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UTILIZATION OF ABANDONED AREAS IN AMAZONIA BY POLYCULTURES OF PERENNIAL USEFUL PLANTS

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ABSTRACT

Degraded fallow areas of primarily monocultural plantations will be transferred into a locally-adapted form of utilization through special consideration of soil microbiological factors (fungal and bacterial symbionts). In accordance with the heterogeneity of natural plant communities, polycultures of several perennial and annual ecologically adapted useful plants are installed. During the installation phase mycorrhizal fungi are introduced as important biological factors to optimize the ecological fitness of the plant material. After the implantation of the polyculture the spontaneous secondary vegetation is managed carefully to reach a jointly beneficial growth of the secondary vegetation with the useful plants. In this type of naturally enriched polyculture special regard is paid to a careful use of pesticides and fertilizers in order to come to a plant production system with low input and sustaining medium output. Low input systems with a mixture of annual and perennial plants result in an ecologically and economically equilibrated situation for small scale producers. In this contribution the organization of a multidisciplinary project between Brazilian and German institutions is demonstrated as well as the results of the installation phase of the project.

INTRODUCTION

Although numerous attempts exist to recultivate degraded sites of formerly utilized areas in Amazonia, the success of reaching to a sustainable land-use is relatively small.

The handling of short nutrient cycles, leaching of nutrients on one hand, bad availability of nutrients on the other hand, the importance of the heterogeneity of the natural plant cover, and the interactions between flora, fauna, and microorganisms are so far not well analysed and understood. The few data yet available must be supplemented and put into practice rapidly to allow the prompt development of concepts for effective protection of the rainforest and simultaneous ensurance of the social and economic development of the region.

A resolution for the agricultural problems of Amazonia probably can be found in a mixed cultivation of selected, perennial plants adapted to the special environmental conditions of the region and combined with annual and biannual crops. The polyculture system may help to create conditions which are similar to those existing in the primary plant cover. The function of perennial trees as reservoires for nutrients and their role in the recycling of biomass in complex systems was demonstrated (e.g. Shubarth 1977; Sioli 1980; Burger 1986). Especially in Amazonia a consequent transfer of these findings to practice is still in its beginnings.

When a recultivation of fallow lying areas in the Amazon region is planned one has to pay regard especially to pedological and soil-microbiological problems: all of the areas have been established by slashing the primary forest, impairing the soil caracteristics, and destroying soil-microorganisms by burning. In nearly all cases the areas have been cleared mechanically afterwards, and were treated with a high input of pesticides during the cultivation phase (Fassbender 1990). Soil-biological analysis in rubber tree plantations show that a dramatic change in the populations of the soil-microbes occured (Feldmann and Lieberei 1992) and that the plants became much more susceptible to stresses. By inoculation of soils with mycorrhizal fungi (self-produced inoculum or soil from natural stands) an improvement of the soil as substrate for plant growth is possible (Feldmann 1990).

Several studies indicate, that principally a recultivation of abandoned areas is possible. The main problems lie in the fact that a recultivation has to be sustainable for a very long time period and therefor has necessarily to be profitable for small scale producers. That means that methods have to be developed which lower the input into a production system especially during the critical installation phase - and ensures an output which meliorates the life standard of the producers without loosing the productivity of the fields already after a short time.

In the attempt reported here different factors are taken into account which are stabilizing biological controlling systems (*e.g.* for nutrient cycling or epedimiology of diseases). The management practices include treatments for the improvement of biological factors of soils (Feldmann *et al.* 1989; Feldmann and Idczak 1992; Feldmann *et al.* 1993a), *e.g.* the introduction of symbionts and the utilization of plants which are mycotroph and living in symbiosis with N-fixing bacteria (Feldmann *et al.* 1993b); beneath that a high number of plant species together with the useful plants is allowed to grow, and the use of pesticides is minimized.

