SECTION 1 – AGROFORESTRY SYSTEMS DESIGNED TO RESTORE DEGRADED AREAS TO PRODUCTIVE LAND USE SYSTEMS FOR RURAL PEOPLE

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Chapter 1

IMITATING NATURAL ECOSYSTEMS THROUGH SUCCESSIONAL AGROFORESTRY FOR THE REGENERATION OF DEGRADED LANDS - A CASE STUDY OF SMALLHOLDER AGRICULTURE IN NORTHEASTERN BRAZIL

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ABSTRACT

Agroforestry techniques to restore degraded lands and environmental functions and services are an important issue for achieving sustainable land use and improving rural livelihoods. Agroforestry systems basically differ in diversity and complexity. The following chapter investigates an approach that aims to imitate the structure and function of the local ecosystems through the use of successional agroforestry systems to restore degraded lands and provide subsistence to smallholder farmers.

The conversion of the natural vegetation cover to pastures and farmlands on more than half of the northeastern region of Brazil has led to serious soil degradation and furthermore to the desertification of about

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181,000 km² in the semiarid part of the region. About 88% of the population are smallholder farmers, and are directly dependent on the conservation of soils and the efficient use of water. This case study compared two climatic regions within the Northeast, where smallholders applied the successional agroforestry method. This cultivation system imitates and actively accelerates natural succession by planting locally adapted edible plants with similar functional characteristics as plants of the same successional level of the local ecosystem. In the first successional step the main goal is the augmentation of organic material, enabling the integration of plants of a higher successional level in the next step. With increasing development of the successional system, a higher diversity of plants with different functional and structural characteristics leads to shorter nutrient and water cycles. With this method, highly degraded areas have been regenerated, leading to an approximately four-fold increase of agricultural production compared to the annual cropping systems formerly practiced, and at the same time reducing the risk of drought-related harvest loss due to crop diversification and use of perennial plants.

INTRODUCTION

Convertion to agricultural land use is the most important factor leading to the loss of natural ecosystems and their environmental services (Millennium Ecosystem Assessment; Wood et al. 2001). According to Glover (2003), large-scale conversions of natural ecosystems to annual cropping systems have profound effects both at the local and at the landscape level. In comparison to perennial plants found in natural ecosystems, agriculture based on annual crops inefficiently utilizes water and nutrients, resulting in degradation of soil and water quality (Glover 2003). Worldwide, around 9% of agricultural land is estimated to be so severely degraded that it has become unproductive (Wood et al. 2001). Although the total area under agricultural production has remained relatively stable since the 1970s (Wood et al. 2001), this stability hides the phenomenon of the annual loss of an estimated 5 – 6 million hectares of agricultural areas due to soil degradation (UNEP 1997), while agricultural expansion is estimated to be around 3.8 – 5 million hectares/year (Bruinsma 2003). This means that forest ecosystems have been converted to agricultural land not only because of increased demands since the 1970s, but also to compensate for areas that have been lost due to severe soil degradation. Furthermore, increases in the agricultural sector will be unavoidable due to an expected population growth from 6.5 billion people in 2004 to 9 billion in

2050 (UN Population Division, 2004, medium estimate). Expansion of agricultural production is expected to stem mainly from agricultural intensification, as well as from further conversions of natural ecosystems mainly by smallholder farmers (Bruinsma 2003).

Next to agro-industrial production, smallholder farmers play a significant role in the degradation of soils as well (Scherr 1999). At the same time, smallholders are directly dependent on the conservation of soil fertility (Scherr 1999). In Latin America, smallholder farmers, particularly those on marginal lands, are frequently unable to compete with large-scale agriculture (Grau and Aide 2008), and often do not have sufficient knowledge, security in land tenure, or the necessary financial means to apply soil protection measures. Therefore they contribute to a downward spiral of overuse, degradation and abandonment leading to further conversions of natural ecosystems, with the respective loss of environmental functions and services. Smallholder farmers are therefore an important group of actors that need to be considered in strategies concerning sustainable land use and the restoration of degraded lands.

