Characteristics of Sustainable Polyculture Production Systems on Terra Firme

Lieberei, R.[1], Gasparotto, L.[2], Preisinger, H.[1], Schroth, G.[1] and Reisdorff, C.[1]

[1] Institute of Applied Botany, Ohnhorststr. 18, 22609 Hamburg

[2] CPAA Amazonia Oriental Manaus.

Abstract

The two phases of the recuperation project (ENV 23 and 23/2) so far carried out aimed at the development of sustainable polyculture systems that can be transferred to small holders for economically stable use. Both aims, the selection of useful plant species suitable for combination in production systems and the identification of plants for combination with components of secondary vegetation or with additional management support plants in order to obtain functional ecosystem stability in the sense of HOBBS and MORTON (1999) have been reached. Many dynamic factors concerning recycling of matter and concerning regulation of microclimate have been qualitatively and quantitatively analyzed in collaboration with the projects ENV 42 (investigation on tree species suitable for recultivation of degraded land areas in Central Amazonas), ENV 45 (water and nutrient fluxes as indicators for sustainability), ENV 52 (soil fauna and litter decomposition in primary and secondary forests and in polyculture forestry plantations in Amazonia), which had been invited by ENV 23 and 23/2 to study their respective aspects on the experimental plantation system.

This polyfactorial experimental site had been installed in the first experimental phase (ENV 23) from 1992 to 1995. Over more than eight years the developing planting systems have been qualitatively and quantitatively analyzed with respect to biotic interactions, water and mineral element mobility and specific plant properties. Plant characteristics and polyculture developmental factors with respect to stabilized production and to stabilized microclimate conditions and cycling of matter were collected and form the basis for a rational design of production systems which can be transferred to the small farmers.

In addition the cost-benefit analysis of the polyculture systems reveals that this concept is viable and that it represents an economically acceptable approach for the user.

Keywords

Crop plants, Economics, Gap management, Microclimate, Nutrient recycling, Polyculture systems, Secondary vegetation, Soil biology.

Introduction

The original vegetation of terra firme in Central Amazon is humid tropical rain forest. This vegetation is rich in plant species of many growth form types (KLINGE 1973, PREISINGER et al. 1994) and in contrast to many former statements, it is not homogeneous on a large scale. It consists of many small vegetation units adapted to the highly diversified local geomorphological and climatic conditions. The overall uniformity of this highly heterogeneous vegetation is far more expressed in its functional uniformity and stability than in its species composition. Instead, narrowing the species diversity by cultural measures as carried out in enrichment plantings diminishes functional stability and impairs stabilizing compounds and their interaction.

The inclusion of human beings and their action in the ecosystem leads to new agricultural systems which are spread within the diversity of ecosystem units of the primary vegetation cover. The approach presented here contributes to the development of managed agroecosystems with special regard to stability of both, economic production and ecological service functions. The overall basis for a sustainable, stable and productive vegetation on terra firme sites is the occurrence and maintenance of regulated energy flow and almost "closed" cycles of water flows and mineral element distribution. The highly weathered soils do not provide any stable mineral pool for plant nutrition. In order to compensate this functional deficiency, the native vegetation developed surface near root mats which take up the compounds before they are washed into the ground. Thus the vegetation in itself buffers and regulates the dominating nutritional factors they depend on for survival and development.

When this functionally adapted native vegetation is eradicated and is substituted by crop plants for small farming, any new system will only be sustainable and ecologically comparable to primary vegetation, when it takes over the interactive processes in energy partitioning and resource recycling as known for the primary vegetation cover.

The concept of the projects ENV 23 and ENV 23/2 was to make use of locally accepted crop plants, to study their potential contribution to resource cycling and to assess their behavior and development in polycultures, i.e. to evaluate their potential to interact with other plant species in order to build up artificial systems which mimick the ecological service function with special regard to energy flow and microclimate regulation.

Besides the crop plants included in the agroecosystem, a group of plants with special environmentally important features were selected from the native vegetation. These plants can be used to avoid resource losses from production systems and can contribute to close functional gaps in the agroecological services. In 1988 (LIEBEREI and GASPAROTTO 1998), we summed up the ecophysiologically relevant parameters of some plants in order to use them as components for a rational system design. These parameters have been developed to a more detailed state and have been assessed with respect to functional services.

