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Sustainable land use systems in Central Amazon rain forests

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COLONIZATION AND DEFORESTATION

The Amazon rain forest is of high importance for conservation of biological diversity and genetic resources. It is an essential factor for regulation of global climate and it is under a tremendous pressure to be transferred into agricultural production systems in order to cover the national needs.

Rapid growth of the local population and accelerated migration of thousands of families of small farmers from the dry Northeast, the South and Southeast to the Amazon cause changes in the primary forest ecosystems. The emergence of agriculture has drastic environmental and social consequences [1]. The colonization leads to a severe loss of species diversity of primary vegetation on the one hand and to the introduction and propagation of useful plant species on the other hand. Immigrants occupy land for agriculture and compete with indigenous people, with hunters and extractivists, e.g. rubber tapper communities. The need of land use planning and the development of land use concepts in order to avoid political and social conflicts is obvious [2,3].

Former concepts for colonization of the Amazon basin were based on plantations of major cash crop plants: rubber trees, oil palm or cocoa. All these projects were very ambitious, but all of them failed due to phytopathological constraints [e.g. 4] and/or edaphoclimatic restrictions [5]. In the course of transformation of highly diverse and complex rain forest vegetations into monocultures the regulatory functions of the primary vegetation were destroyed. Instable land use systems resulted from these activities. Rapid degradation of floral and faunistic diversity, loss of soil fertility, changes in physical and chemical soil characters and soil losses by erosion were consequences of these colonization activities.

Meanwhile new approaches for better land use systems are in progress. Governmental research institutions work out strategies for sustainable development and small farmers are exploring various plant combinations on their own initiative. This empirical way of action of direct users is an important step for the development of stable and accepted production systems [6].

General development concepts for sustainable use of the Amazon basin need approaches which are based on detailed knowledge of the biotic and abiotic peculiarities of the region. Further on the concepts must provide means to make use of the high amount of more than 40 million hectares of forest which have already been cleared for various purposes [7]. In 1996 Prance [8] stated, that deforestation can only be halted, if areas that have already been deforested provide a long term sustainable living for the people of the region. Over 50% of deforestation was for extensive grazing and cattle production, about 30 to 35 % for shifting cultivation, and about 10 % for logging and mining [9].

More than 75% of the Amazon basin soils are oxisols and ultisols, which reveal a lot of chemical constraints to plant production: low exchangeable base contents, very low nutrient reserves, low soil organic matter, high aluminum toxicity, low phosphorous availability and low pH values [10]. Climatic conditions are governed by intensive so-

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radiation, high rainfall between 1400 and 3500 mm per year and high evapotranspiration between 1350 and 1650 mm per year [11].

Development of agroforestry systems

For the development of agricultural systems for sustainable use of the Amazon the factors which stabilize the naturally occurring primary vegetation have to be understood and have to be transferred into anthropogenic land use concepts.

Important steps in this development were

1. the description of the root mat system, which is formed by the primary vegetation and which forms a root layer on top of the mineral soil [12],
2. the direct mineral cycling theory [13],
3. the analysis of nutrient balance which revealed that more than 70 % of the mineral elements are stored in the living biomass [14, 15],
4. the analysis of the importance of soil microbes, especially arbuscular mycorrhiza [12], N_2-fixing (e.g. [16]) and phosphate solubilizing bacteria,
5. the critical evaluation of soil quality and climatic frame conditions [e.g.11].

Based on these informations a consequent transfer of these ecologically important factors to practice was initiated [17].

Actually, a large number of agroforestry configurations are being developed by small farmers. They are tested in home gardens, but transfer of these plant combinations to larger systems has not been done [18]. In a survey carried out in the years 1988 to 1994 Smith et al. [19] found 85 plant species used in various combinations in 142 polycultural fields in upland areas of the Brazilian Amazon. The combinations were extremely heterogenous, only 15 species were planted in 10 or more polyculture combinations, whereas 39 species were only used in one combination.

Plant resources

Tropical rain forests all over the world support a vast biological array of living organisms. High species diversity is a characteristic of these forest ecosystems. In a 1 ha plot of primary forest on the terra firme near Manaus, Brazil, Preisinger et al. [20] identified 465 plant species, in another plot near Manaus, Klinge [21] found 502 higher plant species. Related to the species diversity is a low species density. Often not more than two or three individuals of the same species are present per ha [22].

