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Recultivation of Degraded, Fallow Lying Areas in Central Amazonia with Equilibrated Polycultures: Response of Useful Plants to Inoculation with VA-Mycorrhizal Fungi*

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Summary

Degraded and abandoned fallow areas of primarily monocultural rubber tree plantations are transferred into a locally-adapted form of land use with agro-forestry characteristics. Taking into consideration the importance of soil microbiological factors for tropical perennial useful plants, VA-mycorrhizal fungi were used to meliorate growth and health of the useful plants in the nursery, where the plant material was prepared for planting into the field, and during the installation phase of the project in the field. The effects of the mycorrhizal treatment to the useful plants were estimated in the nursery and after transfer to the field.
Most plant species revealed a positive growth response to the inoculation with mycorrhizal fungi in the nursery. The plants' loss rates were minimized after transfer to the fields. Field in situ inoculations of corn with VAM-fungi resulted in higher yield.
However, leaf diseases of the rubber tree caused by the pathogens *Microcyclus ulei* and *Thanatephorus cucumeris* were not altered significantly following mycorrhizal treatment.

Introduction

The rainforest in the Brasilian Amazon basin is the last and largest primeval tropical forest area of the world. Rapid growth of the local population and rising migration into the central amazone region of Manaus cause a strong pressure to the tropical ecosystem. So far no suitable concepts do exist to protect the rainforest and to give support to the necessities of the local population. The high number of people requires large areas for agricultural and agrosilvicultural production systems, to guarantee the subsistence of the population (Sioli, 1980; Silva and Silva, 1993).

Besides the use of rainforest areas for extractivism, -mainly for subsistence - by the forest farmers (Homma, 1993), a transformation of primary forest into monoculture plantations, especially for rubber and oil palm took place, but most of them failed. Traditional slash and burn treatments provide a basis for agricultural production only for a short time period of three to five years. When the productivity declines the areas are left without further use, because due to the soil character of the region, the non-adapted cultivation modes, the selection of non adapted useful plants, the supporting costs soon become higher than the return (Burger, 1986). These circumstances, and also the instability of the local markets and missing infrastructures for storage and transport of perishable plant products are causal factors for the failure of concepts of use. Without the possibility to store the goods the profit from agriculture is very instable. One or two years of price depression can force people to give up the production systems.

More than 7 % of the rainforest of Amazonia have already been destroyed by short-termed and non-adapted use. These areas now are cultivated with low-profit monocultures or lie fallow since years.
Under social, economical and logistic aspects these fallow lying areas have been optimal sites. A reactivation of the use of these fallow lying agricultural areas by stable, long lasting, profitable production systems instead of burning down new areas of primary rainforest is of high importance for an agricultural management concept in Amazonia.

An approach to an adapted agricultural use of the Amazonian region is to develop mixed cultivation systems of selected, perennial plants adapted to the ecological conditions, combined with short living plants. Such polyculture systems may help to create conditions similar to those existing in the primary plant cover.

In natural sites the function of perennial trees as reservoires for nutrients and the importance of living root mats for recycling of mineral elements in complex tropical ecosystems was clearly proven (Klinge, 1976; Schubart, 1977; Jordan, 1982). The occurrence of abundant mycelial nets of vesicular-arbuscular mycorrhiza (VAM) forming fungi led to the "direct mineral cycling theory" (Went and Stark, 1968). A consequent transfer of these ecologically important findings to practice is necessary, especially for acid soils of dry and humid tropics (Mukerji et al., 1991; Diederichs and Moawad, 1993).

In a first approach to develop sustainable polyculture systems some ecologically adapted plant species have been chosen and are tested in experimental cultures (Feldmann et al., 1995a; Lieberei et al., 1993) for their suitability to install stabilized production systems.

The importance of soil microbes, especially of VA-mycorrhizal fungi (VAMF) as important functional factors in the root mats of polyculture systems has unequivocally been shown by various studies (Feldmann et al., 1989; Diederichs and Moawad, 1993). Soil-microbiological problems arise from the traditional slash and burn procedure: slashing the primary forest and burning the biomass causes severe changes of the soil structure and loss of soil-microorganisms. Most of the areas prepared for cultivation in traditionally ways, are clearly mechanically after burning, and are often treated with pesticides during the cultivation phase (Fassbender, 1990). As a consequence the autochthonous soil microbiol flora is distroyed. In rubber tree monoculture plantations after seven to eleven years of culture the qualitative composition of the population of the soil-microbes still is completely different from the microbial flora found in natural sites of rubber (Feldmann and Lieberei, 1992). The VAMF in such monoculture plantation sites are less efficient in plant growth promotion and the plants became more susceptible to biotic and abiotic stress. By inoculation of plantation sites with mycorrhizal fungi an improvement of the plant development was achieved (Feldmann, 1991).
This indicates, that a recultivation of abandoned areas can be carried out using management practices which include treatments for the biological improvement of soils (Feldmann et al., 1989; Feldmann et al., 1995b). Production of VAM fungi inoculum on a low cost base in tropical countries was developed (Feldmann and Idczak, 1992).

This paper describes the polyculture systems used and reports on the results of the first evaluation of the plants' response to the mycorrhizal inoculation directly before planting into the field and after short growth periods under field conditions.

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Material and Methods

The number of useful plants which were inoculated with mycorrhizal fungi and which are grown on a formerly abandoned area near Manaus (KM 28, AM 010, Manaus-Itacoatiara) is shown in Tab. 1. The useful plants were inoculated with mixtures of several VA-mycorrhizal isolates (Tab. 2). The useful plants were planted in plots of 32 m x 48 m size in four different plant combinations (Tab. 3). These plant combinations were compared with monocultures of the useful plants.