1 Plant material and plant descriptions

1.1 Autecological parameters

Many properties of plants suitable for agroforestry systems of multicropping system must be known in detail in order to use them for system management. Unfortunately, in most cases the knowledge about these plants and their potential contribution to planting system is still very sparse. This paper will contribute to push forward the development of a descriptor scheme.

The plant-site relationship is mainly governed by growth and development patterns of the plant. Annual plants only shortly form strong input on a given site, whereas perennial plants regularly completely transform their environment by multifold inputs. Thus, the autecological parameters allow to assess the potential ecosystem services provided by a given plant species.

1.2 Growth form and development type

Perennial plants reveal characteristic growth and development processes leading to species specific growth form types, which do not vary considerably within a domesticated species, but, in contrast which can be highly variable in genotype collections from wild stands.

For plantation use a homogenous development of crop plants is essential for economic management. In contrast, with many plant species used in the tropics, so far the material is not domesticated, consequently the variability in developmental processes and in growth types is high. Especially in agroforestry systems often tropical useful plants are used which have not undergone long lasting and detailed breeding and selection processes, but which consist of seedling collections of primary collected material. This is the case for cupuaçu (*Theobroma grandiflorum*) (REISDORFF et al. 1996), brazil nut (*Bertholletia excelsa*), pupunha (*Bactris gasipaes*) and most of the other native plants like *Swietenia macrophylla*, a mahagoni species or the management plant *Vismia guianensis*.

Many of these morphological factors, e.g. plant height, canopy form, canopy density, branching patterns, leaf initiation, stem form, root system, root distribution are of major importance for polyculture design. These factors allow to select plants for regulation of energy partitioning (light, temperature, wind), nutrition uptake, water distribution, and above all, biotic interactions.

1.3 Dynamic processes

Plant growth patterns are varying with plant growth forms but are also strongly varying with genotypes or species. Woody perennial plants pass a typical juvenile morphological phase before reaching the adult growth form type. This concerns not only crown format, but also leaf shedding patterns, root formation and onset of flowering and fruit formation, consequently a host of physiological and regulating components depend on these processes. Plants with an expressed leaf shedding pattern during the dry months (e.g. in July, August, September in the region of Manaus) do not contribute to the maintenance of high humidity in a polyculture system, but on the other hand they lead to higher soil water content because they reduce evaporation by the formation of a litter leaf layer. Furthermore, complete leaf shedding leads to an expressed recycling of minerals stored in these leaves in an external recycling type (SCHMIDT et al.1995) like Ca^{++}-ions.

Defined onset of leaf formation and subsequent flowering and fruit set, again, leads to a rhythmic attraction of pollinators or fruit consumers, etc. Further on, these plants normally are also thought to contribute to the system with rhythmic root growth pattern. These growth rhythms influence the pattern of exsudate liberation from the roots into the rhizosphere (MARINO et al. 2000, MARSCHNER et al. 2002), consequently enhances soil microflora activity.

Leaf material shed to the ground also contributes to local diversity of litter decaying organisms, esp. meso- and microfauna as "shredder"-organisms, followed by fungi, actinomycetes, bacteria. But also root system development will be influenced by the litter layer and the regulation of humidity, temperature and nutritional factors.

This rhythm in development can be managed and used for agroecological systems design.

1.4 Co-evolutionary aspects: competitiveness and allelopathics

Many non-domesticated or pre-domesticated perennial crop plants of the central Amazon have been selected with special regard to aspects related to production and to management like high latex producing rubber tree clones or spineless peach palm genotypes. But there is still a lack with special regard to further quality parameters like disease resistance or the quality of leaf litter as factor in recycling processes. In this context no selection programs have been initiated. Especially in the central Amazon, with respect to closed recycling processes, it is of high importance to look at the plant as integrated components in complex systems and it is necessary to evaluate the compounds relevant for environmental biochemistry. A mature leaf canopy of an adult rubber tree contains, for instance, up to 160 g of cyanogenic compounds which corresponds to five to six kilograms of cyanide per hectare, which potentially are introduced into the environment during leaf shedding and a canopy of Theobroma grandiflorum is equivalent to 300 to 400 g of tannins which can act on soil biota and soil physical structure during and after leaching. Management of these factors is possible by taking up these factors in lists of descriptors and by including them into selection and breeding aims.