As the reconversion of all agricultural lands into natural ecosystems with their services is not viable, due to the mentioned increases in demand in the future, environmental functions and services need to be gradually replaced on agricultural lands. In addition, strategies have to be found to enable the active regeneration of degraded agricultural areas. The following approach seeks an approximation of agricultural systems to natural ecosystems through the integration of perennial plants and an increase of the functional diversity of plants in agricultural systems. The aim is to imitate the structure and function of the local ecosystems to restore degraded lands through successional agroforestry, with the goal of increasing yields of subsistence crops as well as restoring environmental services in locally adapted, forest-like agro-ecosystems.

METHODS

The following section starts with a comprehensive description of why natural ecosystems serve as “guiding image” for agricultural land use, and is followed by a short review of important functional principles of natural ecosystems. The method of successional agroforestry, which was developed by the agronomist Ernst Götsch in Northeastern Brazil, has been taken as basis for how approaches imitating the structure and function of natural ecosystems can be implemented in the field. Finally, two projects in different climatic settings within the northeastern region of Brazil are described, in which smallholder farmers practice successional agroforestry.

Guiding Image: Natural, Intact Ecosystems

Evolutionary processes turned natural ecosystems into highly efficient structures with long-term stability and the capacity to sustain themselves by using solar energy and cycling their locally limited resources. They are therefore sustainable structures and are taken as a “guiding image” for developing sustainable land use systems. Different authors have mentioned that mimicking natural ecosystems can be advantageous for agricultural systems. The imitation of the locally adapted structure and function of natural systems could be a potential solution in the transition away from land use forms exploiting the natural resources in the short term (Ewel 1999). In addition, the imitation of diversity of natural systems is important (Noordwijk et al. 1999). The critical characteristics of natural land-based ecosystems are perennialism and diversity (Glover 2003). Perennialism is the main characteristic enabling the long-term maintenance of ecosystems (Ewel 1999).

Land use systems based on the principles of natural systems are thought to bring improvements and potential increases in long-term productivity. They also increase efficiency of resources use as well as the amount of human labor needed to establish and manage them, since these agroforestry models work with nature instead of against nature (Noordwijk et al. 1999). It is assumed that the regeneration of a vegetation cover that resembles the local ecosystem leads to improved local nutrient cycling, and also to improved soil conditions and reduced water contamination (Noordwijk et al. 1999, Glover 2003, Ewel 1999, Neher 1999). On the landscape scale, the imitation of natural ecosystems improves the possibilities to maintain environmental service functions (Noordwijk et al. 1999).

Functional Principles of Natural Ecosystems

Natural ecosystems, and especially plants, due to their roots are forced to use locally limited resources like soil nutrients, solar energy and the available water as efficiently as possible in the process of photosynthesis. This means that short cycles tend to prevail in the biological processes of primary productivity and decomposition, with an optimization of the interactions among organisms, to enable the establishment of sustainable ecosystems in a given location (Ripl 1995). The development of ecosystems is characterized by an inherent self-organization process and passes through different successional stages. First, during the stage of establishment successional development occurs with maximum net productivity in biomass, and species undergo strong competition for the locally limited resources. This is followed by a stage of optimization, in which the interactions among species (for example between perennial and annual plants) becomes increasingly important for using the niches within the available resources, including water, nutrients and energy. With increasing optimization through species interactions, relatively short nutrient and water cycles are developed (Ripl 1995) as a result of the self-organization processes of natural ecosystems establishing themselves at a specific location (Ripl and Hildmann 2000). This means that optimized ecosystems in advanced successional stages have the capacity to maintain the locally limited resources through internal coupling and cycling and can therefore be considered examples for the most sustainable land use systems.

Agroforestry Systems with Different Complexities

Agroforestry systems differ basically in diversity and complexity. Whereas many agroforestry systems exhibit higher complexity than monoculture cropping, many of them are a combination of one tree or shrub species with an annual crop, like in many hedgerow systems (see Nair 1993). Higher complexity and diversity of different structural and functional plant types are frequent in multi-strata agroforestry systems, which have been traditionally found in home gardens of Southeast Asia and Latin America (Nair 1993). Multi-strata systems combine the horizontal arrangement of complementary species with vertically overlapping species. The composition of the system is mainly determined by light needs and the available rooting zone, combining species that have a complementary relationship instead of a competitive one. Through the mixture of trees, shrubs and herbs or crops, a broader spectrum of functionally different types of species leads to a more efficient use of the locally available nutrients, solar energy and water. This increased efficiency in resource use through internal cycling gives more stability to the system and reduces the need for external inputs.