Tab. 1: Number of useful plants inoculated with mycorrhizal fungi in a field near Manaus.
All woody species were precultivated and inoculated with mycorrhizal fungi in nurseries before transfer to the field. The annual plants and *Manihot esculenta* were inoculated directly when transferred to the field or sawn, respectively.

species name	indigenous name	abbreviation	plant number
Bactris gasipaes	Pupunha	P	1157
Bertholletia excelsa	Castanha	B	180
Bixa orellana	Urucum	U	288
Carapa guianensis	Andiroba	A	90
Carica papaya	Mamao	M	1056
Citrus sinensis	Citrus	Z	168
Cocos nucifera	Coco	CP	192
Hevea brasiliensis	Seringueira	S	532
Manihot esculenta	Mandioca		4492
Schizolobium amazonicum	Parica	PC	150
Swietenia macrophylla	Mogno	MG	90
Theobroma grandiflorum	Cupuacu	C	360
Vigna unguiculata	Cowpea		2400
Zea mays	Milho		1200

Tab. 2: VA-mycorrhizal isolates used in the experiments.
The source inoculum was provided from Dr. Weritz, Symbionta, Gifhorn, FRG (Wer1, 2 Weritz, Sym12 Weritz), Prof. Dehne, Bonn, FRG (T6, D13), and Prof. Schenck, International Collection of VA-mycorrhizal fungi, Gainesville, USA (Gletc 329, Glinr 208, Glinr 276). The isolates were kept in biotrophic culture for more than four years before they were applied to mass production.

species name	isolate no.	original isolates
Glomus etunicatum	HH6, HH13 HH329	T6, D13 Dehne Gletc 329 INVAM
Glomus intraradices	HH208, HH276	Glinr 208+276 INVAM
Glomus manihotis	HH1, HH2	Wer1 + 2 Weritz
Acaulospora spec.	HH12	Sym12 Weritz

All useful plants received amounts of fertilizers as recommended for monocultural cultivation by the Federal Brasilian Agricultural Research Institute (EMBRAPA) (treatment called "100 %", Tab. 4 and 5) or 30 % of the recommended dosis (treatment "30 %").

The production and the quality control of the VA-mycorrhizal inoculum was carried out following the method described by Feldmann and Idczak (1992). The mycorrhizal colonization of the roots was analysed after clearing and staining (Philipps and Hayman, 1970) following the method by Giovanetti and Mosse (1980). The MTT-test was carried out according to An et al. (1990) and the MPN-test was modified according to Feldmann and Idczak (1992).