1.5 Production related factors

Within the high genetic variability of seedling populations of native undomesticated tropical crop plants, some general features will easily be identified which strongly will influence their suitability for plantation use. Besides positive and or negative product quality parameters many morphological-anatomical aspects and physiological development patterns like time of flowering, fruit set pattern, disease resistance are important for productivity. In perennial plants the annual growth phases, the tree branching patterns and the transition from juvenile to adult stage are factors which can be used for rational plantation design. Further physiological aspects like water use efficiency, mineral element uptake, C- and N-allocation into the plant tissues, should be known for the individual genotypes of the selection, especially when these seedling populations are planned to be the basic material for further selection and propagation. The studies carried out in this context of ENV 23 and ENV 23/2 put a special emphasis on *Theobroma grandiflorum* (GASPAROTTO et al. 1996, REISDORFF et al. 1996, EMMERICH 2002).

1.6 Plant-animal relation

The complete system has been studied with respect to plant-pest interaction (GASPAROTTO et al. 1996, 1998), plant – soil fauna relations (ENV 52, e.g. BECK et al. 1998), to pollinator and seed dispersal activities (GÖCKLER 2000, SKATULLA et al. this volume). Besides a very severe attack of Swietenia macrophylla by Hypsipyla grandella, all other pest indices were low and economically not important.
The soil fauna experiments revealed clearly, that various functional groups can take over the respective functions in different vegetation types. Detailed results are given in this volume by collaborators of ENV 52.

1.7 Plant-plant interaction

The plant combinations in polyculture systems consist of various perennial crops, among them *Bactris gasipaes*, the peach palm, *Bertholletia excelsa*, the Brazil nut tree, *Bixa orellana*, anatto, and *Theobroma grandiflorum*, the cupuaçu tree, together with Pueraria phaseoloides, a legume cover crop (e.g. FELDMANN et al. 1995, REISDORFF et al., this volume). The useful plants develop from their seedling stage after transfer to the fields over a transition state of juvenile plants to a productive phase with adult plants.
The plants grow and interact by root growth, shading, and competition for mineral elements, space, water, and other abiotic and biotic factors. These factors have been studied in detail with respect to root interaction and nutrient uptake kinetics by EMMERICH et al. (2002), by Voss et al. (2000) (root system development), water distribution (SCHROTH et al. 2001) and microclimate (REISDORFF et al. 2002, this volume). Interactions are the ultimate determinants for growth, development and for production.

1.8 Plant-microbe interaction

1.8.1 Bacterial and fungal diseases of the selected crops have been assessed throughout the entire experiment from 1992 to 2000 (e.g. GASPAROTTO et al. 1998). The disease incidence of the major diseases, especially of witches broom of *T. grandiflorum*, caused by *Crinipellis perniciosa* and of target leaf spot of rubber, caused by *Thanatephorus cucumeris*, remains unchanged. There is no indication for any disease reduction in the polycultures. This is most probably due to the restricted size of the systems, which does not allow to observe epidemiologically relevant aspects.

1.8.2 In contrast to these diseases the reaction of seedlings to inoculation with VA mycorrhiza inoculum was positive. The mortality of plants during transfer from the greenhouse to the field plots and early growth were significantly reduced with mycorrhiza inoculated plantlets (FELDMANN et al. 1995). Within these experiments a cultivation device for arbuscular mycorrhiza inoculum propagation based on maize as the propagation host was designed and introduced to the Brazilian counterpart institution by FELDMANN et al. (1998).

1.8.3 MARINO et al. (2000) and MARSCHNER et al. (2002) isolated and characterized more than 400 bacterial isolates from the rhizospheres of *T. grandiflorum* and of *B. gasipaes*. They evaluated the potentials of these microbes for the solubilization of phosphate and they develop ideas for the potential use of these bacteria and of the actinomycete-genus *Gordonia* sp. as biofertilizers for P-nutrition. It seems to be an important approach to study the tripartite systems plant - VA-fungus – *Gordonia* under natural conditions with respect to efficient nutrition use.

2 The experimental polyculture system: an efficient agroforestry plantation

The long term experiment to combine various perennial crops native to Amazonia and to follow its development was a challenge to many specialists. To analyze the system means to follow the development by many scientists and co-workers in an interdisciplinary approach, starting in the slash and burn treatment until reaching the stable production phase.
Within these studies many factors relevant for transfer to practice have been found, characterized in detail, quantified and brought together.