In cooperation with the three large institutions in Manaus: CPAA, INPA and UNAMAZ/UA the following items will be carried out:

- Former plantation areas of the CPAA are recultivated with polyculture systems of different useful plants.
- Symbiontic fungi are multiplied and inoculum is prepared using locally adapted methods.
- In the initial phase of the project selected symbionts are used to optimize the plants' establishing phase, health and growth.
- Recultivation is accompanied by studies on the ecological and economical effect of natural secondary vegetation growing spontaneously in the polycultural system.
- a management concept for the transfer of the results into the common practice will be deduced from the results.

THEORETICAL BASIS FOR THE PROJECT

Prior results demonstrated the importance especially of soil-microbiological factors, the adaptedness of the utilized plants and the heterogeneity of the vegetation for the stability of agroecosystems. These parameters are the basis for a successful recultivation of lying fallow and degraded areas and their long-term use.

The plant production system demonstrated here therefore fulfills the following items:

- An adapted agroecosystem in the Amazon basin has to be a polyculture with the use of mainly perennial, indigenous trees.

- Degraded areas have only very few essential, symbiontic organisms (see Feldmann *et al.* elsewhere in this volume). In the initial phase of a recultivation effective symbionts, especially mycorrhizal fungi, have to be introduced to the plant production system.
- A high soil-microbiological stability and high diversity of effective, adapted soil microorganisms is supported by a high number of different host-species. That means that the inclusion of the natural secondary vegetation should have high importance for the stabilization of populations of soil-microorganisms and therefore for the introduced hosts, the useful plants, too.
- The management of the plantation has to be carried out in a way that a high diversity of soil-microorganisms remains in the soil. That means a low input of pesticides and a controlled amount of fertilizers (normally much less than without mycorrhization of the plants) is recommended.
- A high diversity of useful plants/natural vegetation probably will enhance the disease tolerance of the whole system by changing the microclimate and giving the possibility to establish natural controlling systems, as long as the secondary vegetation does not contain host plants for pathogens or pests, which attack the crops.
- The selected useful plants have to be acceptable for the people of the Amazon region.

- The produced goods must have a commercial value.

- The products must be suitable for being transported.

- The installation of the plantation and the products must be profitable.

- Modifications of the management practice must be accepted by producers and must be practicable under local conditions.

ORGANIZATION OF THE PROJECT

The existing working group is composed of scientists from the CPAA, EMBRAPA, Manaus, Brazil, the Institute for Applied Botany of Hamburg University, FRG, the Federal Institute for Timber and Forestry in Hamburg, FRG, and the INPA, Manaus. It covers areas of several disciplines as shown in Figure 1.

Basic knowledge has been or is being accumulated in the field of mycology, bacteriology and vegetation science; application-orientedness increases in the direction of the arrow. For this reason, the acceptance studies designed to find out whether farmers in the region are in fact willing to apply the tested cultivation systems practice are inpositioned on the far right of Figure 1.

Description of the field trial

In the 19ha plantation, we intend to test the three following ways of stabilizing crops in different test variants:

- Inoculation of the plants with mycorrhizal spores
- Testing of different mixed cultivation systems
- Fertilization in different fertilizer regimes
- Experiments on management of the spontaneous vegetation in the crop systems to improve the competitive conditions for the planted crops.

Planted crops and plantation systems

14 species of useful plants were planted in the experimental field (Table 1).