Tab. 3: Layout of the four main planting systems for VAM-inoculated useful plants.
The numbers indicate distances between plants or rows, respectively [m]. The abbreviations for the plant material is given in Tab. 1.

```
System I:    4     2,5    2,5    2,5    2,5    2,5    2,5    2,5m
          ------S------M------P------M------C------M------P------M->
              4m|    3m|    2m|    3m|    6m|    3m|    2m|    3m|
                S      M      P      M      C      M      P      M
          + Pueraria as cover plant

System II:     4      4      4      4      4      4      4      4 m
           -------B------U------C------P------B------U------C------P->
               7m|    4m|    7m|    2m|    7m|    4m|    7m|    2m|
                 C      U      B      P      C      U      B      P
           + Maniok between the rows + Pueraria as cover pl.

System III:    4      5      5      7      6      5      5      7    4m
           -------S------C------CP-----Z------S------C------CP-----Z---
               4m|    7m|    8m|    5m|    4m|    7m|    8m|    5m|
                 S     PC     CP      Z      S     PC     CP      Z
           + Maniok, Corn, Cowpea, + Pueraria as cover plant

System IV:      4        10        10        10        10       4m
           ----------S---------MG---------PC---------A---------S-----
                   4m|       7m|        4m|       7m|       4m|
                     PC        A          S         MG        PC
           + spontanous secondary vegetation between rows
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Tab. 4: Recommended fertilizer doses (100 %-treatment) for the perennial useful plants [g/plant].
The amounts of fertilizer were applied directly during planting or within two months after planting (marked with *). Data for chicken dung are liter/plant.

	lime	P_2O_5	KCl	urea	dung
Bactris gasipaes	200	111	56/56*	37/37*	-
Bertholletia excelsa	500	155	100	65*	-
Bixa orellana	200	67*	16/16*	22*	-
Carapa guianensis	500	155	100	65*	-
Carica papaya	1000	155	50	111	3
Citrus sinensis	1000	155	100	67*	5
Cocos nucifera	1000	230	173	173	-
Hevea brasiliensis	500	155	100	65*	-
Schizolobium amazonicum	500	155	100	-	-
Swietenia macrophylla	500	155	100	65*	-
Theobroma grandiflorum	500	100	30	22*	-

The evaluation of the rubber tree leaf blight followed the method of Chee (1976), target leaf spot was estimated according to Gasparotto et al. (1982).

Tab. 5: Recommended fertilizer doses (100 %-treatment) for the annual useful plants and *Manihot esculenta*.
The amounts of fertilizer were applied directly before sawing (*Zea mays* and *Vigna unguiculata*) or during planting of cuttings (*Manihot esculenta*) or within one month afterwards (*).

	liming up to x % base saturation	P_2O_5 [kg/ha]	K_2O [kg/ha]	Nitrogen [kg/ha]
Manihot esculenta	50	40*	40*	-
Vigna unguiculata	60	60*	30*	20*
Zea mays	60	60*	45*	30*

Results

Mycorrhizal status of the experimental area

The experimental area for recultivation studies was covered by an eight year old fallow vegetation. The dense secondary vegetation in the former monocultural rubber tree plantation contained 312 plant species (PREISINGER et al., 1994). Together with the high number of plant species, a high number of spores of vesicular-arbuscular mycorrhizal fungi occurred on the area (Tab. 6). About one third of these spores were alive, according to MTT-tests. The soil under the secondary vegetation revealed a high inoculum potential, but slashing and burning of the fallow vegetation led to a reduction of the active microbial population of the soil. Still spores of VAM-fungi were found in the treated fields, distributed homogenously over the experimental area, but all spores were dead (determined with the MTT-test; AN et al., 1990). Directly after burning a MPN-test (FELDMANN and IDCZAK, 1992) with five repetitions showed no colonization of the test plants' root system at all. Even six months after burning in an MPN-test with *Zea mays* as test plant no active mycorrhizal fungi were detected. Using a long term bioassay with slow growing parsley (*Petroselinum crispum*) as test plant for viable spores, within four months after inoculation the roots of the parsley plants were colonized by mycorrhizal fungi derived from the soil samples collected in the plantations six months after burning. According to this result six months after burning a mycorrhizal inoculum of low infectivity exists, but it could neither be detected by the MTT-test nor by the standardized MPN-test using *Zea mays*.

Tab. 6: Influence of slashing and burning on the inoculum potential of mycorrhizal fungi in the soil.
