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Recultivation of cleared and abandoned sites in the Amazon by agroforestry systems, a SHIFT - project

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INTRODUCTION

The rainforest in the Brazilian Amazon basin is the last and largest primeval tropical forest area of the world. According to Fearnside et al. [1], until 1989, 478,882 km^2 (47,888,200 hectares) of native forest have been transformed into other forms of soil use, in the course of the regional development process. Nowadays the greater part of this land has been abandoned, occupied by 'capoeiras', secondary forest, bush fallow and degraded pastures. Under social, economical and logistic aspects these fallow lying areas have been optimal sites. The reactivation of these fallow lying agricultural areas by stable, long lasting, profitable use systems will help to reduce the clearing of new areas of primary rainforest. Development of recultivation strategies is of high importance for a sustainable agricultural management concept in Amazonia.

Traditional management forms of the rainforest as carried out by indigenous people in the Amazon basin [2, 3] are not practicable to feed large populations because they are of low output and depend on a semi-nomadic life cycle of the people. The fast increase of the local human population requires large areas for agricultural production systems, to guarantee the subsistence of the population and to support the urban centers.

The disaster in the attempt to establish monocultures of rubber trees by intensive financial support of the Brazilian government shows, that the knowledge about the ecosystems, about their delicateness, fragileness and the internal network is very small. The low fertility of 90% of the soils in the tropical regions of Brazil and heavy rainfall are the largest handicaps for agriculture and food production in a conventional sense in Amazonia [4].

A general solution of the agricultural problems can only be found in agroforestry systems using selected, perennial plants. They give the possibility to build up conditions similar to those which exist in the primary forest. The function of perennial trees as reservoirs for nutrients and their role in the recycling of biomass in complex systems was analysed and described [5, 6, 7].

The objective of this research project is to develop multiple cropping systems which are ecologically, socially and economically viable for the humid tropics by rising and stabilizing the productivity of these areas and, consequently, by using the areas for a long period of time. The strategic aim of the project is to reduce clearing and burning of primary forests and to reduce the rural-to-urban migration.

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Table 1. List of useful plant species planted and their use.

Useful plants			Use	
Comm. name	Scientific name	Plant family	* = harvesting in process ** = harvesting finished	
Rubber tree	*Hevea brasiliensis* (Adr.Juss.) Muell. Arg.	Euphorbiaceae	Rubber production, oil production from seeds, wood production	
Cupuaçu	*Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum.	Sterculiaceae	* Pulp (juice, ice, dessert), pods (chocolate)	
Peach palm	*Bactris gasipaes* Kunth	Arecaceae	* Palmito, fruit, fodder (leaves), food colorings (fruitflesh), weaving material	
Brazil nut	*Bertholletia excelsa* Hum. & Bonpl.	Lecythidaceae	Brazil nuts, timber	
Urucum	*Bixa orellana* L.	Bixaceae	* Dyestuffs, sunscreens	
Coconut tree	*Cocos nucifera* L.	Arecaceae	Oil, copra, coconut milk, feeding stuffs (oil cake), weaving material, fibers, construction timber, particle board	
Citrus	*Citrus sinensis* (L.) Osbeck	Rutaceae	*Fruit, oil, pectin	
Paricá	*Schizolobium amazonicum* Ducke	Caesalpinaceae	Timber, charcoal	
Mahogany	*Swietenia macrophylla* King	Meliaceae	Timber	
Andiroba	*Carapa guianensis* Aubl.	Meliaceae	Timber, oil	
Papaya	*Carica papaya* L.	Caricaceae	** Fruit, papain, carpain, feeding stuffs	
Cassava	*Manihot esculenta* Crantz	Euphorbiaceae	** Starch, vegetables from the leaves	
Cowpea	*Vigna sinensis* L.	Fabaceae	** Green fodder, starch	
Corn	*Zea Mays* L.	Poaceae	** Starch, edible oil, feeding stuffs	
Kudzu	*Pueraria phaseoloides* (Roxb.) Benth.	Fabaceae	Cover crops	Spontaneous vegetation
Several species of secondary forests and weeds (preferably grasses); dominant: *Homolepis aturensis* (Kunth) Chase				Spontaneous vegetation

MATERIAL AND METHODS

The experimental area is located on terra firme lands on the Embrapa site to the north of Manaus. The fields had been cleared of primary forest at 1981 to make way for an experimental rubber plantation. The plantation was abandoned soon after. In August/September 1992, the approximately eleven-year-old secondary forest which had evolved was cleared and burnt in the traditional manner. The polyculture agroforestry system is now established and some short lived and perennial plants are already being harvested (see Table 1).