Imitation of Local Natural Ecosystems: The Concept of Successional Agroforestry

Successional agroforestry is a special type of multi-strata system. This method aims at the systematic imitation of the successional processes of ecosystems of the same climatic area and similar soils. The aim is to create agro-ecosystems that are similar to the local natural systems in structure and function. The concept of successional agroforestry has been developed and tested by Ernst Götsch since 1982 in the state of Bahia in Brazil. It has been employed on degraded sites, where natural regeneration through succession is constrained by a lack of seed banks, soil organic matter, or humidity, and would take long periods of fallow to develop. Successional agroforestry strives for an active and systematic acceleration of the successional processes to restore these degraded sites.

The most important requirement for vegetation growth on degraded soils without nutrients is the accumulation of organic material. A first step must therefore focus on biomass accumulation, which can be achieved by planting pioneer plants that do not have major soil requirements. If this step is successful, the successional process will continue. Successional agroforestry does not apply inorganic fertilizers, but aims for local cycling of nutrients and an increase in soil organic matter within the plantation (Götsch 1992).

System Implementation

The first step is the selection of appropriate assemblages of plant species, which are similar in eco-physiology to plants growing on comparable soil and climate conditions, and the sequence of plants within the successional process. Creating an agro-ecosystem with a similar structure, function and dynamic to the natural system requires detailed observation and analysis of site conditions (Götsch 1992). Selection of species within the successional sequence includes early, medium, and late successional species, with knowledge of their specific ecological stratum and life cycle (Figure 1). The goal is to select complementary species to increase the probability of coupling through different functional and structural types.

Plants of the first successional stage are densely seeded to cover the soil and to increase the organic material. Fast-growing species with low nutrient demands like Fabaceae are planted as pioneers and improve the soil with their capacity to fix nitrogen, which serves as a preparation for the successional phases that follow. Shortly after establishment, seeds of the next successional step are planted. Systematic interventions, such as the introduction of plants of the next successional step, accelerate the successional process. Thus, succession is advanced at a much faster rate than in the natural regeneration process.

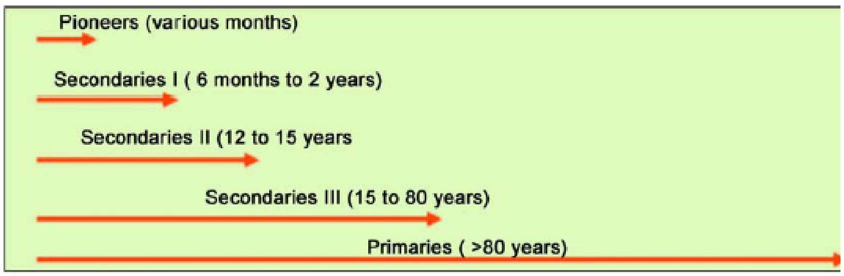

Figure 1. Schematic diagram of the lifecycle – types of plants within a successional sequence (Milz 2004).

During each step within the successional process, plants are introduced at high density to reduce spontaneously appearing plants and to find an optimal placement of each plant within the system. Based on the establishment and growth of each species within the plant community, plants are selectively removed to systematically create gaps for the plantation of crop or other useful plant species of a higher successional level.

Nevertheless, only few plants are removed, and the biomass is used to cover the soil, leading to the accumulation of an organic layer and reduction of soil moisture evaporation. Another intervention consists of pruning, which corresponds to the loss of foliage and branches in natural systems and contributes to soil improvement through mulching. Therefore, biomass retrieved from pruning needs to be chopped and spread evenly on the soil, increasing the development of humus and improving humidity and water retention in the soil. Other effects of pruning are the acceleration of nutrient cycling and the systematic creation of clearings or gaps for other desired plants. Selective removal and pruning are the main steering procedures to determine changes in the development of single plants and the formation of a complementary plant community.