Soil samples were taken in the upper soil layer (0 to 10 cm depth). The spores were counted after wet sieving (n=6, means ± SD), the percentage of living spores was analysed using the MTT-test (AN et al., 1990(*), or using a bioassay with *Petroselinum crispum(**)* as test plant. The infectivity was tested in bioassays with *Zea mays*.

	Spores/ cm³ soil	living spores	infectivity (MPN-test)
before burning	13,2 ± 3,0a	27 %	yes
directly after burning	10,8 ± 2,7a	0*	no
six months after burning	5,8 ± 3,3b	yes**	no

The evaluation of components of the secondary vegetation spontaneously growing after burning (PREISINGER et al., 1994) revealed that mycorrhizal fungi obviously survived the burning process together with plant parts (Tab. 7).

Tab. 7: Degree of root colonization by mycorrhizal fungi in plants of the secondary vegetation [%].
Roots were derived from mixed root samples of several plants per growth form type. The plots had been burnt in October 1992. In March 1993 the recultivation process was started by planting VAM-fungi inoculated useful plants. nd = not determined.

	degree of colonization [%]		
growth form	May 1993	March 1994	June 1994
stolon grasses	< 1	9	< 1
tussock grasses	< 1	< 1	6
ferns	< 1	< 1	4
trees	< 1	41	60
creeping herbs	15	nd	56

Reaction of useful plants to inoculation with VAMF

All perennial plant species revealed a positive growth response to mycorrhizal inoculation (Tab. 8). The positive growth response was not correlated with the degree of root colonization. E.g. *Schizolobium amazonicum* revealed a low positive growth response though the roots were heavily colonized by VAM-fungi (61 ± 7 % root colonization), whereas *Carapa guianensis* responded with far better growth though the root colonization after inoculation was only 10 ± 5 %.

Tab. 8: Growth response of nursery grown useful plants after VAM-inoculation.
Most of the perennial plant species used in this project were produced from seeds or stem- or root-cuttings and were inoculated with mycorrhizal fungi during the nursery growth phase, using plastic bag cultures. All plants received 1 to 5 VAM-infection units/cm³ of the not sterilized substrate. In average four months after inoculation the plants were planted into the field (six months after burning of the experimental area).
Cocos nucifera had to be bought from other nurseries and was inoculated only a few days before planting,
Hevea did not form an intensive fine root system in the preparation phase,
* *Carica papaya* had to be produced in a shorter time period and *Manihot esculenta* was planted as cuttings directly into the field.

Plant species	growth response	root colonization M+ [%]	root colonization M- [%]
Schizolobium amazonicum	0,3	61 ± 7	26 ± 1
Bixa orellana	7,0	59 ± 10	31 ± 8
Cocos nucifera	7,0	#	0
Hevea brasiliensis	9,6	##	##
Theobroma grandiflorum	10,0	1 ± 1	0
Bertholletia excelsa	14,7	< 1	0
Bactris gasipaes	15,0	0	0
Carapa guianensis	28,9	10 ± 5	42 ± 17
Swietenia macrophylla	38,4	35 ± 19	8 ± 4
Manihot esculenta *	51,0	52 ± 15	0
Carica papaya *	70,0	48 ± 12	0

For the inoculation procedure unsterile soil of the test area was enriched with the inoculum of defined VAM isolates (Tab. 2). Consequently, a competition of the autochthonous VAM-fungi in the test soil with the introduced fungi takes place.
The introduced VAM fungi in 8 of 10 cases obviously competed successfully with the indigenous fungi, because the degree of root colonization was higher in inoculated treatments than without inoculation. In one case (*Carapa guianensis*) the root colonization was much lower with inoculation of mycorrhizal fungi than without. But even in this symbiosis a positive growth response of 28,9 % height enhancement could be observed.

Losses of useful plants after transfer to the fields

The plant losses during the preparation and establishing phase of a recultivation process can be economically decisive for the success of a recultivation project. Losses can occur during the preparation phase of the plant material in the nurseries. They have to be minimized by using the adequate management practices. Transfer of plants into the field and planting procedures often give rise to additional plant losses.
In order to evaluate the influence of the management factor "mycorrhizal inoculation" after three months of growth the loss rate of the useful plants was calculated (Fig. 1).

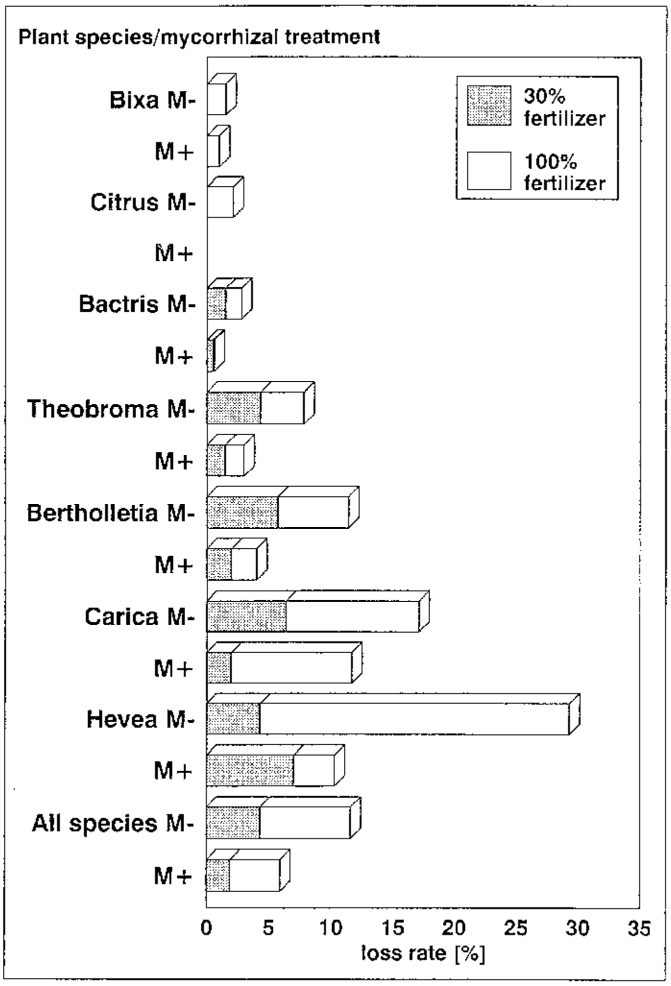

Fig. 1: Plant losses after transfer of plants to the fields

Due to the management practices during the preparation phase and the selection of the plants for planting into the field the loss of most of the plant species in the commonly recommended management treatment were very low. But in some species up to 25 % plants were lost after planting (e.g. *Hevea brasiliensis*).