Within this diverse vegetation, the amazonian rain forest provides a great potential for exploitation. Prance [8] lists more than 60 Amazonia plant species which are marketed and which have a developmental potential. Besides these plant species with commercial potential, a lot of plants await further domestication for their use as agriculturally important 'helper plants' in polyculture systems. Clement [23] pointed out, that there is an urgent need for a detailed analysis of the genetic diversity centre in western Amazonia and stated 'The region is an unrecognized but important centre of plant domestication'.

Polyculture systems

Plant associations which allow nutrient cycling and plant – environment interactions in the same way as they are typical in primary rain forests will be long lasting and sustainable. This hypothesis is a general basis for agroforestry research. In order to understand regulatory factors of agroforestry systems and to be able to develop rational strategies for locally adapted polyculture systems, an interdisciplinar experimental approach was started.

In 1992 an experimental polyculture experiment was initiated on a 19 ha fallow area north of Manaus in order to study and quantify interactions between biotic and abiotic compartments. The experimental area was prepared in the traditional way by slashing and burning. Selected perennial plants adapted to the ecological conditions were combined with short living plants [24]. All useful plants were fertilized as recommended by the EMBRAPA (Federal Brazilian Agricultural Research Institute) and in reduced amounts (30% of recommended amount).

The development of the complex polyculture plant system on slash and burn areas was formally divided into three phases. The changes of the experimental systems in space and time were studied on the levels of water and nutrient dynamics, soil biology, plant-microbe interaction, plant competition and vegetation science, agricultural aspects, phytopathology and productivity, forestry aspects and socio-economic aspects.

The developmental phases of the systems were defined as

I. Initial phase, characterised by the establishment of the plant cover

In this phase highest priority is given to plant uptake of nutrients, which have been liberated from the former biomass by slashing and burning. Generally more than one third of the minerals stored in living biomass is volatilized in the course of burning [18] and further losses occur by rainfall run off, soil erosion, nutrient transfer to subsoil, volatilization. In the initial phase of the polyculture system the nutrient recycling root mats must be developed and the soil microbes and soil fauna must regenerate. Plants suitable for this phase must be tolerant to direct solar radiation, strong changes in soil surface temperature, and short local droughts. Furthermore these plants must produce high amounts of living biomass in short time, in order to accumulate and store the mineral elements. It is recommended to chose fast growing plants which produce a high amount of leaves. Thus a good quality mulch can be obtained for slower growing plants of the following system transition phase, provided the leaves do not contain allelopathically active substances and can easily be degraded and recycled. Considering plant health, it is important to avoid, that the helper plants act as host plants for pathogens and predators of the crop plants of the polyculture system.

Helper plants should be facutatively mycorrhizotrophic. After slash and burn treatment the infection potential of the topsoil is very low. Even six months after slash and burn no living spores of arbuscular mycorrhizal fungi were found in the topsoil of our polyculture system, the recolonization by mycorrhizal fungi of the experimental area was not initiated from spores, but obviously from mycorrhiza-infected plant diaspores like roots of *Vismia guianensis* [25].

The titer of legume nodulating bacteria is also very low after slash and burn treatment. Ten months after slash and burn topsoil samples (upper ten cm) of 31 plots were collected and used for inoculation of the soil cover legume *Pueraria phaseoloides*. Seven seeds per pot were used, incubation was carried out under ambient conditions in a greenhouse. Only samples from 21 plots induced nodules in the root systems, with a mean of 0.98 nodules per root system. The maximal number of nodules per root system was 8. Germination of test plants was impaired by soilborne factors in 24 out of 31 samples, but soil samples of primary forests and of fallow areas exhibited an expressed germination inhibition potential.

For future routine methods in agroforestry a management of soil microbes must be developed. The first results using inoculation with arbuscular mycorrhiza in Amazon polyculture systems indicate, that the introduction of these symbionts reduces the plant losses in the transfer phase of plants from the nursery to the fields. A simple production method for arbuscular mycorrhiza which can be used on farm is described [26].