The higher the diversity of species with different or complementary functions on the site, the higher the chance to achieve interactive processes between species and to optimize the correlation of the components. This is similar to the self-optimizing process of natural systems and contributes to the adaptation to the local conditions and limited resources. With increasing age and successional progression, the system develops multiple strata and approaches the functionality of natural ecosystems. The sequential development of the successional system increases humidity, fertility, biomass, and biodiversity over time and with increasing structural complexity (Figure 2).

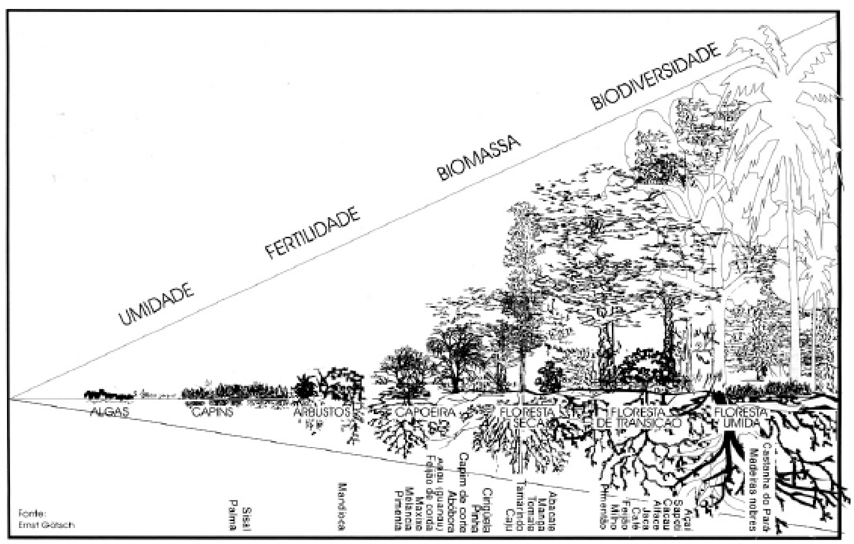

Figure 2. Illustration of the development of an ideal-typical succession within an agroforestry system (Götsch 1997).

CASE STUDIES ON DEGRADED AREAS IN NORTHEASTERN BRAZIL

Study Region

The Northeast of Brazil is one of five major administrative units in the country, accounts for about 18% of the area of Brazil (1,561,177 km²), and contains about one third of the Brazilian population (MRE 2005). Around 50% of the Northeast with its prevailing semiarid climate is affected by ongoing soil degradation, with about 181,000 km^2 considered areas of desertification

(Lacerda and Lacerda 2004). The first step in the process of landscape degradation has been the reduction and destruction of the natural vegetation, which in this region varies from a deciduous dry forest to a thorn tree Caatinga. While in 1960 only 20% of the vegetation had been destroyed, by 1990 around 53% of the Northeast had experienced loss of the permanent natural vegetation cover (IBGE 1992). The loss of vegetation cover together with soil degradation led to desertification, which enhanced the periodic dry periods, leading to a drastic aggravation of the living conditions for the local population, especially threatening the existence of smallholder farmers.

The Northeast is one of Brazil's poorest regions and a large part of the rural population is directly dependent on the soil resources. Around 88% of agricultural operations are smallholders, farming on about 44% of the area (Bittencourt and Di Sabato 2000). Around 59% of the smallholders have on average 1.7 ha of land, on which mainly subsistence farming is practiced (Bentes-Gama and Vilcahuaman 2004). Soil protection measures are not widespread and intensive cultivation leads to quick degradation of soils with subsequent conversion of more natural vegetation to new farmland.

When subsistence farming cannot sustain the farmers anymore, rural-urban migration tends to occur. The percentage of urban population has increased from 36% to 60% between 1960 and 2005 (IBGE 1966, MRE 2005). In the medium term, there is a risk for the Northeast region that the increasing demand for goods cannot be sustained due to the loss of productive land and the increase in climatic extremes. Therefore investigation of locally adapted techniques that restore the land and enhance its productive capacity is urgently needed. Environmental functions that were lost with the natural vegetation cover need to be substituted, at least gradually. Two case studies of projects that applied the method of successional agroforestry in two climatic zones of the Northeast, in distinct natural ecosystems (Mata Atlântica and Caatinga) will be described in the following sections.