The comparison of the four treatments with different fertilizer regimes and VAM inoculation (100 % NM, 100 % M, 30 % NM, and 30 % M) reveals that application of only 30 % of the recommended amount of fertilizers without inoculation of mycorrhizal fungi in some cases reduces the number of plants lost (*Hevea brasiliensis*, *Carica papaya*, *Citrus sinensis*), or does not change the number of lost plants (*Bertholletia excelsa*, *Theobroma grandiflorum*).

The introduction of mycorrhizal fungi led to positive results in both fertilizer treatments (*Bertholletia excelsa*, *Theobroma grandiflorum*, *Bactris gasipaes*, *Citrus sinensis*), or in combination with the low fertilizer treatment (*Carica papaya*, *Bixa orellana*). In one case (*Hevea brasiliensis*) the smallest loss rate of all treatments was found in the 100 % fertilizer treatment with introduced mycorrhizal fungi while in the 30 % M treatment the number of lost plants was doubled compared with the 100 % M treatment.

In general the lowest losses of useful plants were obtained with 30 % M treatment (Fig. 1).

Growth responses of *Hevea brasiliensis* and epidemiology of leaf diseases

The loss of *Hevea* plants after transfer to the field was reduced by VAM-treatment. Analysis of the root system before planting revealed that there were almost no fine roots. Even ten months after planting the root systems of the rubber tree were only weakly developed. Nevertheless, a significant influence of the inoculation with VAM-fungi on plant growth could be observed (Tab. 9).

The height of the rubber plants is a very important factor in the management practice of the rubber trees in central Amazonia. Normally in this area the rubber trees have to be budded with *Hevea pauciflora* crowns, resistant to the attack of *Microcyclus ulei*, the causal agent of rubber tree leaf blight, a devastating disease of rubber (Moraes, 1989). Crown budding is carried out, when 70 % of the plants in the field reached the height of 1.90 m. In this experiment the percentage of plants which could be budded succesfully ten months after planting was only reached by the VAM-inoculated plants. The non-inoculated plants remained smaller. Thus, the VAM-inoculated trees could be budded much earlier than the non-inoculated plants. This time factor is of high economic value because young non crown budded rubber trees are threatened by leaf diseases which can cause the death of the plants especially in early stages of the plant development.

The mycorrhizal effect occurred independently of the fertilizer treatment. The most expressed differences between the mycorrhizal and non-mycorrhizal plants was observed comparing plants in polyculture system III (Tab. 3) with rubber trees grown in monoculture (Tab. 9).

Tab. 9: Height of *Hevea brasiliensis* under field conditions after VAM-inoculation [m].
Means of n = 12, groups with the same index letter are not significantly different (Student-Newman-Keuls Test).
/ = treatment was not realized.

treatment	100/M-	100/M+	30/M-	30/M+
system I	1,81ab	2,05ab	1,78ab	1,94ab
system III	1,86ab	2,12a	1,92ab	2,14a
system IV	/	/	/	1,84ab
Monoculture	1,75b	/	/	/

The most serious leaf diseases of rubber trees in central Amazonia are South American leaf blight (SALB) caused by the ascomycete *Microcyclus ulei* (Chee, 1976) and target leaf spot caused by the basidiomycete *Thanatephorus cucumeris* (e.g. Gasparotto et al., 1982). Both diseases occurred directly after the installation of the experimental plantation. The development of the diseases was followed by monitoring the infected leaf areas. First symptoms of diseases were observed 105 days after transfer of plants to the fields. This time coincides with the occurrence of the first new leaf flushes produced in the field after planting. Both pathogens do attack the young leaf stages, whereas mature leaves with more than 20 days of individual age are not any more infected due to a pronounced stage specific resistance of mature rubber tree leaves (Holliday, 1970). The epidemiological pattern of development of the two diseases were different.

Target leaf spot occurred in all plots containing rubber trees, with an average of 30.8 + 19.5 % of leaf area attacked. The disease incidence in the plots is neither correlated with mycorrhiza treatment nor with the localization of the plots to primary or secondary forest or experimental areas planted with rubber. The inoculum of *T. cucumeris* does not seem to be dispersed from a defined focus (Fig. 2).

