Biodiversity and Key Ecosystem Services in Agroforestry Coffee Systems in the Brazilian Atlantic Rainforest Biome

Helton Nonato de Souza

Thesis committee

Thesis supervisors
Prof. dr. L. Brussaard
Professor of Soil Biology and Biological Soil Quality, Wageningen University

Prof. dr. I.M. Cardoso
Department of Soils, Federal University of Viçosa, Brazil

Thesis co-supervisors
Dr. M.M. Pulleman
Researcher, Department of Soil Quality, Wageningen University

Dr. R .G.M de Goede
Assistant professor, Department of Soil Quality, Wageningen University

Other members
Prof. dr. P. Kabat, Wageningen University
Prof. dr. B.J.M. Arts, Wageningen University
Dr. ir. J. de Graaff, Wageningen University
Prof. dr. R.G.A. Boot, Utrecht University

This research was conducted under the auspices of the C. T. de Wit Graduate School of Production Ecology and Resource Conservation

Biodiversity and Key Ecosystem Services in Agroforestry Coffee Systems in the Brazilian Atlantic Rainforest Biome

Helton Nonato de Souza

Thesis
submitted in fulfilment of the requirements
for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus
Prof. dr. M.J. Kropff,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Wednesday 18 January 2012
at 4 p.m. in the Aula.

Helton Nonato de Souza

Biodiversity and Key Ecosystem Services in Agroforestry Coffee Systems in the Brazilian Atlantic Rainforest Biome

Thesis, Wageningen University, Wageningen, NL (2012)
With references, with summaries in Dutch and English
ISBN 978-94-6173-109-8

Dedication

To my mom, Maria das Graças (Gracita, in memoriam) who taught me to be brave, persistent without losing the sense of humanity.

To my brother, Geraldo (in memoriam) who taught me that to pursue dreams we have to build our own way.

Abstract

This thesis reports the results of long-term experimentation (since 1993) of family farmers with agroforestry (AF) coffee systems in the Brazilian Atlantic Rainforest region, a highly fragmented and threatened biodiversity hotspot. The farmers used native trees from forest fragments during a transition from the predominant full sun-coffee (SC) production to more diversified agriculture. The aim of the research was to gain understanding of different agricultural management systems within the complex landscape matrix with respect to farmers' capacity to diminish negative impacts on the environment, based on an ecosystem services approach.

Participatory Rural Appraisal was used to obtain data from the family farmers. A method of systematization of their experiments created platforms for reflexion and development of agroforestry systems for farmers, technicians and researchers beyond only listing the negative and positive results. Long-term effects of coffee agroforestry (AF), full-sun coffee (SC) systems and surrounding reference forest fragments (RF) were assessed on: tree biodiversity, microclimate, soil quality, costs of labour and inputs and profitability. Selection of appropriate tree species was essential to the success of agroforestry. The main criteria for selecting tree species by farmers were: compatibility with coffee, amount of tree biomass produced, diversification of the production and the labour needed for tree management. The farmers used 85 tree species across the area, 28 of which belonged to the Leguminosae, a family of nitrogen-fixing plants. Most trees were either native to the biome, or exotic fruit trees. The diversification of production, especially with fruit trees, contributed to food security and to a low cost/benefit ratio of AF.

Comparisons between reference forest fragments, agroforestry coffee and sun coffee revealed the potential of AF to conserve local tree biodiversity. Litter quality on-farm was functional in terms of soil erosion and fertility management. The canopy of the trees mitigated high temperature extremes: maximum temperature in SC systems (32^{o}C) was 5.4 ^{o}C higher than in AF. Some soil quality parameters (total organic carbon, microbial carbon, soil respiration and potential nitrogen mineralization) showed higher values in RF than AF and SC, but no differences were observed between AF and SC.

There was considerable diversity in the strategies and management of farmers for AF (including the choice of tree species), affecting the productivity and profitability. The total production value of AF was on average 43% higher than that of SC, largely due to other

products than coffee. Both systems had an overall higher return of labour than the wage rate in the area.

Continued participative work among scientists and stakeholders may help to increase the delivery of ecosystem services provided by family agriculture. Production systems based on ecosystem service delivery beyond just crop production have potential to reduce the need for external inputs and contribute to major local, regional and global objectives, such as food security, adaptation to climate change and conservation of biodiversity.

Propositions (Stellingen)

1. Soil management in agroforestry is key to enhance ecosystem services at different scales (**this thesis**).

2. Diversity in agroforestry systems generates resilience (**this thesis**).

3. Using indigenous instead of exotic trees in agroforestry enhances the delivery of ecosystem services.

4. Sustainability will only be achieved when above- and belowground interactions in ecosystems become part of land managers' collective awareness.

5. Agriculturalists and conservationists must learn from each other, including the mistakes made by both, to be able to inform society's decisions on natural resource management.

6. Agroecology must be understood as a combination of science, practice and movement.

7. "The best things in life are free".

Propositions accompanying the PhD thesis **'Biodiversity and Key Ecosystem Services in Agroforestry Coffee Systems in the Brazilian Atlantic Rainforest Biome'**

Helton Nonato de Souza

Wageningen, 18 January 2012

Table of Contents

Chapter 1 General Introduction ………………………………………………… 01

Chapter 2 Learning by Doing: a Participatory Methodology for Systematization of Experiments with Agroforestry Systems, with an Example of its Application 13

Chapter 3 Selection of native trees for intercropping with coffee in the Atlantic Rainforest biome 37

Chapter 4 Protective shade, tree diversity and soil properties in coffee agroforestry systems in the Atlantic Rainforest biome ……….…………………………………… 59

Chapter 5 Strategies and economics of farming systems with coffee in the Atlantic Rainforest Biome ……………………………..……………………… 87

Chapter 6 General discussion and Conclusions 110

References ……………………………………………………………………..…… 118

Summary ………………………………………………………………………..… 136

Samenvatting …………………………………………………………………… 142

Acknowledgements ……………………………………………………………………… 149

Biography ……………………………………………………………………..…… 151

Education Certificate …………………………………………………………..…. 153

Chapter One

General introduction

One of the challenges to society in areas with high biodiversity and a large human population is to develop agriculture that produces food and income to sustain rural livelihoods without further compromising biodiversity conservation. This raises the need to improve our understanding of the relations between biodiversity, agricultural production, resilience and equity in models of agriculture and land use. The overall objective of this thesis was therefore to obtain knowledge on agroforestry systems linked to ecosystem services.