Resource	Management Option	Reference
Water	Water distribution varies with plants Soil hydraulic conductivity is changed by plants Root distribution, deep root pumping	Schroth et al 1999 b Dissertation W. Teixeira, Bayreuth 2001 Emmerich et al. 2000 a
Light	Shade trees, Canopy structure, planting pattern and density Active life span of leaves	Reisdorff 2002, Thesis ms
Mineral elements	Uptake, root competition Avoiding losses by root gap management Internal and external recycling Adjust fertilization time scale to needs	Schmidt et al 1999 Schroth et al 2001 b, c
N-management	Balance between N inorganic and N organic, use of legume plants and management of soil microbes	Schroth et al. 1999, 2001 d Lehmann et al. this vol.
P-management	Mycorrhiza nurse plants Transfer P inorg to P org by continuous litter of Pueraria phaseoloides, lateral nutrition transport through P. phaseoloides, soil microbes for P solubilization	Feldmann et al. 1995 Feldmann 1998 Marino et al. 2000a,b Marschner et al. 2002
Litter management	Combination of leaf qualities with low and with high degradation patterns Analysis of mineral storage in leaves	Schroth et al. 2002 Boehm, thesis in prep. Duenisch et al Schmidt et al. 1999 Uguen et al. this volume
Soil biology management	Select plants with suitable litter quality, combine root systems of tolerant species	Emmerich et al. 2000 a,b Beck et al. 1998
Microclimate management	Fast growing trees, no border effects, stay near to primary forest margin, modify planting patterns	Reisdorff et al this vol.
Biological disease control	Hyperparasites, plant health management by mycorrhiza, manual pruning control	Gasparotto et al 1996, 1998
Economy of production	Selection of high quality plants Value added product in cottage industry	Rodrigues et al. 1998 Reisdorff et al. 1996
Regeneration processes	Suitable plants for seed dispersal fauna Pollinator attractants Maintain soil seedbanks	Preisinger et al 1994 Skatulla et al. 2000

Table 1: Resource management and options for influencing polyculture development

Parameters for almost all levels of management are known now and need to be transferred to practice. Hopefully this transfer can be carried out in a follow up approach. In Tab. 1 some of the potential approaches are summarized. A detailed management manual can be developed using these data.