South American leaf blight is not spread over all experimental plots. It is restricted to 32 of the 50 rubber containing plots (Fig. 3). 18 plots are without any disease symptom of SALB. In seven plots less than 10 % of leaf area is revealing *M. ulei* symptoms, and only in seven plots 30 % or more of the leaf area was destroyed. Plots with severest disease incidence were distributed on the margins of the experimental areas, especially in contact areas to secondary

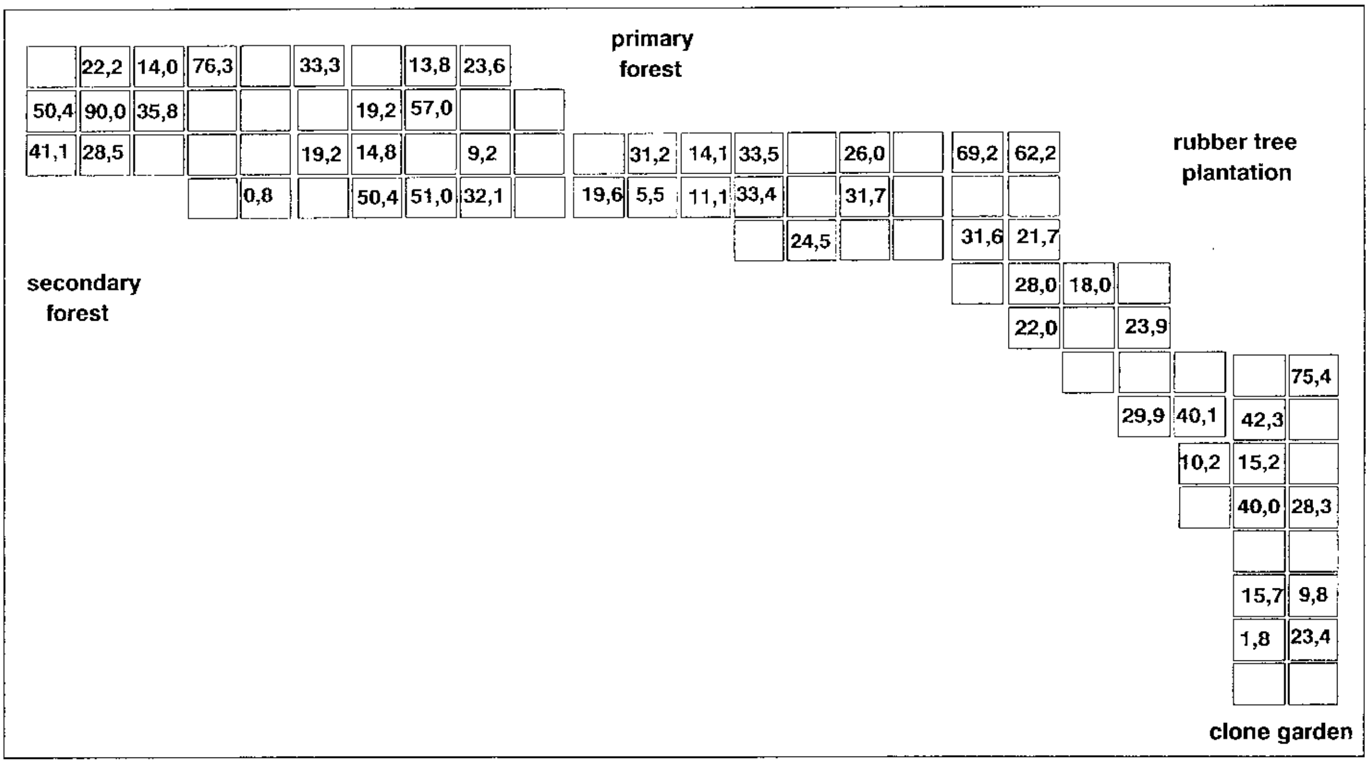

Fig. 2: Area [%] of rubber tree leaves attacked by *Thanatephorus cucumeris*, the causal agent of Target leaf spot of rubber. The experimental plots containing Hevea plants in the blocks A to E (from left to right) were evaluated for *T. cucumeris* symptoms. Each block consists of 18 plots, ten plots per block contain rubber plants in polyculture.

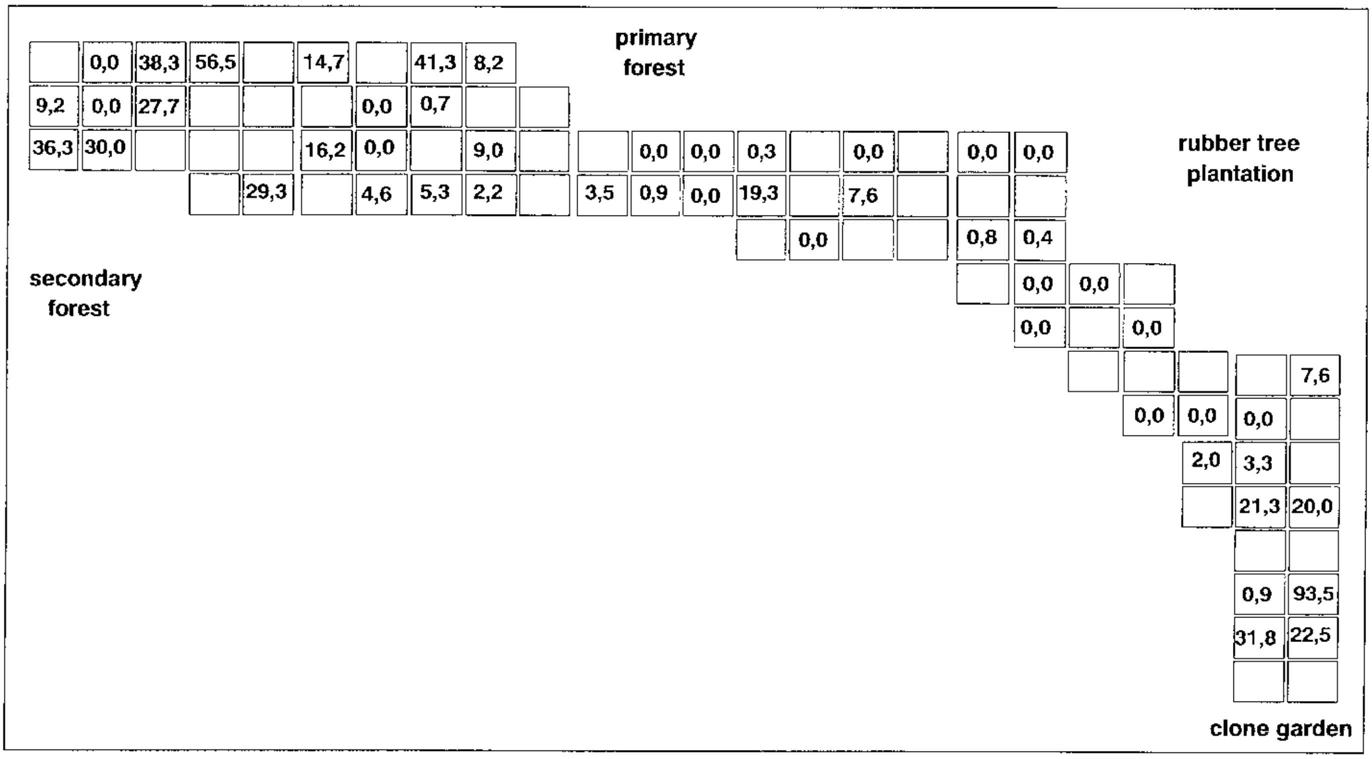

Fig. 3: Area [%] of rubber tree leaves attacked by *Microcyclus ulei*, the causal agent of rubber tree leaf blight. The percentage of leaf areas revealing symptoms of blight were evaluated according to CHEE (1976). Conidia forming lesions as well as stromatic regions were counted. Block definition see Fig. 2.

vegetation (Block A 25,2 ± 17,8 %) or near a rubber tree clone garden (Block E), in contrast to plots in blocks B, C, and D. The distribution pattern is not correlated with special agricultural treatments. It can be assumed that the most important factor leading to the disease incidence of *M. ulei* in the fields is the occurrence of spore producing infected rubber trees very near to the experimental plots.
The plots nearest to the primary forest revealed a low incidence of SALB, suggesting that no effective sources of inoculum were present in these forests. This is in accordance with the fact, that *M. ulei* reveals an extremely narrow host range with only five out of eleven *Hevea* species so far described (Schultes, 1970). No other plant species are infected by *M. ulei*. As long as no Hevea species do occur in the primary forest surrounding the experimental plot, no spore producing focus is present.

Growth and yield of *Carica papaya* under field conditions

Carica papaya is a plant which shows an expressed positive growth response to VAM-inoculation in greenhouses or nurseries (Tab. 8). When these papaya plants are transferred to the fields, the mycorrhizal plants continue to grow better under field conditions and reveal better yield (Müller et al., 1993).
In order to test the effect of VAM inoculation on *C. papaya* plants directly under field conditions a population of test plants was grown in very small pots. By this limitation of root growth papaya seedlings of the same height and physiological developmental stage could be produced which differed only in the factor of presence or absence of VAM-inoculation.

Already a few days after planting the VAM-inoculated plants were higher than the non-inoculated plants (up to 12,5 % of height, Fig. 4). The development of both mycorrhiza/fertilizer treatments was similar, thus apparently not influenced by the fertilizer dose applied. The non-inoculated plants remained smaller than the inoculated plants for more than 80 days after transfer to the fields.
Ten months after transfer of the plants to the field the VAM inoculated plants started to produce fruits. The non-mycorrhizal plants revealed delayed fruit production. The first fruits could be collected thirteen months after transfer to the fields. The fruit production was higher in the VAM-treated plants (Fig. 5).

At the time of transfer of the plants to the fields the roots of non-inoculated plants revealed no root colonization by mycorrhizal fungi

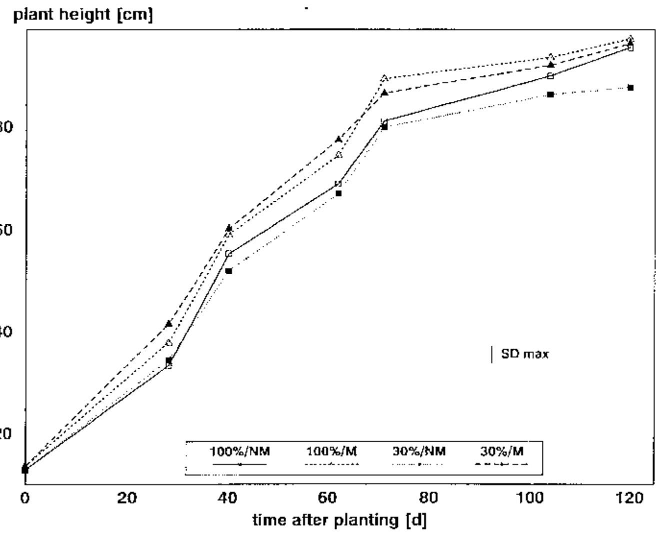

Fig. 4: Growth response of Carica papaya to fertilization and to inoculation with VAM-fungi. Plant height was estimated in groups of n = 18 per treatment.

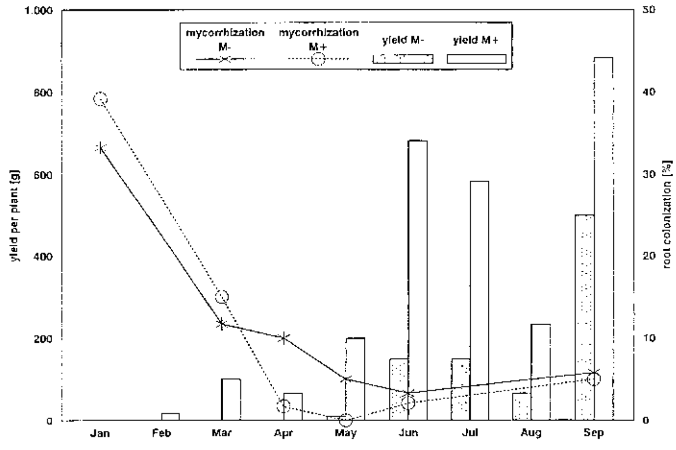

Fig. 5: Fruit yield and root colonization with VAM-fungi of *Carica papaya* plants. The yields are the absolute production data obtained from all five experimental blocks. Root colonization was tested in at least 12 plants per treatment.

compared to 43 % of colonization in the inoculated plants. After ten months of growth in the fields the roots of non-inoculated plants had only slightly lower colonization rates than the inoculated plants. Correlated with the onset of fruit production, the root colonization was reduced to lower than 10 % in both treatments.

Growth response of corn to VAM in field trials

In planting system III (Tab. 3) in the spaces between the rows of the perennial plants *Zea mays* was sawn, combined with 50 to 100 VAM-fungi infection units, bound to expanded clay particles (Feldmann and Idczak, 1992). The inoculum was brought in direct contact to the corn seeds.