Planted crops and plantation systems

Fourteen species of useful plants were planted in the experimental field (see Table 1). Four different agroforestry systems (Systems 1–4, see Table 2) and four conventional monocultures (rubber tree, cupuaçu, peach palm and citrus) 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 follow its own course. 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 and on ecophysiological traits.

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. Systems 4 is the most 'extensive' of the test systems. The species planted produce timber. Secondary vegetation is tolerated between the trees. In systems 1–3 and in monocultures, on the other hand, a cover plant (*Pueraria phaseoloides*) was sown, the spontaneous vegetation, which developed within days after slash

Table 2. Useful plants and plantation systems.

	Plantation systems									
	Agroforestry systems				F	Monocultures				
	1	2	3	4	5	6	7	8	9	
Rubber tree	•		•	•		•				Perennial useful plants
Cupuaçu	•	•	•				•			
Peach palm	•	•						•		
Brazil nut		•								
Urucum		•								
Coconut tree			•							
Citrus			•						•	
Paricá			•	•						
Mahogany				•						
Andiroba				•						
Papaya	•									Short lived useful plants
Cassava		•	•							
Cowpea			•							
Corn			•							
Kudzu	•	•	•			•	•			Cover crops
Spontaneous vegetation				•	•			•	•	

F = Fallow (for comparison)

and burn treatment, was completely overgrown by *P. phaseloides* within 3 months.

Plantation systems and test variants implemented

The nine cropping systems described were established in different test variants (see Table 3). In systems 1–3, plants inoculated with mycorrhizal fungi (VAMF) are compared to control plants. The fungi were applied to all plants cultivated in system 4, but not to the monocultures. The fertilization variants include 30 % and 100 % of the recommended dose of fertilizer for the respective species.

Experimental area

In the field experiment the 18 variants are being laid out in five separate, i.e. repeat blocks. The position of the variants within the blocks is completely randomized. The plots have an area of 48 × 32 m² each. The arrangement of the plants in the four agroforestry systems is shown in Table 4.

RESULTS

Reaction of useful plants to inoculation with VAMF in nursery conditions and in the field

The percentage of the VAMF colonization under nursery conditions in roots of urucum, papaya and paricá was about 50 % and in roots of mahogany 35 %.

Table 3. Plantation systems and test variants applied.

	0 fertilizer		30 % fertilizer		100 % fertilizer		
	myc.		myc.		myc.		
n = 54	-	+	-	+	-	+	
System 1			*	*	*	*	Agroforestry systems
System 2			*	*	*	*	
System 3			*	*	*	*	
System 4				*			
System 5	*						Fallow
System 6					*		Monocultures
System 7					*		
System 8					*		
System 9					*		

\- myc = not inoculated with spores of mycorrhizal fungi
\+ myc = inoculated with spores of mycorrhizal fungi

Table 4. Layout of the four agroforestry systems.

System I:	4 2,5 2,5 2,5 2,5 2,5 2,5 2,5 -----S-----M-----P-----M-----C-----M-----P-----M--> 4| 3| 2| 3| 6| 3| 2| 3| S M P M C M P M * Kudzu as cover crop
System II:	4 4 4 4 4 4 4 4 4 -----B-----U-----C-----P-----B-----U-----C-----P--> 7| 4| 7| 2| 7| 4| 7| 2| C U B P C U B P + Cassava between the rows + Kudzu as cover crop
System III:	4 5 5 7 6 5 5 7 4 -----S-----C-----CP----Z-----S-----C-----CP-----Z--> 4| 7| 8| 5| 4| 7| 8| 5| S PC CP Z S PC CP Z + Cassava, Corn, Cowpea + Kudzu as cover crop
System IV:	4 10 10 10 10 4 -------S-------MG-------PC-------A-------S----------> 4| 7| 4| 7| 4| PC A S MG PC
Legend: ---- distances between the rows (m) | distances between the plants in the row (m) Abbreviations of the plant species: S = Rubber tree, C = Cupuaçu, P = Peach palm, B = Brazil nut, U = Urucum, K = Coconut, Z = Citrus, PC = Paricá, Mg = Mahogany, A = Andiroba, M = Papaya	