This chapter aims to give context to the current societal and scientific debate on the contribution of ecosystem services to the functioning of agroecosystems and the connection of biodiversity and human well-being, linking this to a case study in the Brazilian Atlantic Rainforest biome.

1. Common interests leading to a sustainable future

Today's challenge for society is to simultaneously achieve goals in the areas of food production, biodiversity conservation and sustainable natural resource management. In the context of an increasing global population, changing diets, climatic change, and environmental degradation, sustainability is gaining more and more urgency (Costanza et al, 1997; Evenson and Gollin, 2003; Tallis et al., Vandermeer et al., 1998). Continued climate change is foreseen to result in further biodiversity loss and to negatively affect production of agricultural goods, which in many cases poses an additional challenge to ecosystem management (Cincotta et al., 2000).

The attention for food security, environmental protection, biodiversity, climate change, and the relations among them, is reflected in international policy frameworks, conventions and research efforts. These are, e.g., the Convention on Biological Diversity (CBD), the United Nations Convention to Combat Desertification (UNCCD), the reports of the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Development Goals (MDGs) which aim at reducing disparities by eradicating hunger, poverty, child mortality, inequity between genders, lack of primary education and unhealthy conditions, all striving for environmental sustainability and forging a global partnership for development.

An international scientific appraisal of the condition and trends in the world's ecosystems has been conducted in the Millennium Ecosystem Assessment (MEA, 2003; MEA, 2005a). In order to stimulate scientific understanding of the relationships between human beings and ecosystems and to inform international policies, the DIVERSITAS science program strives to address the scientific questions about the conservation and sustainable use of biodiversity by linking biological, ecological and social disciplines (DIVERSITAS, 2002). Together, these policy frameworks complement each other in targeting social, political and scientific aspects (Figure 1).

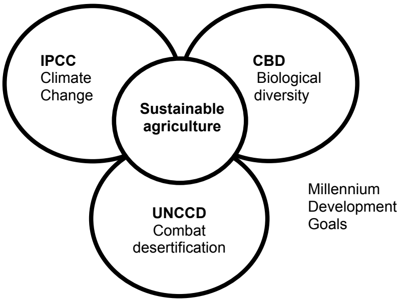


Figure 1: Convergence of goals among recent international assessments and conventions.

The key challenge is to improve food and feed production systems with less reliance on external inputs, lower impact on ecosystems, but ensuring benefits on all scales of society by understanding and respecting the natural ecosystem functioning (Kremen and Ostfeld, 2005). Thus, interventions must be conducted in favor of poverty and hunger alleviation, adaptation to environmental changes, and reduction of the pressure on natural ecosystems (Jackson et al., 2007a).

In the near future, realistic solutions to current unsustainable natural resource management must be provided through a more integrative approach and regionalized actions (MEA, 2005b; Nair, 2007). Climate change is predicted to lead to a significant productivity reduction in agriculture and biodiversity (IPCC, 1996), especially in dry areas of tropical regions (Assad et al., 2004; Lobell et al., 2008; Parmesan and Yohe, 2003; Thomas et al., 2004). The IPCC and the International Assessment of Agricultural Knowledge, Science and Technology for Development (McIntyre et al., 2009) consider, among several options, the implementation of more diversified agroecosystems as an important component for farming systems, and affirms that this technology demands fewer financial resources while gaining higher benefits and potentially contributing to climate change adaptation through diversification (IPCC, 1996). Furthermore, simple and efficient practices can be applied to enhance SOC (soil organic carbon) including planting trees, mulch farming, conservation tillage, cover crops, nutrient and animal husbandry management and soil and water management as suggested by Lal (2003). In tropical food systems and land use such technologies could potentially mitigate greenhouse gas (GHG) emissions and produce 46-200 Mt/yr of biomass as C offset, meanwhile restoring degraded areas and reducing deforestation (IPCC, 1996).

With the focus on biodiversity, it has been stated that more effective protection of the natural resources inside protected areas is necessary, at the same time considering what happens outside these areas (Bennett and Balvanera, 2007; CBD, 2008; Harrop, 2007). Diversified agricultural systems (specifically agroforestry), e.g. in buffer zones of national parks, can complement conservation efforts. Not all biodiversity can be protected in nature reserves. According to Buck et al. (2006) natural areas benefit from clean water and biological control from neighboring farming systems. In return, the plentiful fauna and flora species provide resistance and resilience in managed ecosystems against abrupt changes between harvests caused, for instance, by droughts and hails (Altieri, 2002; Gliessman, 2004). Hence, the maintenance of ecologically balanced high productivity on existing farms around protected areas, reduces the pressure on natural habitats. Indeed, CBD (2010) reports that agricultural landscapes maintained by farmers and herders using locally adapted practices not only maintain relatively high crop and livestock genetic diversity, but may also support distinctive natural biodiversity. Therefore, fields and farm with a high diversity can serve as a buffer zone around protected areas (Clergue et al., 2005; Jackson et al., 2007a). Thus, understanding the mechanisms, impacts, and interactions that occur between natural and managed neighboring ecosystems can help society to optimize the benefits obtained from both ecosystems.

