techniques as increasing legal and political initiatives forbidding the use of fire in land preparation put pressure on them. Recently, farmers in the study region were observed collecting plant material on marginal land and bringing it to pepper plantations to cover the extremely bare soil. Perhaps such biomass transfer systems with *ex-situ* mulch production and permanent land use will dominate the future land use in the region. Cutting and chopping of the vegetation on fallowed fields will, however, certainly not lose its importance in the near future, particularly when land falls into short supply.

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