The roots of cupuaçu, coconut, peach palm, rubber tree, Brazil nut and andiroba had only a low colonization. Inoculated with VAMF, all species showed a positive growing response independent to the percentage of colonization. After inoculation with VAMF the initial growing was about 70 % in papaya, 36 % in mahogany and 28 % in andiroba. The low colonization in roots of some species like rubber tree, cupuaçu and Brazil nut was caused by difficulties of VAMF to colonize the roots of these species [8]. The radicular system of these species has only a low density of radicells. The plant losses during the preparation and establishing success of a recultivation process can be economically decisive for the success of a recultivation project. Transfer of the plants into the field and planting procedures often give rise to additional plant losses. No plant died during the breeding time. But generally the non-inoculated plants and the species with low VAMF colonization of the roots suffered more stress directly after the transplantation of the young plants into the experimental area and ,consequently, had greater losses due to the death of plants. The mortality of yo rubber trees without VAMF inoculation and a tilization of the recommended 100 % was 25 % general the lowest losses of useful plants were tained with 30 % of fertilizer with inoculation o plants with mycorrhizal fungi [9].

The level of root colonization of the cultiv useful plants by VAMF in field condition depend the management and treatment (monocult agroforestry systems, with or without inoculatic VAMF, quantity of applied fertilizer). The ru tree, Brazil nut and paricá have not been analyz it was not possible to collect root samples wit heavy disturbance of the trees. Cupuaçu, peach p and coconut, which showed no or only low con tration of VAMF at the time of planting into field, also hardly developed a mycorrhiza later

In agroforestry systems with two level of ferti treatments the application of only 30 % of recommended amount of fertilizer generally sulted in higher levels of root colonization by VA than the 100 % treatment. Micorrhization of c grown in agroforestry systems was better than in monoculture. Differences in the root colonization between plants inoculated and not inoculated with VAMF which occurred in the nursery, did not continue in the field. This might be due to the colonization of non-inoculated plants by autochthonous VAMF in the field soil.

Development of single species of the useful plants (see Table 5).

CASSAVA

For cassava, significant difference in production between the two levels of fertilization was observed, but an effect of inoculation by mycorrhizal fungi does not exist. The production on the '30% fertilization level' was 6910 kg/ha, on the '100 % fertilization level' 8833 kg/ha.

CORN

In corn, significant differences of production were observed regarding to the level of fertilization (556 kg for 30 % and 881 kg/ha for 100 % fertilizer level). The mean values of the plants inoculated by VAMF tend to be higher than those not inoculated (e.g. 604 kg for + VAMF and 556 kg for – VAMF in the plots '30 % fertilizer').

PAPAYA

Being a crop of rapid growth and development, papaya showed some statistically significant differences with regard to the treatment groups. An important factor for growth is fertilization. The fruit production in the treatment group '30 % fertilization-VAMF' was 569 kg, where in '100 %/-VAMF' the production raised to 1862 kg. Though not being statistically significant, in the '30 % fertilization level' papaya gained in the 2 and 3 year of growth, within 22 months of time, 559 kg in the '-VAMF' and 971 kg in the '+VAMF' treatment. This result undoubtedly has to be valued as a success due to mycorrhizal fungi application.

PEACH PALM

The results give evidence that peach palm develops significantly better in the '100 % fertilization level' than in the '30 %'. The effect of the mycorrhization is not significant. Moreover, peach palm shows a

Table 5. Qualitative evaluation of useful plants development in the four treatment groups and in the plantation systems (monoculture: mono, agroforestry systems: agro); Basis of valuation = cupuaçu, papaya, cassava, corn, peach palm and urucum = production data; all other plant species = biometric data (plant heights, diameter of trunks).