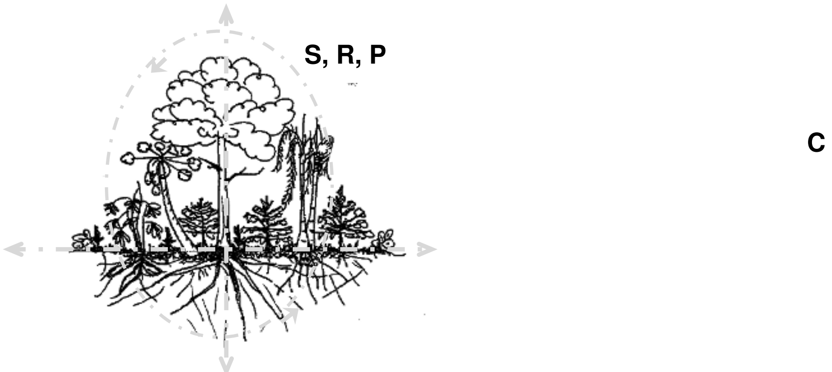
2. From the agenda to the arena: management and changes in landscapes

Different farmers' categories are distinguished according to their access to technologies. On the one extreme, modern farmers take advantage of the high-technology means available, such as agricultural implements, chemical fertilizers and soil amendments, varieties and cultivars, biocides and software (Benbrook, 2009). On the other extreme, in marginal areas, smallholders (or indigenous peoples) rely on benefits provided by nature, uninfluenced by "conventional" technical assistance or financial support (Posey, 1985). In this thesis, I focus on an intermediate group of family farmers that are partly connected to markets and intensive farming practices. In Brazil, 4.8 million family farmers represent 85% of the total producers, occupying 30% of the total agricultural land (Altieri, 2004). They keep around 50% of their land devoted to diversified food crops, and are responsible for 33% of maize, 84% of cassava and 67% of all beans produced at the national level. In Africa small farmers represent 60-80% of the labour force in agriculture and produce most of the continent's food (Altieri and Koohafkan, 2008). The relevance of studies on family farms/small producers is, therefore, unquestionable.

Heller and Zavaleta (2009) analyzed twenty-two years of general recommendations for conservation and regional planning and found that concrete practices in the field are not yet connected at different levels of institutional responsibilities (e.g. government, civil society, extension, credits). Ongoing development projects dealing with ecosystem goods and services relating to agrobiodiversity are running in different places on earth (Cassano et al., 2009; Egoh et al., 2008; Giller et al., 2006; Harvey et al., 2008; Rice, 2008; Vandermeer and Perfecto, 2007; Zheng et al., 2008). These projects can be seen as "field laboratories" for research, innovations, and policies for a better use of natural and human resources.

3. Ecosystem services

Ecosystem services can be defined as the benefits people obtain from ecosystems (Costanza et al., 1997; Daily and Matson, 2008; MEA, 2003; MEA, 2005a). They are divided into four groups: 1. *Provisioning services* (the goods provided by the ecosystem, e.g. food, fiber, wood, and medicines); 2. *Regulating services* (e.g. pollination, climate regulation, water quality, erosion control, disease control); 3. *Cultural services* (the nonmaterial benefits, e.g. spiritual and religious values, ecotourism, aesthetic values); and 4. *Supporting services* (those that are necessary for the production of all other ecosystem services, e.g. soil formation, photosynthesis, nutrient and water cycling. The four groups are intrinsically linked and operate together (Figure 1).



R. Regulating services

Carbon sequestration
Erosion control
Water regulation
Temperature regulation
Pollination
Biological control

P. Provisioning services

Food
Feed
Wood
Fiber
Fuel

S. Supporting services

Soil formation
Nutrient cycling
Photosynthesis
Genetic resources

C. Cultural services:

Farm and landscape aesthetics
Tourism

Figure 1: The potential of agroforestry systems to simultaneously provide a wide set of ecosystem services at different levels and scales.

4. Connections between biodiversity, ecosystem services and human well-being

Human well-being is considered to be closely related to biodiversity (MEA, 2005a; 2003). Biodiversity is the diversity within and between species and amongst ecosystems and the ecological complexes of which they are part (MEA, 2003). A high biodiversity is a driver for a better functioning and structure of ecosystems (Buck et al., 2006; Vandermeer and Perfecto, 1995). As a result, ecosystem management can generate a meaningful impact on food security, sovereignty, autonomy and environmental care for the world's population (Altieri and Koohafkan, 2008).

Humans manage ecosystems for supplying food, fiber, fuel, feed and clean water. Planned biodiversity, together with associated biodiversity, forms agrobiodiversity (Jackson et al., 2007a; Jackson et al., 2007b). Planned biodiversity is composed of the crops, cultivars, trees and livestock breeds used by the farmers, whereas associated biodiversity includes all components from the surrounding environments that colonize the agroecosystem, both of which are influenced by management (Altieri, 1999; Bennett and Balvanera, 2007; Jackson et al., 2007a; Vandermeer and Perfecto, 1995). Functional biodiversity is the biotic part of the agroecosystem that affects specific ecosystem services such as decomposition, cycling of nutrients, maintenance of soil moisture, control of diseases and soil fertility (Kibblewhite et al., 2008; Moonen and Bàrberi, 2008). Therefore, different types of biodiversity have strong connections to biogeochemical cycles, and are influenced by human activities (Figure 3).

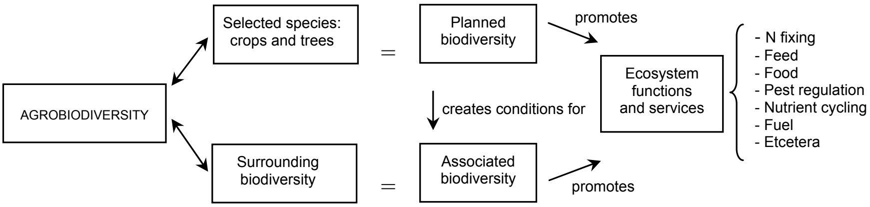


Figure 3: Different types of biodiversity and relations to ecosystem functions and services. Adapted from Altieri (1999).