The corn was harvested after three months of cultivation (Tab. 10). Efficacy of fertilizer was low, as given by the comparison of the non-VAM inoculated plants (30 %/NM and 100 %/NM): 70 % more fertilizer resulted in only 22 % more yield. When VAM-fungi are introduced together with the low fertilizer dose (30 %/M) the difference to the treatment with the recommended fertilizer dose (100 %/NM) is even smaller: 70 % more fertilizer result in only 12% more yield.
The inoculation of VAM-fungi at recommended fertilizer doses (100 %/M) results in highest production: in average 37 % more yield than in the treatment without mycorrhizal inoculation (100 %/NM) and 59 % more yield compared with the low fertilizer/no inoculation treatment (30 %/NM).
Without introduction of mycorrhizal fungi (100 %/NM and 30 %/NM) the indigenous VAM-fungi colonize the root system of corn up to 23,5 % ± 16,1 %. Yield and degree of root colonization are not correlated (corr = 0,37). Also no correlation between the amount of fertilizer and the root colonization by mycorrhizal fungi could be observed.

Root colonization of VAM inoculated plants (30 %/M and 100 %/M) reveals a percentage of colonization in the 100 %/M treatment which is as high as in the non-inoculated treatments (20,8 % ± 8,7 %), but an increased colonization is obtained in the 30 %/M treatment (54,8 % ± 11,8 %). Surprisingly the quantitatively unchanged degree of colonization in the 100 %/M treatment was accompanied by an increase of yield up to 53 %. This circumstance indicates a qualitative change in the mycorrhizal roots of the 100 %/M treatment, possibly a colonization by the inoculated VAM-fungi or at least an inhibition by competition of the root colonization by ineffective indigenous fungi (compare Feldmann et al., 1993).

The higher degree of root colonization by VAM-fungi in the 30 %/M treatment compared to the 100 %/M treatment indicates that the

Tab. 10: Corn yield and mycorrhizal status of *Zea mays* with and without field inoculation with mycorrhizal fungi under different fertilizer regimes.
Corn plants were sawn between the rows of system III (Tab. 3). The mycorrhizal colonization was tested four weeks before harvest.

treatment		100/M-	100/M+	30/M-	30/M+
Plot A	yield [kg/ha]	661	775	479	460
	yield [%]	100	117	73	70
	colonization [%]	18	3	21	64
Plot B	yield [kg/ha]	435	630	305	436
	yield [%]	100	145	70	100
	colonization [%]	12	27	17	55
Plot C	yield [kg/ha]	538	653	538	548
	yield [%]	100	121	92	102
	colonization [%]	35	6	26	34
Plot D	yield [kg/ha]	557	838	497	358
	yield [%]	100	150	72	64
	colonization [%]	66	63	35	66
Plot E	yield [kg/ha]	315	483	258	320
	yield [%]	100	153	82	102
	colonization [%]	55	35	13	55
Plots A-E	yield [kg/ha]	501	676	388	424
	yield [%]	100	135	77	85
	colonization [%]	25	21	22	55

introduced fungi are negatively influenced by an increase of fertilizer dose (Feldmann and Lieberei, 1992) and it reveals that the effectivity of the symbiosis is not linearly correlated with the degree of colonization by VAM-fungi. The results give rise to the assumption that a competition between indigenous and introduced fungi will be one of the most decisive criteria in the management of a polyculture plant production system as tested here.

Discussion

Degradation of land in the Amazon basin is a consequence of non-adapted land use systems. The degradation of land is defined on different levels. For landscape planning and future land use concepts there exists an urgent need for analysis of progression of degradation. Nepstad et al. (1993) analysed the environmental degradation in relation to land use by extractivism, logging, cattle ranching, and mining and Vieira et al. (1993) defined the levels of degradation as a) agricultural degradation, b) degradation of biodiversity, and c) degradation of ecosystems. Agriculturally degraded areas are characterized by a loss of economic production, loss of species is the characteristic feature of degradation of biodiversity whereas loss of functional traits of biological systems is the indicator for ecosystem degradation. The degradation levels are interdependent and need to be analysed in more detail. More informations on independence of biotic and abiotic ecosystem factors are still lacking. This study focusses on both, the agricultural degradation and the degradation of biodiversity with special emphasis on soil biological factors.