II. Transition phase

Short living plants deliver first crops, e.g. *Carica papaya*, nutrient losses due to harvested products must be calculated and losses must be compensated by fertilizer or manure. Plant material shall be recycled into the system whenever possible. Fruit shells of *Theobroma grandiflorum*, Cupuaçu, contain high amounts of minerals. Calculating with an average production of 12 fruits per 4 years old trees, an amount of 28 g of potassium, 1.1 g of calcium, 2.0 g of magnesium and 1.2 g of phosphorous are exported with the fruit shell mass, which comprises 1.73 kg of dried biomass per harvest.

After harvest of short living crops like corn, beans, cassava, new crop plants can be introduced into the system. Unfortunately so far no detailed knowledge is available about the root systems of the useful plants. For strategic planning on root system – soil interaction and for root managements measures intensive research activities on root development and root interactions are necessary. This holds also true for plant-microbe interaction for both, fixing microbes (symbionts and plant associated, living bacteria [16], and phosphate solubilising bacteria and fungi [27].

New plants which are introduced in the transition phase have to be selected due to their competitiveness with already exisiting crops and with regard to their shade needs. Fast growing crops of the initial phase like the peach palm (*Bactris gasipaes*) are suitable this purpose, but they develop a very rigid root system, which can cause mechanical and physiological competition.

III Sustainable production phase

For sustainable production fertilizer doses have to be applied to compensate the harvest losses of the system. A major task for polyculture system management is to develop fertilizer recommendations adapted to various plant combinations. Nutrient and water balances need to be studied in detail and root management systems need to be worked out. Roots are key factors in nutrient and water recycling, but they are also essential factors for amelioration of soil organic matter, for maintaining an active interaction of plants with soil organisms and for stabilizing soil physical parameters. Schroth [26] developed a strategic approach for root management with special emphasis on the management of tree root systems and their function in nutrient and water recycling from subsoil compartments.

Legumes

Nitrogen fixing legumes are expected to enrich soil with organic matter e.g. [29] and are regarded to be positive management factors, but in nutrient limited marginal soils legumes can also compete with useful plants for site specific minimum nutrition factors. In these cases legumes do not promote polycultures but lead to retarded development of other system compounds. Field observations in our polyculture systems give evidence for competitive effects between *Pueraria phaseoloides* and other useful plants. *P. phaseoloides* reacts positively to fertilization of useful plants in our experimental plots.

An evaluation of a plant as a management factor is polyfactorial: *P. phaseoloides* is a positive factor with regard to nitrogen-enrichment. It may be negative with respect to nutrient competition with crop plants. Other management factors have also to be considered: the growth form of *P. phaseoloides* as a winding liana results in a stable living soil cover, about 50 cm high. This cover produces continuously leaf litter and provides decaying organic material to the soil fauna. A good developed fine root system prevents nutrient losses by surface run off and by erosion. Competing plants of the spontaneous vegetation e.g. the tussock grass *Homolepis aturiensis* are suppressed by *P. phaseoloides*. The closed vegetation layer of *P. phaseoloides* reduces daily changes of topsoil temperature and thus buffers the influence of ambient factors on root systems of useful plants. Another important ecological factor under management aspects is the lateral growth of P. phaseoloides. This growth habit allows to distribute biomass and nutrient factors through litter production within the polyculture system.

Disadvantages for the use of *P. phaseoloides* arise from the fact, that this helper plant cannot be combined with other crop legumes like *Vigna sinensis* or *Phaseolus sp.*, because some pests of P. phaseoloides strongly attack these crop plants.

CONCLUSIONS

Polyculture systems are of major importance for agriculture in moist tropical areas. The plants available for these associations are numerous and have to be evaluated under various aspects besides productivity. The systems can be divided in three developmental phases. Most of the plants so far are not fully domesticated and have to be studied in detail. Ecological parameters as well as productivity parameters of the system need to be studied in a quantitative manner. Nutrient balances and energy and water flow in the system are sensitive levels for management.

The socio-economic sector requires intensive research input for the development of value added agricultural products by small industries. Plant products of new useful plants like cupuacu pulp, guaraná seed powder, palm heart from peach palm, oils and resins from trees etc. are available in high amounts.

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