Above and below-ground diversity across spatial scales

The structure and composition of aboveground biodiversity is crucial for ecosystem functions. Heal and Simon (2001) found that more benefits for agroecosystems could be obtained with higher diversity of functional groups, or diversity of plant species within a functional group, for example, nitrogen-fixing crops or trees in combination with non-N fixing trees, shade plants, shallow and deep rooting crops. Canopy layers at different heights allow for the coexistence of different plant species in the same space without competition (Beer et al., 1997). Looking at larger spatial scales, knowledge on landscape ecology contributes to strategies to conserve biodiversity and sustain wildlife in rural areas through targeted spatial configuration of landscape elements and corridors (Cassano et al., 2009; Harvey et al., 2008). However, little is known about how to promote the integration of remaining forest fragments with the most beneficial tree species in agricultural systems. This is where management of biodiversity may contribute to improving primary productivity and environmental quality. Such management also considers the direct and indirect effects on the soil environment and its biota. Soil organisms are responsible for many ecosystem services such as waste recycling, soil formation, nitrogen fixation, and biological control (Barrios, 2007; Brussaard et al., 2007; Heal and Simon, 2001). According to Young & Crawford (2004) 1 g of fertile soil has 10^{12} bacteria, 10^4 protozoa, 10^4 nematodes, and 25 km of fungi hyphae. Furthermore, soil biota mediate 60 % of the total of ecosystem services such as erosion control, soil formation and nutrient cycling (Moreira et al., 2008). Aquino et al. (2008) showed that richness of a functional group of soil organisms is related to the type of management. They are frequently threatened by inappropriate soil management practices.

Soil quality can be understood as the capacity of a specific soil type, within the boundaries of the ecosystem or agroecosystem, to sustain the productivity of plants and animals, to preserve the quality of water and air and to enhance human health (Karlen et al., 2003). It is expected that a healthy soil, with high quality, will be biologically active and diverse and that plant species will demonstrate their potential to recycle nutrients, creating a productive environment (Altieri and Nicholls, 2003). In these processes, organic matter dynamics are considered essential because the input of organic material will be reflected in the bio-chemical-physical parameters of soil quality (Alfaro-Villatoro et al., 2004). Therefore, high diversity can contribute to the function and structure of agroecosystems (Vandermeer and Perfecto, 1995).

An urgent need arises for the comprehension of benefits provided by ecosystems to cope with the earlier-mentioned global objectives across different scales. Better understanding and documentation of land management practices and their effects on biodiversity and associated ecosystem functions will be essential to enhance benefits people can obtain from ecosystems through sustainable management. These scales range from the individual (e.g. tree species) to the plot (field), farm, regional (e.g. watershed, basin, community) and global scale. As reported by Moonen and Bàrbieri (2008), it has become clear that the use of biodiversity depends on the assessment and monitoring of the impacts of land use patterns on environmental services.

5. Sustainable agriculture: the Brazilian context

Brazil is known for its high diversity of natural tropical environments and wildlife biodiversity, as reflected by the distribution of seven biomes (Figure 4). Among these biomes is the Atlantic Rainforest, a biodiversity hotspot of the world, which has lost seventy percent of its original habitat (Myers et al., 2000).

Figure 4: Distribution of biomes in Brazil and the location of the Zona da Mata region.

Historical degradation of the Atlantic Rainforest is due to wood, gold and diamond extraction, the expansion of cattle, sugarcane and coffee monocultures and industrialization (Dean, 1995). The current debate in Brazil relates to the challenge of reconciling agriculture and conservation in line with global concerns and lessons learned from the past (Tollefson, 2010). In the 1970's, Brazil implemented modern agriculture with two main goals: the maximization of production and the increase of profits. It was based on six main components: intensive tillage, monoculture, irrigation, chemical fertilizers, pest control and genetic manipulation (Gliessman, 2004). The "*green revolution package*" did provide a large increase in crop production and reductions in food prices (Evenson and Gollin, 2003), but the socio-environmental consequences are being questioned, especially in the case of developing countries (Dean, 1995; Galindo-Leal and Câmara, 2005; Perfecto and Vandermeer, 2008)

Due to the extent and variation of natural resources in Brazil, generalization of land management is ineffective. Despite this, a general policy is applied for land use at the country level. Currently, emblematic ecosystems such as the riparian areas (alongside rivers and streams), buffer zones around protected areas, and permanent preservation areas (PPA, e.g. slope more than 45%, nesting sites, BRASIL (1965; 2006a; 2006b)) are subject to special land use restrictions. In fact, such protection schemes have become ineffective due to the over-simplification of differences in geo-physical, cultural, social and institutional contexts. As a result, many areas are abandoned while they could be more attractive, as well as productive without jeopardizing the ecological functions. In such biodiversity-rich ecosystems habitat fragmentation is a challenging issue to overcome. Therefore, land use planning and policy should integrate intervention guided by economic, social, ecological, cultural, political and ethical considerations (Costabeber and Caporal, 2003). These aspects should be taken into account when investigating strengths and constraints of alternative land use technologies, such as agroforestry systems.

6. Agroforestry as a provider of multiple ecosystem services

One of the benefits of agricultural diversification through agroforestry is the capacity to strengthen ecological processes and interactions among species (fauna and flora) with positive impact on multiple aspects of ecosystem functioning, e.g. soil quality, nutrient cycling, productivity and climate regulation (Altieri, 2002; Bhagwat et al., 2008; Kiptot et al., 2006; Tilman, 1996; Tilman et al., 1997). Agroforestry systems (AF) are a well-known example of farming system that makes use of the multifunctional dimensions of the agroecosystem components (Filius, 1982; Perfecto and Vandermeer, 2008; Pollini, 2009; Sanginga et al., 2007) in order to deliver important ecosystem services worldwide (Lin, 2007; van Schaik and van Noordwijk, 2002; Verchot et al., 2007). In addition to its broad conceptualization, it can be defined as a form of multiple cropping combining crops and/or livestock with woody perennials (trees and shrubs) (Somarriba, 1992; Verchot et al., 2004) Historically, practicing agroforestry is considered a successful livelihood strategy as used by Amazonian indigenous peoples (Posey, 1985).