Project A: Humid Coastal Zone (Mata Atlântica)

This case study is located in the municipality Abreu e Lima in the state of Pernambuco. Annual precipitation in this subhumid coastal zone ranges from 1300 mm to 2000 mm and soils are mainly sandy loams with low fertility. The natural ecosystem in this zone before degradation took place was a sub-humid, semi-deciduous tropical forest (Mata Atlântica). Experiments of successional agroforestry were started by the farmer Jones Severino Pereira and his family in 1994 with the impulse and technical support of a local NGO (Centro Agroecologico Sabiá) to find alternatives for restoring heavily degraded soils. Main production on their land (about one ha.) had been cassava (*Manihot esculenta*) (Figure 3), which had to be given up, as fertilizer cost exceeded the value of the harvest. The family found a first alternative with the production of honey and made various attempts to recover the soil with agro-ecological techniques. These experiments were not successful until Mr. Pereira received a three-week training on the method of successional agroforestry by Ernst Götsch that enabled him to regenerate his land.

Figure 3. Pre-treatment plot with cassava monoculture *(Manihot esculenta*).

Implementation of the Successional Agroforestry Approach

One hectare of farmland was divided into six experimental areas, and each of them was systematically planted with different mixtures of annual and perennial seeds of crops, fruits and locally adapted Leguminosae species.

The experiment was useful for finding out which plants were able to germinate in the initial phase and which ones needed improved soil conditions and therefore were considered plants for later successional stages. On the basis of the results from the 3-year experimental phase a detailed plan for the successional system was compiled and carried out.

According to Mr. Pereira, the implementation based on the experimental observations led to a significant improvement and acceleration in the development of the successional systems, and also helped form the basis of the method's adaptation to this particular site.

For example, it was decided to focus mainly on the cultivation of fruits and nuts in the long term, growing in different strata with little understory vegetation like *Zea mays*, *Ananas comosus*, and beans like *Cajanus cajan* to approach the potential natural ecosystem of this site, a sub-humid semi-deciduous tropical forest.

Project Results

When the project was visited at the end of 2004, an agro-forest with similar structural characteristics to the Mata Atlântica had been developed (Figure 4), and the use of fertilizers, burning and tillage had ended. After 10 years, the successful regeneration of a degraded unproductive site had been achieved, enabling the provision of a wide variety of food for the subsistence of four persons, as well as sufficient supply of construction- and firewood (personal communication, Pereira, December 2004).

However, the start of the successional agroforestry system had been very difficult, as very limited yields of the plot coincided with a high workload. The first years of development of the successional system could only be supported due to a newly introduced honey production, which had been installed with the help of the local NGO.

According to Mr. Pereira, the workload of the system decreased proportionally with the development of the perennial plants and after 10 years the system required only low maintenance efforts, leaving sufficient time for the processing of food.

Especially due to advances made in local food processing and direct marketing of organic products on a market in the nearby city of Recife, the family achieved a notable increase in income. Table 1 contains some of the perennial plants that play an important part in the production of the area.

Figure 4. Successional agroforestry system, project A after 10 years.

Table 1. Examples of productive perennial species within the successional system after 10 years

Fruits and nuts	Timber and /or leguminosae species
• Ananas - *Ananas comosus* • Açai - *Euterpe oleracea* • Acerola - *Malpighia glabra* • Avocado - *Persea americana* • Banana - *Musa sp.* • Carambola - *Avherroa carambola* • Cupuaçu - *Theobroma grandifolia* • Jackfruit - *Artocarpus integrifolia* • Genipapo - *Genipa americana* • Coffee - *Coffea arabica* • Cacao - *Theobroma cacao* • Coconut - *Cocos nucifera* • Lemon – *Citrus limon*	• Pepper tree - *Schinus molle* • Spanish Cedar - *Cedrela odorata* • Crotalaria - *Crotalaria sp.* • Embiriba - *Eschweilera x luschnatii* • Ingá - *Inga sp. (fagifolia)* • Juazeiro - *Zizyphus joazeiro* • Jurema - *Mimosa hostilis* • Yellow poui - *Tabebuia serratifolia* • Butterfly pea tree - *Clitoria fairchildiana*