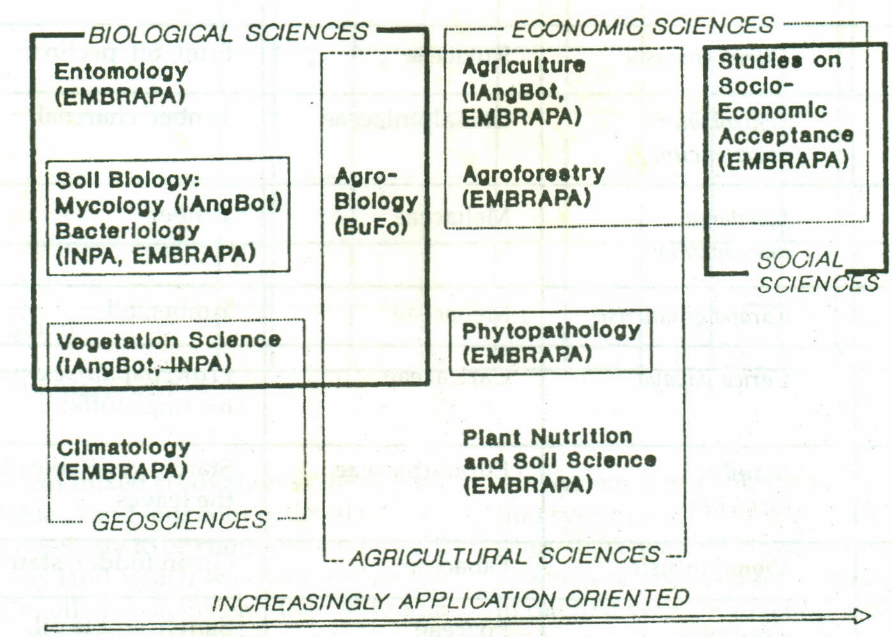


FIGURE 1. Scientific disciplines and institutions involved.

TABLE 1. List of planted species.

Common name	Scientific name	Plant family	Use
Seringueria	*Hevea* spp.	Euphorbiaceae	Rubber production, oil production from seeds
Cupuaçu	*Theobroma grandiflorum*	Sterculiaceae	Pulp (juice, ice, dessert), pods (chocolate)
Pupunha	*Bactris grandiflorum*	Arecaceae	Fruit, palmito, fodder (leaves), food colourings (fruit flesh), weaving material
Castanha do Brasil	*Bertholetia excelsia*	Lecythidaceae	Brazil nuts, timber
Urucum	*Bixa orellana*	Bixaceae	Dyestuffs sunscreens
Côcos	*Cocos nucifera*	Arecaceae	Oil, copra, coconut milk, feeding stuffs (oil cake), weaving material, fibres, construction timber, particle board
Citrus	*Citrus sinensis*	Rutaceae	Fruit, oil, pectin
Paricá	*Schizolobium amazonicum*	Caesalpiniaceae	Timber, charcoal
Mogno	*Swietenia macrophylla*	Meliaceae	Timber
Andiroba	*Carapa guianensis*	Meliaceae	Timber, oil
Mamão	*Carica papaya*	Caricaceae	Fruit, papain, carpain, feeding stuffs
Mandioca	*Manihot esculenta*	Euphorbiaceae	Starch, vegetables from the leaves
Feijão	*Vigna sinensis*	Fabaceae	Green fodder, starch
Milho	*Zea mays*	Poaceae	Starch, edible oil, feeding stuffs
Puerária	*Pueraria phaseoloides*	Fabaceae	Cover crops

TABLE 2. Useful plants grown in different plantation systems.

	Plantation systems									
	mixed cultiv.				f	monocultures				
	1	2	3	4	5	6	7	8	9	
Seringueira	*		*	*		*				
Cupuaçu	*	*	*				*			
Pupunha	*	*						*		
Castanha do Brasil		*								perennial
Urucum		*								useful
Côcos			*							plants
Citrus			*						*	
Paricá			*	*						
Mogno				*						
Andiroba				*						
Mamão	*									short
Mandioca		*	*							living
Feijão			*							useful
Milho			*							plants
Puerária	*	*	*			*	*			cover
spontan. vegetation				*	*			*	*	crops

f = fallow (for comparisons)

Four different mixed cultivation systems (systems 1-4, see Table 2) and four conventional monocultures (systems 6-9) are to be compared in the field trial. System 5 is land which was prepared in the same way as the other systems and then left to its own devices. Perennials, short-term crops for planting between the rows and cover plants are being used in the systems. The choice of crops was based largely on current marketing prospects.