From the farm to landscape scale, AF can simultaneously deliver regulating, provisioning, supporting and cultural services, with positive spin-off to the regional and global scales, e.g. in case of climate regulation (Figure 2). The use of intercropping systems, including AF, has been among the most important recommendations following three relevant international policy reports (CBD, 2008; IPCC, 1996; UNCCD, 2008), however their implementation is limited in many parts of the world including the tropics. The adoption and up-scaling of AF technologies remains a challenge due the complexity in terms of field implementation and optimization, which requires local knowledge on biodiversity-productivity relations and other ecosystem services, education and extension and social organization (Daily and Matson, 2008; Harvey et al., 2008; Hernández-Martínez et al., 2009; Verchot et al., 2007). Up-scaling, such biodiversity-ecosystem service relations from the plot level to a complex landscape requires further research at multiple scales. Furthermore, the combination of both local and scientific knowledge regarding suitable strategies for preservation of the ecological interactions and social mechanisms, seems to be essential within different local contexts (Mertz et al., 2007; Vandermeer and Perfecto, 2007). Such understanding is important to inform future interventions related to agriculture and biodiversity conservation, handled by policymakers, rural extension services, research and educational systems.

7. The case of the Zona da Mata region

The Zona da Mata has a tropical highland climate. Currently, around 18% of the population lives in the countryside and is mainly practicing family agriculture (IBGE, 2000). Over the last century, coffee production has replaced most of the rainforest, which has resulted in severe soil erosion, soil fertility loss and loss of productivity as well as biodiversity through loss of habitat area and quality (Dean, 1995; Padua, 2002). Agricultural production in the area is currently characterized by permanent land use, small-scale and low input systems. Forty-two percent of farms have less than 10 ha of land (IBGE, 2000). Since 1993, recovery of soil quality has become the focus of efforts to improve livelihoods and to overcome soil degradation (Cardoso et al., 2001).

Located in the fragmented landscape of the Brazilian Atlantic Rainforest of Minas Gerais state, a group of farmers has adopted and improved coffee agroforestry systems (AF), using agroecological[1] principles, in partnership with local institutions, including NGOs and the Federal University of Viçosa (Cardoso et al., 2001; May and Trovato, 2008). In small fields, farmers have to create and maintain microclimate conditions for optimal coffee and crop productivity. Originally, the coffee plant is a shade-tolerant plant (Heal and Simon, 2001). Due to land-size and biophysical constraints as well as farmers preferences many different AF systems (in terms of structure and composition) were established. This process has generated many lessons and accumulated knowledge.

MEA (2003) emphasizes that decisions affecting ecosystems are taken at three organizational levels that should be investigated: i) individuals and small groups at the local level, ii) public and private decision-makers at regional levels, iii) international conventions and multilateral agreements that operate at the global level. It is therefore essential to generate data

---

[1] Agroecology gives the ecological principles to study, plan and manage the environment (Altieri, 2002).

and to document changes occurring in space and time based on local experiences and using participatory approaches.

8. Research question and hypotheses

The general objective of this thesis was to gain knowledge on the impact of agroforestry systems in terms of sustainability at the farm and landscape level, i.e. to make farms less dependent on external inputs, to reduce production costs, to promote biodiversity, to improve soil and water conservation and to identify environmental (quality) indicators for ecosystem services. The specific objectives were i) to document changes in agroforestry systems management since the introduction of agroforestry in the region in 1993; ii) to describe and analyze the influence of agroforestry management on biodiversity, microclimate and soil quality; iii) to identify possibilities and constraints for reconciling biodiversity conservation at the landscape level with production and other ecosystem services at the farm level. The general hypothesis is that tree biodiversity of the agroforestry system is intermediate between reference forest and sun coffee and that tree biodiversity is positively related to the delivery of multiple ecosystem services. A better understanding of ecological and social processes related to agroforestry systems will contribute to improvements in the management of agroforestry systems at the farm level and will have a positive impact on biodiversity and the sustained delivery of ecosystem services at landscape level.

Field sites

Three different land use types within farms in Zona da Mata were selected for this study: agroforestry coffee (AF); full-sun coffee (SC) and reference forest fragment (RF), belonging to two different municipalities. The main difference between SC and AF is the presence of trees in AF. Chemical fertilizers and tillage are sometimes used. Some farmers introduce or allow the growth of herbaceous plants between coffee. They do not use pesticides or herbicides in both systems. Correction of soil acidity is practiced. Farm workers can come from outside of the family. The reference forest fragments are situated on the farms. Although secondary forests are not connected to other fragments, we consider these sites to at least partially represent the condition of the natural forest. In each farm, the systems were chosen to have the same soil type and solar incidence.

From a number of other farms and reference forest fragments belonging to different municipalities information has been collected on soil quality, biodiversity, management, farm arrangement and social-economic aspects (income/profit).

Outline of the thesis

The outline of the thesis is as follows: In chapter 2, I present historical information on a long-term participatory experiment of agroforestry systems for soil quality improvement in the Zona da Mata of Minas Gerais, Atlantic Rainforest Biome, Brazil. Chapter 3 reports on the use and management of trees on family farm systems related to reference forest fragments. Chapter 4 describes the influence of agroforestry management at the field level on supporting and regulating ecosystem services. The influence of coffee agroforestry and conventional coffee production systems on productivity and profitability at the farm level is the subject of chapter 5. In chapter 6 I synthesize the results on utilizing biodiversity and ecosystem services for optimal management of family agroforestry systems.