Traditional land use systems use fire for liberation of mineral nutrition factors stored in the perennial biomass. Due to the humidity in plant material and soil and due to physical factors like wind the temperatures during burning may vary from more than 400° C to less than 100° C on the soil surface. There is a steep temperature gradient in the soil. In ten centimeter depth temperature during burning procedures often is less than 60° C and in 30 cm depth soil, temperature is not altered by burning (e.g. Fassbender and Bornemisza, 1986).

For management of polyculture plant production systems using secondary vegetation and soil microbes as factors for agroecosystem management the effect of fire on these components has to be known. An analysis of the spontaneous vegetation after burning has partially been carried out (Preisinger et al., 1994) revealing a high species diversity and different strategies for survival of fire and for colonization of burned areas. The VA-mycorrhizal populations are still under study, but they are strongly impaired as given by the actual results presented here. Though high VAM-spore numbers can be found after burning, no root infections take place and the MTT-tests revealed, that the morphologically intact spores lost their viability.
Therefore the introduction of VAM-fungi into freshly burned areas is considered to be an important management factor. The influence of VAM-spores was positive on the useful plants tested. There was no direct relationship between degree of root colonization and growth response, but this feature is well known from VAM-plant associations. The biotic plant-fungus interaction is dependent on many factors like time of inoculation, physiological status of the host plant, environmental factors etc. (e.g. Sieverding, 1991).

A threshhold level of root colonization, necessary for positive VAM influence on plant growth and plant health exists and has to be evaluated for the plant-fungus combinations used. The time needed for a plant to respond to a symbiont seems to be dependent on the plant species. A very significant short time effect of VAM in annual cultures has been shown in corn. The time course of restoration of the indigenous VAM-populations so far has not been studied. Also is unknown, in how far these populations are acting as positive symbiontic partners with the introduced useful plants. There is a need for the evaluation of stability and effectiveness of autochthonous VAM-fungi before they are used as management factors.

The first results using VAM-fungi in the Amazonian polyculture production system indicate that the introduction of defined fungal symbiont lines during the nursery production of perennial plants have a remarkable economic effect by reducing the production costs, plant losses, and fertilization costs.
In the establishing phase now the question whether an ecological stabilization arises from the polycultural layout of the plantation and which role the secondary vegetation could play in this process has to be answered. In order to avoid nutrient losses, special emphasis has to be given to the development of the root systems. Strong functional root mats with high effectivity in nutrient uptake are needed. Root systems of the useful plants in the polyculture, their competition or their ecological compatibility must be studied as well as their interaction with other factors of the agroecosystem, especially soil microbes and roots of the secondary vegetation.

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Zusammenfassung

Rekultivierung degradierter Bracheflächen Zentralamazoniens mit Mischkulturen: Reaktion der Nutzpflanzen auf Inokulation mit VA-Mykorrhizapilzen

Aufgelassene Bracheflächen ursprünglich als Kautschukbaum-

Monokultur genutzter Flächen in der Nähe von Manaus, Brasilien, werden in einer an die ökologischen und sozioökonomischen Bedingungen des Amazonasgebietes angepaßten Bewirtschaftungsform mit agroforstlichen Charakteristika rekultiviert. Unter Berücksichtigung der Wichtigkeit von bodenmikrobiologischen Faktoren für tropische mehrjährige Nutzpflanzen werden VA-Mykorrhiza-Pilze (VAMF) zur Verbesserung des Pflanzenwachstums und der Pflanzengesundheit eingesetzt. Der Einsatz findet sowohl in Baumschulen als auch direkt im Feld statt.
Nach einer Schilderung des Mykorrhizastatus der Flächen zu Beginn der Rekultivierung werden die wachstumsfördernden Effekte der eingesetzten VAMF auf 12 ein- und mehrjährige Nutzpflanzenarten dargestellt. Detailliert wird die Bedeutung der Wirkung auf das Wachstum am Beispiel des Kautschukbaumes und die Bedeutung für den Fruchtertrag am Beispiel von *Carica papaya* dargestellt. Eine Auswirkung der Inokulation auf die Ausbreitung von Blattkrankheiten des Kautschukbaumes wird diskutiert.

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