System 1 is a comparatively intensive cultivation system with little space left between the rows. More space was left between rows in systems 2 and 3, which can be used for growing short-term crops in the first year. In practice, this would help farmers survive the first years after establishment of the plantation, during which the longer-lived species are not generating any income. System 4 is the most "extensive" of the test systems. The species planted

TABLE 3. Plantation systems and test variants applied.

n = 54	0 fertilizer		30% fertil.		100% fertil.		
	- myc.	+ myc.	- myc.	+ myc.	- myc.	+ myc.	
system 1			*	*	*	*	mixed cultivation
system 2			*	*	*	*	
system 3			*	*	*	*	
system 4				*			
system 5	*						fallow
system 6					*		monoculture
system 7					*		
system 8					*		
system 9					*		

- myc. = not inoculated with mycorrhizal fungi spores
+ myc. = inoculated with mycorrhizal spores

produce timber. Secondary vegetation is tolerated between the trees. In systems 1-3 and in monocultures 6-8, on the other hand, cover plants have been sown (Pueraria phaseoloides). For the later transfer to practice probably not only one but an appropriate combination of different systems will be recommended.

Plantation systems and layout on the fields

The nine plantation systems described are being established in different test variants (Table 3). Some of the young plants have been inoculated with mycorrhiza, the remainder have not. The fertilization variants include zero fertilizer, 30% and 100% of the recommended dose for the respective species.

That gives a total of n=54 possible variants. In our experiment we implemented the 18 variants which promise to give the most meaningful comparisons.

In the field test the 18 variants are being laid out as blocks, with five complete blocks and repeats. The position of the variants within the blocks is completely randomized. The plots have an area of 48 x 32 m^2 each. The layout of the plots is determined by the elongated, irregular shape of the experimental area. A 100 x 100 m^2 patch of secondary forest was left standing at the edge of the area for comparative studies of the secondary vegetation.

The experimental area concerns terra firme lands on the EMBRAPA site, Km 28, Am 010. These areas were first cleared of primary forest about ten years ago, then used as rubber tree monocultures and last left unattended. In August 1992, the approximately eight-year-old secondary forest was cleared and burnt in the traditional manner. Since April 1993 the plantation is established.

FIRST RESULTS OF THE PROJECT'S INSTALLATION PHASE

Spontaneous vegetation four months after clearing

Before the secondary forest on the test area was cleared, a floristic study was carried out, which yielded 178 species, mainly trees. Four months after clearing - and after the area had been surveyed and divided into plots - growth form types of the spontaneous vegetation of all 90 plots of the trial were assessed quantitatively, *i.e.* on the basis of their respective area coverage. The patterns are the result of the former use of the sites and of pedological differences between sites within the experimental area.

A preliminary analysis of the data reveals heterogenous vegetation patterns within the plots (on a m^2 scale), but clearly distinguishable patterns in a north-south direction (from block A to block E). The following growth forms show dominance in the blocks of the experimental area as shown in Table 4.

A more detailed analysis of the data is yet to come. So far the patterns are interpreted as patterns of different intensity of use, or also differences in intensity and frequency of disturbance. Although these differences will in part be cancelled out by subsequent management measures, the vegetation differences observed are important as they represent the starting conditions of the experiment and must be included as site differences in the final trial evaluation.

Control of wild vegetation in the plantation

The spontaneous vegetation which regenerates or colonizes the space between the plantation crops can, on one hand, constitute competition for the crops (light, nutrients, space) and must be suppressed in this case. On the other hand, the wild vegetation can be an important store of nutrients, which become available to the crops after dieback and mineralization of the biomass. As well a high diversity of the secondary vegetation probably will mean an equilibration of ecological controlling systems, *e.g.* occurrence of diverse communities of symbionts or other beneficial microbes. Whether these two opposed processes can be optimized in favor of the crops by appropriate control of the wild vegetation, is a question which has to be examined.