Chapter Two

Learning by Doing: a Participatory Methodology for Systematization of Experiments with Agroforestry Systems, with an Example of its Application

Helton Nonato Souza [1, a], Irene Maria Cardoso[2], Eduardo de Sá Mendonça,[3], Anôr Fiorini Carvalho[2], Gustavo Bediaga de Oliveira[4], Davi Feital Gjorup[4], Verônica Rocha Bonfim[4]

[1]Depart. of Soil Quality, Wageningen University, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[2]Department of Soil and Plant Nutrition, Federal University of Viçosa; Brazil, Campus UFV, 36571000
[3] Department of Plant Production, Federal University of Espírito Santo, Alegre-ES, 29500000, Brazil
[4] Centre of Alternative Technologies of Zona da Mata, Viçosa, Brazil, PO Box 128, 36570000

[a] Corresponding author: heltonnonato@yahoo.com.br

Under review for publication in Agroforestry Systems

Learning by Doing: a Participatory Methodology for Systematization of Experiments with Agroforestry Systems, with an Example of its Application

Abstract

Participatory research methods have helped scientists to understand how farmers experiment and to seek partnerships with farmers in developing technologies with enhanced relevance and adoption. This paper reports on the development of a participatory methodology to systematize long-term experimentation with agroforestry systems carried out in a hotspot of biodiversity by non-governmental organization and local farmers. A methodological guide for systematization and techniques used for Participatory Rural Appraisal formed the basis of our work. We propose an analytical framework that recognizes systems of reflexive and learning interactions, in order to make the learned lessons explicit. At the process level, the main lessons and recommendations are as follows. It is important to establish partnerships to conduct innovative and complex experimentation with agroforestry. Participatory systematization allows us to improve the methodological aspects of design, implementation, and management of on-farm participatory experimentation. It also serves to synthesize the main findings and to extract lessons from agroforestry systems experiments. It fosters the technical improvement of agroforestry systems. It creates possibilities for reflection on agroforestry systems by farmers, extensionists and researchers, as well as their learning with respect to management of such systems. The findings are placed in the context of current theory on participatory experimentation in agriculture. Extractive and interactive approaches help to produce rich insights of mutual interest through collaboration by identifying local, regional and global convergences, complementarities, and conflicts of interest; which affect the advance of new eco-friendly technologies, to both improve the livelihoods and to reverse biodiversity loss and environmental degradation.

Key words: agroforestry; family farmers; participatory experimentation; systematization

1. Introduction

Agroforestry has been pointed out as a technology that can increase biodiversity, diversify production, protect the soil (Jose 2009) and in general contribute to the sustainability of agroecosystems (Cardoso et al. 2001). Agroforestry is more knowledge-intensive than green-revolution agriculture (Altieri and Nicholls 2008). Therefore, farmer education and experimentation, leading to systems modification, are more important for agroforestry development than for "modern" agriculture (Douthwaite et al. 2003; Mercer 2004).

Agroforestry as the basis for agricultural production is recommended for densely populated hilly regions of the tropics (Young 1997), such as the Zona da Mata, Brazil. The Zona da Mata belongs to the Atlantic Rainforest Biome (Figure 1), one of the five hotspots of biodiversity (Myers et al. 2000). In the past, the biome was covered with forest; nowadays, only 12-14 % remains (Ribeiro et al. 2009) due to deforestation and agriculture (Dean 1995). Family agriculture is vital within the Zona da Mata region, producing coffee as cash crops and food crops specially for domestic consumption (Gomes 1986; Ferrari 1996). However, the most common agricultural management practices of the farmers (bare soil, burning, etc.) have degraded the agroecosystems, causing social and environmental problems. These problems were intensified with the use of green-revolution types of technologies, such as the use of inbred varieties, pesticides and chemical fertilizers (Gomes 1986). This resulted in loss of biodiversity, decrease of soil and water quality, increases in agrochemical pollution, erosion due to deforestation, and weakening of the family agriculture as an economic enterprise (indebtedness, dependency on single crops, rural exodus, competition with large commercial enterprises, etc. (Ferrari 1996).

In an attempt to revert some of these problems, in 1993, the NGO Centre of Alternative Technologies of Zona da Mata (CTA-ZM) started participatory experimentation with agroforestry systems in the region. Participatory research methods can improve relevance of technologies and their adoption (Reed 2008). These methods have helped scientists to understand how farmers experiment and to form partnerships with farmers to develop technologies (Kuntashula and Mafongoya 2005). CTA-ZM works in partnership with the Agriculture Family Farmer Unions and the Federal University of Viçosa (especially the Soil Science Department). As agroforestry systems were relatively unknown to the farmers and therefore considered an innovation, CTA-ZM started participatory experimentation in small plots (Cardoso et al. 2001). CTA-ZM and partners implemented a perennial-crop combination (classification according to Young, (1997)) with coffee (*Coffea arabica L.*) as the main crop. In 1994, it set up 39 experimentation sites in 25 communities from 11 municipalities. From those, 37 sites included coffee and two pastures. The average size of the sites was 1000 m^2 (Cardoso et al. 2001). CTA-ZM and partners assisted the farmers with design, implementation, monitoring, evaluation and re-designing of the experiments in a continuous learning process (Cardoso et al. 2001). The approach used was ‘learning by doing’ and was adapted during the process (Douthwaite et al. 2003).

In order to capture lessons learned from agricultural development projects or practical experiments, such as the agroforestry systems developed by CTA-ZM and partners, Diez-Hurtado (2001) suggested systematization as a process to generate knowledge and derive lessons and recommendations for continuous development of projects and practices. Here, systematization is understood as the act of organising something according to a system (Oxford Advanced Learner’s Compass dictionary) or a rationale (www.wordreference.com). Systematization is by no means limited to the point where conclusions and recommendations are reported; useful lessons can be extracted from the systematization process itself. In agriculture, this can help to develop better insight into how and why farmers adapt and modify adopted technologies (Orr and Ritchie 2004) and into methods to improve the sustainability of agroecosystems (Mejía and Croft 2002).