• Lime - *Citrus × aurantiifolia* • Malay apple - *Syzygium malaccense*	
Fruits and nuts	Timber and /or leguminosae species
• Mango - *Mangifera indica* • Maracuja - *Passiflora edulis* • Murici - *Byrsonima crassifolia* • Munguba - *Eriotheca crenulaticalyx* • Orange – *Citrus × aurantium* • Papaya - *Carica papaya* • Peach palm - *Bactris gasipae* • Pitomba - *Talisia esculenta* • Yellow Mombin - *Spondias mombin*	

Project B: Poly-Culture in the Semiarid Zone (Caatinga)

The second project is located in the semiarid zone in the state of Bahia and the municipalities of Cafarnaum, Ourolândia and Umburanas. The project was initiated in 1999/2000 by the Instituto de Permacultura da Bahia and started with a few farmers on experimental pilot plots. In 2009, the project was collaborating with around 1500 farmers, with a minimum experimental area of 1000 m² each.

The semiarid project area receives 550 mm of annual precipitation, nevertheless the area has a negative water balance due to annual potential evapotranspiration of 2000 mm.

The annual dry period lasts 7 to 9 months, with periodic droughts of up to 18 months.

The natural ecosystem is a thorn tree savanna called Caatinga, which is under serious threat, like most of the dry tropical forests of the region (Miles et al. 2006).

In the three municipalities about 70% of the natural vegetation has been lost due to slash and burn farming and the production of charcoal, which remains an important economic activity, leading to a significant decrease in vegetation cover. The soils in the area are shallow, sandy, rocky and have a low organic matter content. Due to agricultural production, soils are strongly degraded and wind erosion has led to the accumulation of sand dunes. Together with the periodic droughts this has led to a loss of the subsistence basis of the rural population, which in turn has led to high levels of migration to urban areas.

System Implementation

At the beginning of the project in 1999/2000 members of the Instituto de Permacultura da Bahia initiated experimental poly-culture areas in a successional system on degraded soils in collaboration with local farmers. The cultivation technique closely followed the principles of successional agroforestry established by Götsch, who advised the project.

The plantation scheme included the locally established cultures of castor-oil plant and beans, as well as at least 20 other species from locally collected seeds and seedlings. Plantings at high densities were carried out at the beginning of the rainy season to kick-start the accumulation of organic material. The initiation began mainly with annual and perennial pioneer plants like Fabaceae, without major soil requirements, and well adapted to the local conditions. Plants were often seeded in small parallel ditches that favor water retention.

The abundance of different species increases the chance of good initial growth and therefore accumulation of organic material on the degraded soil, as the least amount of biomass possible is being removed during harvest. One of the important factors is the interruption of the formerly practiced slash-and burn cycle, as the remaining vegetation increases water retention and reduces soil moisture evaporation.

This is especially important in a semiarid region, and a lot of effort goes toward the establishment of drought-resistant perennial species. Species with good resprouting capacities are preferred. Pruning is important for creating as much soil cover as possible. As the growth period is severely limited by water availability, the rainy seasons have to be used most efficiently, as successional agroforestry is implemented without irrigation.

RESULTS

Examples from the harvest on two farms in the municipality of Cafarnaum after four years of successional agroforestry show clear increases in productivity as compared to the regional mean value of castor oil crops in monocultures, which were formerly cultivated on these farms (Table 2). The productivity of castor oil plants within the successional system was almost double that in the monoculture. Comparing productivity of the monoculture with the total productivity of six other crops within the system, the amount harvested had been raised by a factor of about 4.2 per hectare.

Table 2. Productivity of two farms in the municipality of Cafarnaum after 4 years of successional agroforestry (Data: Instituto da Permacultura da Bahia, 2004, with independent calculations based on this data and data from the Agricultural Census (IBGE, 2005))

Municipality Carfanaum		Site "Valdoberto"	Site "J. Barbosa"	Mean
Common name	Scientific name	Harvest kg/ha	Harvest kg/ha	Harvest kg/ha
Castor-oil plant (in SAF)	*Ricinus communis*	2100	895	1,497.5
Cowpea	*Vigna unguiculata*	220	350	285
Broad bean	*Vicia faba*	80	300	190
Maize	*Zea mays*	405	500	452.5
Watermelon	*Citrullus vulgaris*	(1040 units) ca. 1000-1500	(400 units) ca. 400-600	875
Sesame	*Sesamum indicum*	45	30	37.5
Barbary fig	*Opuntia ficus-indica*	no production yet	no production yet	-
Fruits		no production yet	no production yet	-
Productivity SAF		3850 – 4350	2475 - 2675	3,337.5
Castor-oil plant – monoculture Mean harvest in municipality				800
Production increase of castor-oil plant in successional system compared to castor-oil plant in monoculture				~ factor 1.9