		Treatment groups				Plantation systems	
		30% fertilizer		100% fertilizer			
		-	+	-	+	Mono	Agro
	Rubber tree		o		o		o
	Cupuaçu		o		o		η
Perennial	Peach palm	o		o			o
useful	Citrus		o		o		o
plants	Urucum	o		o			
species	Coconut	o		o			
	Brazil nut	o		o			
	Paricá		o	o			
	Papaya		η	η			
Short	Cassava	o		o			
lived	Corn		η		η		
crops	Cowpea*						

(-) absence and (+) presence of VAMF
* destroyed by attack of the insect *Diabrotica speciosa*
development in the treatment group/plantation system: o = slightly advanced
• = distinctly advanced

better production in agroforestry system than in monoculture.

RUBBER TREE, CUPUAÇU, AND CITRUS

These useful plants show mean values in growth parameter (rubber tree and citrus) and in production (cupuaçu) slightly advanced in treatment with VAMF than in treatments without VAMF. In the agroforestry systems the performance is better than in monoculture for all species. Cupuaçu shows production statistically significant in agroforestry system.

URUCUM, COCONUT, BRAZIL NUT, AND PARICÁ

These species show no relevant response to the mycorrhization. The treatments without VAMF show the production or growth slightly advanced.

MAHOGANY AND ANDIROBA

These species were planted only in system 4, where the secondary vegetation could regenerate and only the plantation lines were cleaned. The plants were inoculated with VAMF and got 30 % of the recommended fertilizer. Growth was hindered by the concurrence with the 'capoeira' and the high incidence of *Hipsipilla grandella*, a pest which attacks these plants on the apical growing points.

INCIDENCE OF PESTS AND DISEASES

Until now no significant differences of the incidence of diseases and pests between the agroforestry systems and the monocultures plots was found, but in general, the incidence of pests and pathogens was much lower compared to farmland in the region. The use of pesticides in all experimental area has been lower.

DISCUSSION

The obtained results show that under nursery conditions the use of VAMF was favourable for the development of the seedlings and young plants. The VAMF can be used in commercial measure to reduce both, the production time of young plants and the quantity of fertilizer. An other important factor is the greater resistance to stress of mycorrhizal treated plants during the transplantation into the field and, consequently, the lower mortality of plants during the installation in the plantation. However, the colonization level of VAMF in the roots of inoculated and not inoculated plants does not differ one year after the installation of the plants in the field. There are no evident effects of VAMF to further growing and/or production of the plants. The fact that the plants show an significant response under nursery conditions and during the transplantation time proves that an adequate selection of VAMF could renders better results, that is, the selection of native fungi from the forest or from the experimental area, probably, increasing the managerial sustainability of the VAMF in the field (9). The effective use of VAMF on a commercial scale in field conditions depends on biological studies of VAMF populations, the interrelationships between isolated VAMF and their effects on the plant. The use of VAMF in the production of seedling, in nursery conditions, appears to be economically viable.

The results show the fertilization is a major requirement for the type of soil abundant in the experimental site ('clayish yellow latosol'), but they revealed as well a need to carry on optimizing the dose and composition of fertilizer for the useful plant species under controlled conditions. Inoculating the useful plants with mycorrhizal fungi spores can be seen as a partial success, especially in the case of papaya. The results are promising and encouraging for more studies in the field on mycorrhizal research.

The reasons for the fact that there are only few significant differences in growth or yield parameters between the treatment groups, are to be sought in the heterogeneity of the site conditions relatively to the micro climate, the existent topographic gradients, the soil fertility (10) and the existence of an ecological gradient advancing from block A to E (11).

The agroforestry systems for the Amazonia region provide better conditions for the development of useful plants than the monoculture which has been conducted according to common practice. The plantation of annual and perennial cultures permits the use of only on area for several years without cutting new areas, in case of the rubber tree until 25 years. The use of fertilizer and biological agents like VAMF, which can improve the physical and chemical soil conditions, allow the recultivation of cleared and abandoned sites with great economical returns. This reduce the 'slash and burn' agriculture, as practised by the local small holders, the environmental destruction and the rural exodus.

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