The lack of systematization is common in agroecological projects run by Non Governmental Organizations (NGOs) because of lack of habit to register, to profoundly analyze and to synthesize the executed activities. Also important is the lack of explicit analysis and synthesis of the indigenous ecological knowledge, which deserves special attention in agroecology (Altieri 2004). Numerous reviews and evaluations are carried out in agricultural organizations each year, but the attempt is mainly aimed at accountability and little effort is made to synthesize the main findings (Horton and Mackay 2003). This obstructs the scaling up and out of technologies developed by these organizations (Douthwaite et al. 2003).

The mobilization and synthesis of knowledge, including that of farmers, is one way to fill the gap between available and necessary knowledge on agroforestry systems (Walker et al. 1995). The objectives of the systematization were set, during the process of systematization itself, as to reflect on the successes and the failures of the experimentation and to identify the learned lessons. The lessons could then indicate new strategies to construct a more sustainable and socially acceptable agriculture in the region. As participation alone is not enough to address issues of environment and natural resource management (Woodhill 2002), we propose an analytical framework that considers systems of reflexive learning interactions, in order to make the lessons explicit. According to the social learning theory, the interactions among stakeholders determine the nature of the processes and the content of learning (Steyaert and Jiggins 2007; Blackmore 2007). The bases of our work were the methodological guide for systematization (Guia Metodologica para la Sistematización de Experiencias del Secretariado Rural, Diez-Hurtado, 2001) and techniques used for Participatory Rural Appraisal, PRA (Guijt 1998; Geilfus 2000). The systematization included a) clarification of the objectives b) collection, preparation and organization of the information, c) analysis and synthesis, d) conclusions, e) gathered lessons, and f) diffusion of the results.

The objective of this paper is to present and evaluate the participatory methodology for systematization of long-term experimentation with agroforestry systems in the Zona da Mata of Minas Gerais, Brazil (Figure 1). We will henceforth discuss the implications of this work for current theory of participatory experimentation in agriculture.

2. Materials and Methods

2.1. The study site

The systematization involved farmers from seven municipalities (Araponga, Miradouro, Eugenópolis, Espera Feliz, Divino, Carangola and Tombos) of the Zona da Mata (Figure. 1). A great part (70%) of Zona da Mata has a tropical highland climate. The average temperature is 19° C, average precipitation is 1300 mm, with 2 - 4 dry months per year. The slopes range from 20 to 45% and the altitude from 200 to 1800 m (Golfari 1975). Oxisols are the main soil type; they are deep and well-drained, but acidic and poor in nutrient availability.

Nowadays, around 18% of the regional population are family-agriculture farmers living in the countryside (IBGE 2000). The characteristics of family agriculture are long-term land use, small-scale production systems, traditional agricultural practices, and the main input of labour being the family itself. Pasture and full-sun coffee, often inter-cropped with maize and/or beans are the most important crops in the region. Other crops are sugarcane, cassava, fruits and vegetables (Cardoso et al. 2001).

Figure 1: Map of Brazil highlighting the Zona da Mata of Minas Gerais, where the systematization of the participatory experimentation with agroforestry systems took place.

2.2. The main steps of the systematization

Two researchers, one extensionist, one master student and two under-graduate students formed a research team that facilitated the process of systematization. A flexible array of tools and techniques was used for the facilitation process (Buchy and Ahmed 2007), which included a) visits and interviews with farmers, staff of CTA-ZM, and researchers, b) review, organization (in the matrix of the systematization), and analysis of the literature on agroforestry systems in the Zona da Mata, and c) workshops with farmers, staff of CTA-ZM, and researchers. The steps are described below and a synthesis is given in Figure 2.

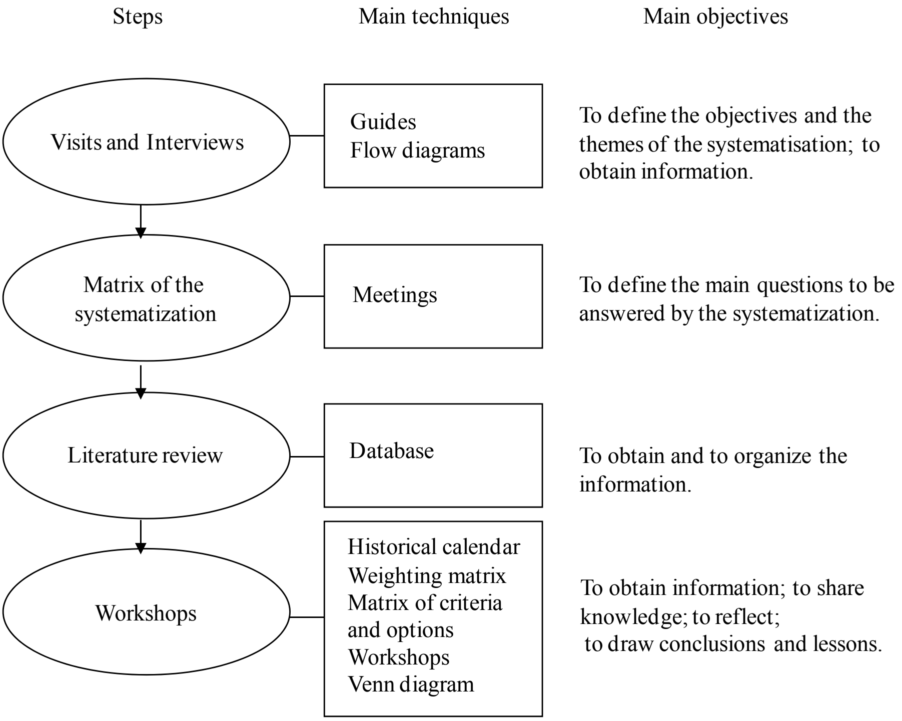


Figure 2: The main steps, techniques and objectives of each step of the participatory systematization of experience with agroforestry systems in the Zona da Mata of Minas Gerais (Brazil).