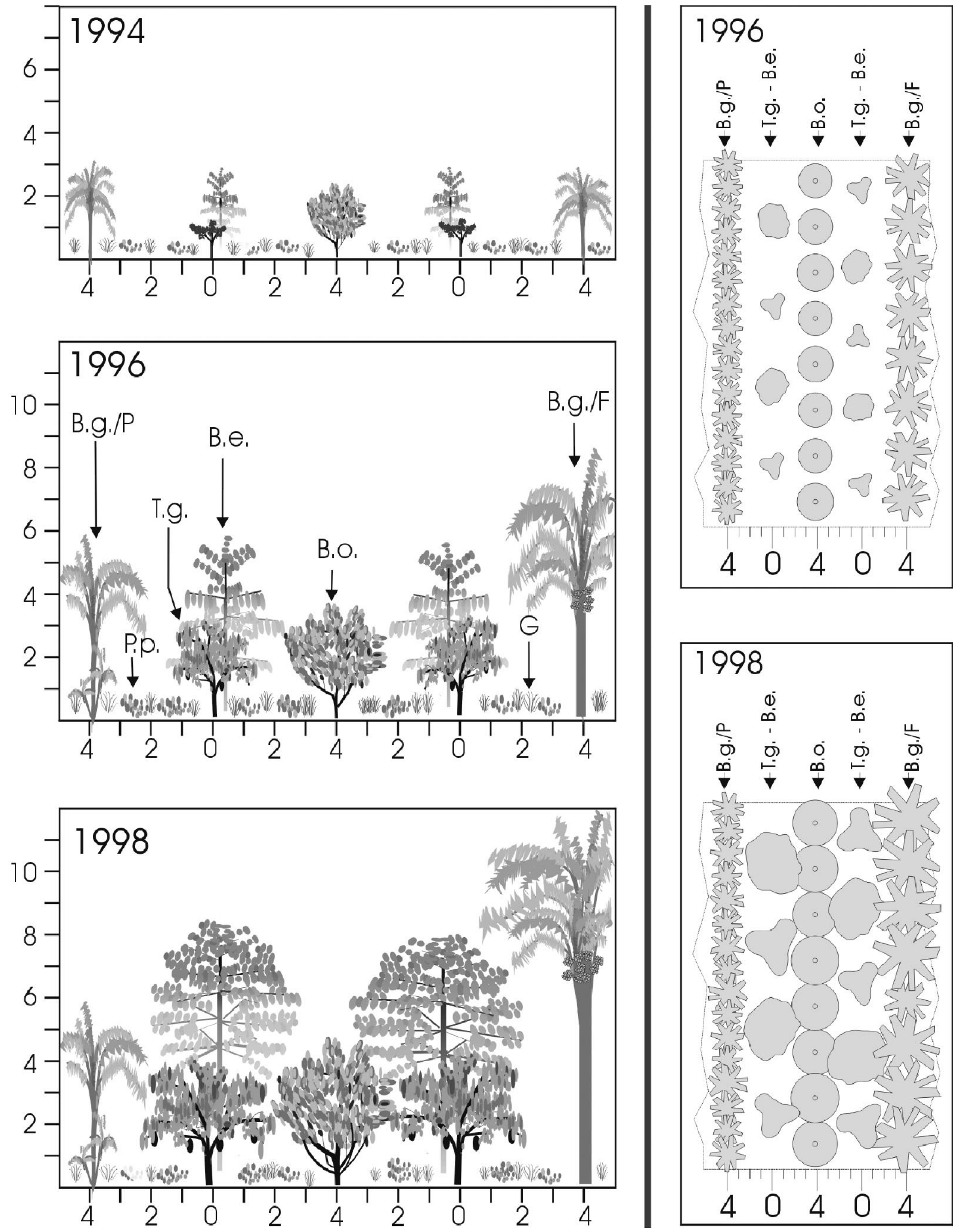

Fig. 1: Development of a given polyculture system in time and space

B.g./P: *Bactris gasipaes* for palmito production
B.g./F: *Bactris gasipaes* for fruit production
Pp.: *Pueraria phaseoloides*
G.: grasses
B.o.: *Bixa orellana*
B.e.: *Bertholletia excelsa*
T.g.: *Theobroma grandiflorum*

3 Conclusions

The natural system allows to apply various management measures simply by using the right plants which perform the necessary environmental service functions in the desired spatial and seasonal patterns. These functions allow also to minimize losses of fertilizer input and to optimize the distribution of natural resources. In order to install suitable economically stable and ecologically acceptable polyculture combinations, more detailed features about crop plants and management plants native to the areas under study have to be worked out. These components will be the tools for environmentally friendly and cost efficient management.

4 Acknowledgements

The research project was carried out under the auspices of the agreement on scientific-technological cooperation of the governments of Germany and Brazil. The Brazilian partner (CPAA Manaus, EMBRAPA) was sponsored by the Council for Scientific and Technological Development (CNPq Project 08.0.94.010). The German partner (University of Hamburg) was sponsored by the Federal Ministry of Education and Research (BMBF) through the DLR project management group (Förderkennzahl 01 LT 0009).

5 References

Beck., L., Höfer, H., Martius, C., Garcia, M.B., Franklin, E., Römbke, J. (1998) Soil Fauna and Litter Decomposition in Primary and Secondary Forests and a Polyculture System in Amazonia – Study, Design and Methodology. Proceedings of the Third SHIFT Workshop Manaus 1998, 463-469.

Emmerich, S., Lösch, R., Lieberei, R. (2000) Root Responses of four Tropical Useful Trees to Localized Soil Enrichment. In: GERMAN-BRAZILIAN WORKSHOP ON NEOTROPICAL ECOSYSTEMS. Hamburg, 2000. Program and Abstracts. Hamburg: University of Hamburg. p. 31.

Emmerich, S., Lösch, R., Lieberei, R. (2000) Mineral Uptake by Roots of four Tropical Useful Trees. In: GERMAN-BRAZILIAN WORKSHOP ON NEOTROPICAL ECOSYSTEMS. Hamburg, 2000. Program and Abstracts. Hamburg: University of Hamburg. p. 168.