Basically there are three ways of controlling growth of wild vegetation (Figure 2):

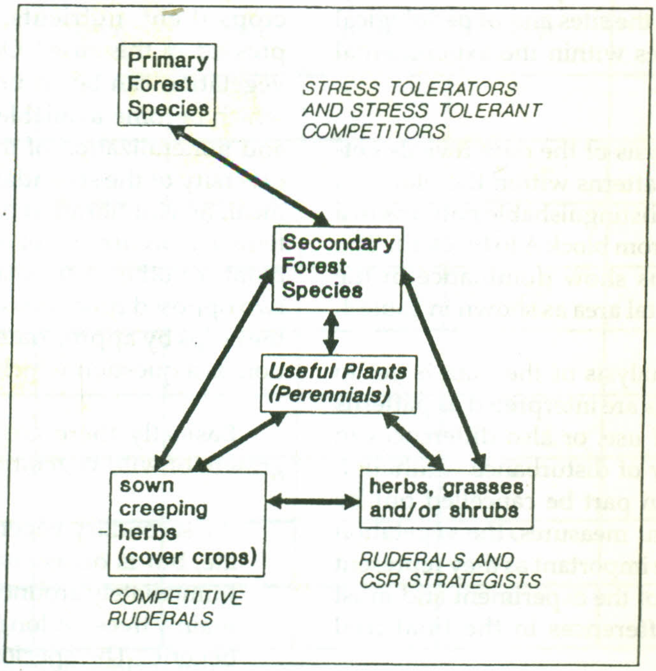
the secondary vegetation is allowed to regenerate, but is occasionally cleared from the space immediately around the crop plants. In this case mainly trees, *i.e.* long-lived growth forms, would benefit. The species spectrum would be compressed due to the occasional disturbance.

TABLE 4. Growth form structure of the spontaneous vegetation in the different blocks 4 months after clearing.

Growth forms		dominant in block(s):
Trees		A, B
Shrubs		nowhere dominant
Herbs	Tussock grasses	B, D, E
	Stolon grasses	nowhere dominant
	upright growing dic. herbs	D
	creeping, dicotyl. herbs	C, D
	Ferns (bracken)	E

dic./dicotyl. = dicotyledones

FIGURE 2. Three ways of controlling wild vegetation in the plantation.



- the cultivation area is kept free of taller growth forms, *i.e.* the regeneration of secondary forest species is frequently disturbed. In this case the long-lived herbs and grasses would benefit.

- herb species with creeping growth forms are sown, *e.g.* Pueraria. This would lead to a dense undergrowth of one or a very few species.

The three different ways of treating the undergrowth each favor different ecomorphological plant types according to Grime (1979, 1988): - sowing favours fast-growing types with a high nutrient requirement (competitive ruderals).

- frequent cutting and hoeing favours short-lived herbaceous species and species which can regenerate quickly from the buds at the soil surface (ruderals and CSR strategy types),

- minimum management favors regeneration of part of the species spectrum of the secondary forest.

The arrows indicate different competitive situations due to the management of the planting systems. CSR strategists according to Grime (1979, 1988).

In the field experiment cover plants have been sown (see above) in some of the test variants, because of the positive experience on the farming site that exists with this method; in other variants secondary vegetation will be tested as cover plants.

Occurrence of mycorrhizal fungus spores before and after burning

The highly important symbionts of most of the useful plants in tropical regions are severly influenced by the management practices in Amazonian plantations (Feldmann and Lieberei 1992). To estimate the influence of burning before the plantations' establishment, 40 soil samples were surveyed to count the number of spores and to classify the occurring spore types before burning. Immediately evaluated. At the same time a further estimation of the most probable number of propagules in the plantation soil was done (following the method of Feldmann and Idczak 1992).

It was found that all over the plantations an average of 658 spores per cm^3 soil of vesicular-arbuscular mycorrhizal fungi (VAMF) occurred, but only one third of them was alive. An infection and rapid colonization of the root systems of catching plants (Zea mays, Petroselinum crispum) was easily possible.