Production increase through successional AF			~ factor 4.2

Figure 5. Sequence of the successional system on different sites of project B; a) first cultivation year, second month of the rainy season; b) second cultivation year, end of the rainy season; c) third cultivation year, end of the rainy season; d) third cultivation year, beginning of the dry season (Photos: Instituto de Permacultura da Bahia).

According to the Instituto de Permacultura da Bahia, the participation of around 1500 farmer families in 5 communities was facilitated by a payment of 34 Reais (around 19 US$) per month during the first four years. This financial support in the initial period is critical for the farmers, as the main focus at that stage is to enhance the degraded soil through the accumulation of biomass, and harvests in these times are reduced. From the fourth year on, complete subsistence was reported to be possible from the poly-cultural plots.

Soils have continuously been improved through this method, while the use of fertilizers, pesticides and herbicides has decreased, leading to financial relief for the collaborating farmers. An important improvement of this land use system is the decrease of the risk of complete harvest loss, achieved through the diversity of perennial and annual plants, giving the farmer a higher resilience towards extreme events like droughts. According to the project coordinator C. Del Arco Sanches, even in a year of extreme drought, like 2003, successional agroforestry plots have been robust and enduring (Sanches, personal communication, December 2004). Altogether, successional agroforestry enables the regeneration of degraded sites even under harsh semi-arid conditions and improves the living conditions of the local farmers through an increase in productivity and diversification of species. The regeneration of an existential basis for the local farmers therefore helps to reduce rural-urban migration.

Important Considerations in the Introduction of Agricultural Innovations

Critical for success of the projects was capacity building in two directions. While the commitment of experts with agro-ecological knowledge gives an important impulse for change, local knowledge is the basis for the development of a locally adapted cultivation technique, and at the same time feeds back into the training and further education of the experts. The NGOs mentioned were involved in the two projects, and formed an important part of the transmission of knowledge and motivation for the implementation of the new agricultural method. From the beginning, the NGOs put a strong emphasis on training local multiplicators, who are able to motivate and convince other farmers of the applicability of the new land use form, mostly through positive practical examples. Also very important for the process of this agricultural innovation is the development of local knowledge exchange networks, which in many cases led to the creation of formal farmer's associations. These forms of organization empower smallholder farmers and are an important step towards the development of local "market chains" for organic products.

A positive side effect of the projects was that farmers reconnected to their local environments, through the need to observe and learn from local ecosystem processes. Due to an increased need for seeds and seedlings of local species, some farmers have engaged in the establishment of tree nurseries with local species, which also could be an important initiative for further advances in terms of landscape restoration.

CONCLUSION

The results of the case study in two different climatic regions of Northeastern Brazil suggest that degraded agricultural lands can be regenerated with successional agroforestry. At the same time, crop diversification and increases in agricultural production lead to the regeneration of the subsistence basis of smallholder farmers, thus helping to prevent rural-urban migration.

The case studies exemplify that an approximation of agricultural land use to natural ecosystems can be achieved through the systematic imitation of successional processes, with perennial and diversified systems. Apart from the restoration of degraded soils, it can be assumed that these forest-like agro-ecosystems can at least gradually replace some of the functions of natural systems, such as water regulation, nutrient cycling, erosion control and prevention, habitat provision, as well as carbon storage. At the same time, the negative impacts of agricultural production can be diminished, as successional agroforestry can be successful without fertilizers, pesticides and irrigation.

Since successional agroforestry is a promising method for the reconciliation between agricultural production and the provision of environmental services, further research is needed to quantify the benefits achieved by these systems. In terms of applicability, one of the main obstacles for farmers is the initial phase of the system, with a time lag between establishment of the land use system and income generation. Here, concepts like payments for environmental services could play an important role, and could contribute to enhance the farmers´ position from being a land user towards being a land caretaker, providing multiple services to society.

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