Feldmann, F., Idzak, E., Martins, G., Nunes, J., Gasparotto, L., Preisinger, H., Moraes, V.H.F., Lieberei, R. (1995) Recultivation of Degraded, Fallow Lying Areas in Central Amazonia with Equilibrated Polycultures: Responses of Useful Plants to Inoculation with VA-Mycorrhizal Fungi. J.Appl.Bot. 69, 111-118.

Feldmann, F. (1998) Application and management of vesicular-arbuscular mycorrhizal fungi in the initial phase of recultivation of a degraded area. In: Denich, M.; Kanashiro, M. (Ed.) Potential land-use and management of altered and abandoned areas in the Brazilian Amazon Region. Studies on Human Impact on Forest and Floodplain in the Topics – SHIFT. Braslia: MCT/CNPq. 128-129.

Gasparotto, L.; Araújo, R. da C.; Silva, S.E.L. da (1996) Cupuaçu em sistemas agroflorestais - Programa SHIFT. In: SEMINÁRIO INTERNACIONAL SOBRE PIMENTA-DO-REINO E CUPUAÇU, 1., Belém, 1996. Resumo. Belém : Embrapa/JICA, 1996. p.26.

Gasparotto, L; Pamplona, A.M.S.R., Lima, M.I.P.M. (1998) The incidence of plant diseases and pests. In: Denich, M.; Kanashiro, M. (Ed.) Potential land-use and management of altered and abandoned areas in the Brazilian Amazon Region. Studies on Human Impact on Forest and Floodplains in the Topics – SHIFT. Brasília: MCT/CNPq. 125-127.

Göckler, K (2000) Fruit and seed Predation and dispersal by Small Mammals in Different Biotope Types in Central Amazonia. In: GERMAN-BRAZILIAN WORKSHOP ON NEOTROPICAL ECOSYSTEMS. Hamburg. Program and Abstracts. Hamburg: University of Hamburg. 2000. p. 120.

Hobbs, R. J., Morton, S. R. (1999) Moving from Descriptive to Predictive Ecology. Agroforestry Systems 45: 43-55

Klinge, H. (1973) Struktur und Artenreichtum des zentralamazonischen Regenwaldes. Amazoniana 4, 283-292.

Lieberei, R., Gasparotto, L. (1998) Agroecologcal Profile of Plants used as Production Factors and as Management Components in Tropical Polyculture Systems. Proceedings of the Third SHIFT Workshop Manaus, 307-312.

Lieberei, R., Gasparotto, L., Preisinger, H., Schroth, G. (2000) Characteristics of sustainable polyculture production systems on terra firme. In: GERMAN-BRAZILIAN WORKSHOP ON NEOTROPICAL ECOSYSTEMS. Hamburg. Program and Abstracts. Hamburg: University of Hamburg. 2000. p. 96.

Marino, W., Marschner, P., Gasparotto, L. (2000) Phosphate Solubilizing Bacteria from the Rhizosphere of Theobroma grandiflorum (Willd, ex Spreng.) Schum. And Bactris gasipaes H.B.K.: Potential for Plant Growth Promotion. In: GERMAN-BRAZILIAN WORKSHOP ON NEOTROPICAL ECOSYSTEMS. Hamburg, 2000. Program and Abstracts. Hamburg: University of Hamburg. 2000. p. 101.

Marino, W., Marschner, P., Lieberei, R. (2000) Mikrobielle Biomasse und funktionelle Diversität von Mikroorganismen in der Rhizosphäre tropischer Nutzpflanzen Zentralamazoniens. In: Rhizodeposition und Stoffverwertung 10. Borkheider Seminar zur Ökophysiologie des Wurzelraumes. Hrsg: Merbach W, Wittenmayer L, Augustin J, Teubner Verlagsges. Stuttgart, 93-97

Marschner, P., Marino, W., Lieberei, R. (2000) Seasonal effect of microorganisms in the rhizosphere of two tropical plants in a polyculture agroforestry system in Central Amazonia, Brazil. Biol. Fertil. Soils (in press)

Preisinger, H., Coêlho, L.F., Siqueira, M. de G., Lieberei, R.(1994) Analysis of Growth Form Types and Floristic Composition of the Spontaneous Vegetation in an Agricultural Test Area near Manaus, Amazonas, Brasil. J.Appl.Bot. 68, 40-46.