A complete identification of the occurring fungi was not yet possible. But a first classification of the spores is shown in Table 5.

From each spore type single spore isolates are now prepared for an exact identification or description.

Directly after burning no infection and no living spore was counted in soil sampled from the above 5 cm of the soil surface. Even six months after burning preliminary examinations (one MPN test with 5 dilutions and 5 replications with a mixed soil sample from all over the plantation) did not show any mycorrhization in the testing plants (Zea mays). This strong impact of fire with regard to the survival of the mycorrhizal fungi was not expected, but shows the dramatic changes which come along with the burning of the fields. Further periodical tests will show how long it will take until the infection potential of mycorrhizal fungi arises again in the test fields.

Use of mycorrhizal inoculum in the plant production

As described above plants of the half of test variants were inoculated with mycorrhizal fungi. How the fungi were selected and how the inoculum was produced is described elsewhere in this volume.

Up to row, all evaluated inoculated plant species showed a much better growth than plants without inoculation (Figure 3).

CONCLUSIONS

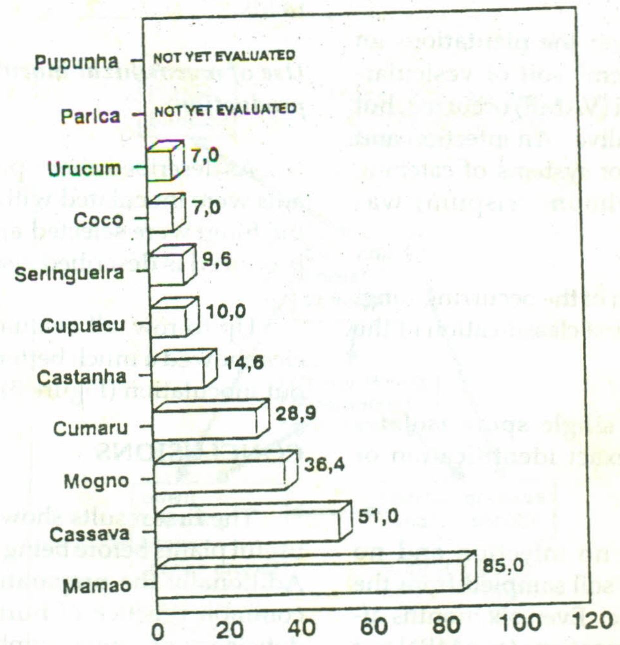
The first results show a growth response of the useful plants before being outplanted into the fields. Aditionally the preparation of the fields with the common practice of burning resulted in a severe deficiency of fungal symbionts in the soil. It is expected that the better growth of the useful plants in the nurseries due to mycorrhizal fungi will result in a better initial growth in the field, too. Possibly this advantage will decide on survival or fading of the plants under the unfavorable conditions of degraded

TABLE 5. Percentage of VAMF spore numbers in soil samples from the plantations before burning and distribution on spore type classes.

spore type	[%] of total n	percentage $_{min}$	percentage $_{max}$
Glomus A	41,2 ± 9,3	28	62
Glomus B	37,2 ± 7,5	24	49
Scutellospora A	9,9 ± 7,1	0	23
Scutellospora B	3,0 ± 3,2	0	11
Acaulospora	3,6 ± 3,7	0	12
not ident./others	5,5 ± 3,1	0	11

The total spore number was in average 658 + 176 spores / $50cm^3$ soil in n=40 samples. Only 27% of these spores were alive, but the infection potential of the soil was high.

FIGURE 3. Growth response of some useful plant species to inoculation with mycorrhizal fungi in nurseries.



stands. While the introduction and utilization of mycorrhizal fungi is very cheap and easily made this would demonstrate the first step of a new plant production system which finally will combine a low input with a sustainable output.

The other steps following from now on in the growing and producing phase of the systems as well as the concluded final polycultural system with its special management practices will be published as soon as possible.

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