Reisdorff, C., Lieberei, R., Souza, A.G.C. (1996) Studies on the Variability of Cupuaçu Plants (*Theobroma grandiflorum* (Wild. ex Spreng.) Schum.) Growing in Different Cultivation Systems on a Degraded Area: State of Development and Productivity of 3 _ Years old Trees. In: CONFERENCE ON FRUIT PRODUCTION IN THE TROPICS AND SUBTROPICS, 1., Proceedings. Berlin. 68-77.

Rodrigues, F.M., Moraes, C.R.A., Gasparotto, L. (1988) Cost/benefit analysis of Agroforestry Systems: a Case Study. Proceedings of the Third SHIFT Workshop Manaus, 373-388.

Schmidt, P., Lieberei, R., Bauch, J., Gasparotto, L. (1999) Biomass Production and Mineral Element Content of Swietenia macrophylla King in the Juvenile Phase under Plantation Conditions in Central Amazonia. Mitteilungen der Bundesforschungsanstalt für Forst- und Holzwirtschaft Hamburg 193, 61-70.

Schroth, G., Silva, L.F., da, Seixas, R., Teixeira, W.G., Macêdo, J.L.V., Zech, W. (1999) Subsoil Accumulation of Mineral Nitrogen under Polyculture and Monoculture Plantations, Fallow and Primary

Forest in a Ferrolitic Amazonian Upland Soil. Agriculture, Ecosystems and Environment. 75: 109-120.

Schroth, G., Silva, L.F., da, Wolf, M.A., Teixeira, W.G., Macêdo, J.L.V., Zech, W. (1999) Distribution of Throughfall and Stemflow in Multi-strata Agroforestry, Perennial Monoculture, Fallow and Primary Forest in Central Amazonia, Brazil. Hydrology Processes. 13: 1423-1436.

Schroth, G., Lehmann, J., Rodrigues, M.R.L., Barros, E., Macedo, J.L.V. (2001) Plant-Soil Interactions in Multistrata Agroforestry in the Humid Tropics. Agroforestry Systems, v. 53, p 85-102.

Schroth, G., Elias, M.E.A., Uguen, K,, Zech,W. (2001) Nutrient Fluxes in Rainfall, Throughfall and Stemflow in Tree-based Land Use Systems and Spontaneous Tree Vegetation of Central Amazônia. Agriculture, Ecosystems and Environment, 37-49. 2001.

Schroth, G., Elias, M.E.A., Uguen, K,, Zech,W. (2001) Nutrient Fluxes in Rainfall, Throughfall and Stemflow in Tree-based Land Use Systems and Spontaneous Tree Vegetation of Central Amazônia. Agriculture, Ecosystems and Environment, 37-49. 2001.

Schroth, G., Elias, M.E.A., Macedo, J.L.V., d'Angelo, S.A., Lieberei, R. (2001) Growth, Yields and Mineral Nutrition of Cupuacu (Theobroma grandiflorum) in two Multi-strata Agroforestry Systems on a Ferralitic Amazonian Upland Soil at four Fertilization Levels. Journal of Applied Botany, 67-74.

Schroth, G., Salazar, E., Silva, J.P. (2001) Soil Nitrogen Mineralization under Tree Crops and a Legume Cover Crop in Multi-strata Agroforestry in Central Amazonia: Spatial and Temporal Patterns. Experimental Agriculture, 253-267.

Schroth, G., d'Angelo, S.A., Teixeira, W.G., Haag, D., Lieberei, R. (2002) Conversion of Secondary Forest into Agroforestry and Monoculture Plantations in Amazonia: Consequences for Biomass, Litter and Soil Carbon Stocks after Seven Years. Forest Ecology and Management, (in press).

Skatulla, M., Coélho, L.F., Gottsberger, G., Lieberei, R., Preisinger, H. (2000) Structural Traits and Regeneration Mechanisms in three Succesional Stages of Terra-Firme-Forest in the Central Amazon. In: GERMAN-BRAZILIAN WORKSHOP ON NEOTROPICAL ECOSYSTEMS. Hamburg, 2000. Program and Abstracts. Hamburg: University of Hamburg. p. 112.

Uguen, K., Bernhard-Reversat, F., Luizâo, F., Silva, J.P., Schroth, G. (2002) Nutrient Fluxes from Litter and Prunings in an Agroforestry System in Central Amazon. This volume.