2.2.1. Visits and interviews

Before starting data organization in the systematization process, it is important to identify the starting points, the hypotheses and the objectives of the practical experience or project to be systematized. To this end, 17 farmers and eight extensionists and researchers were questioned, using semi-structured interviews (Walker et al. 1995; Rusten and Gold 1991). They were asked about the beginning and goals of the experimentation, methodology used to install agroforestry systems, technical advice, general impressions of the systems; characteristics of the experimentation sites, lessons learned etc. The farmers were interviewed on their properties, so the agroforestry systems could be observed during the interview.

2.2.1.1. Flow diagram

Besides the interviews, a flow diagram technique (Thompson and Guijt 1999) was used during the visits of two properties. The flow diagram allows knowing and evaluating the inputs (arrows pointing at the central circle) and outputs (arrows pointing away from the central circle) of the agroecosystems, such as products and services (Figure 3). It also allows identifying the links of the agroforestry systems with the other agroecosystems of the property (Thompson and Guijt 1999). While constructing the diagram, we discussed the information with the farmers.

The interviews and visits were also used to define the objectives of the systematization and the steps to be followed in the process of systematization.

2.2.2. The systematization matrix

In discussion meetings, the research team that facilitated the process defined the themes and sub-themes of the matrix of systematization (Table 1). These themes and sub-themes were the basis for gathering and organizing the information considered relevant to reach the objectives of the systematization, and helped in identifying activities and resources employed to achieve the outcomes, as well as identifying important assumptions or questions to be answered during the systematization (Douthwaite et al. 2003).

According to Diez-Hurtado (2001) the columns of the matrix are the main themes, from which we can extract lessons. The components or sub-themes are the rows of the matrix, and one sub-theme can belong to more than one theme. The themes and sub-themes depend on the goals of the systematization. The combination of one theme and one sub-theme formed one cell of the matrix. We organized the information on a sub-theme within a theme for each cell, by raising questions. These questions guided the search for information. The construction of the matrix was dynamic, i.e., the cells were modified during the systematization, based on the questions and answers. If two cells would contain the same question, one of the cells was eliminated (Table 1).

To help answering the questions, we searched for information in the literature produced by CTA-ZM and partners from 1993 to 2003 related to the experimentation with agroforestry systems. Several documents were produced during the experimentation. Seven PhD and master theses, eight scientific papers and several technical reports and folders were written, lectures were given and the results were presented at conferences. However, the information was scattered, which hindered its use in improving the management of the agroecosystems.

Table 1. Matrix used to organize the information related to the agroforestry systems experimentation. Columns show the themes, rows the sub-themes of the matrix. Examples of questions linking the themes and sub-themes are given in the cells.

Sub-themes	Themes		
	Institutional intervention	Family farmers’ participation	Impacts
Design and management of the systems	What was the history of the institutional intervention related to the agroforestry systems?	What was the influence of the farmers in the design and management of the agroforestry systems?	How were the agroforestry systems designed and modified?
Connection of agroforestry systems with other agroecosystems	Did CTA-ZM support and advise the links of agroforestry systems with other agroecosystems?	How did the farmers connect agroforestry systems with other agroecosystems?	What were the impacts of agroforestry systems on other agroecosystems?
Environmental aspects (fauna, flora, soil, water, climate) at the property	Did CTA-ZM use the results from agroforestry systems on environmental services as benefit to all community?	What were the environmental characteristics used to define the site of the agroforestry systems?	What were the results of the environmental impacts of agroforestry systems?
Partnership	How did CTA-ZM implement partnership?	x	x
Methodology	Did the methodology help in empowerment of the farmers?	x	x
Market	What strategies were developed to create a market for the products of diversification?	x	x

x: Questions of those cells were answered in other cells.

2.2.3. Workshops

As part of the systematization process, we organized six workshops, with farmers, extensionists and researchers. The objectives of these workshops were a) to gather, qualify and quantify the information; b) to create interactions among the participants to promote reflection on the successes and failures of the agroforestry systems and c) in this process, we expected to co-create knowledge in a social learning process (Jiggins 2001). To assure everybody's participation, we used PRA techniques, such as an historical calendar, a weighting matrix, a matrix of options and criteria, and a Venn diagram. These tools have been used to assist facilitation and have been important in learning processes (Steyaert and Jiggins 2007). Below we present each of these techniques in turn.

2.2.3.1. Revisiting the history – First workshop

Seventeen farmers from different municipalities participated in one workshop of three days. During the workshop, we recovered the history of the experimentation, highlighting the main events and pointing out the adopted management. In this workshop we used the historical calendar, the weighting matrix and the matrix of options and criteria.

a) The historical calendar

To construct a historical calendar (Geilfus 2000), the key events remembered by the participants were written on a card and put on a wall in chronological order. In this way, the specific experience of every participant was registered.

b) Weighting matrix

The weighting matrix (Geilfus 2000; Mejía and Croft 2002) was used to deepen the understanding of the results obtained, especially with respect to soil. Based on the historical calendar, the research team divided the experimentation in five phases (periods) and selected the main themes highlighted by the farmers. We outlined the rows and the columns of the matrix on the floor. The phases and themes of the experimentation were written on cards. These phases and themes were used to build the weighting matrix. We placed the cards with the phases in the rows and with the themes in the columns of the matrix.

To evaluate the themes in each phase the farmers used gravel (an available resource). During the discussion, the farmers commented on what happened in each period and the weight of the event. Then, the farmers allocated different amounts of gravel in each cell of the matrix, representing, quantitatively what happened in that phase. By comparing one cell with others, the farmers increased or decreased the amount of gravel in each phase. Often, they would go back to the previous phase to change the weight of the events there. With this technique, it was possible to graphically represent changes and to highlight the relevant aspects of interventions in the agroecosystems.

c) Matrix of options and criteria

This matrix was used to identify the criteria used by the farmers to select trees to intercrop with coffee. The names of the trees (options) used in the experimentation and the main function (criteria) to use or to refuse trees were listed and written on cards. These cards were placed in the column (trees) and in the rows (criteria) of the matrix. In the cells of the matrix, the number of farmers that agreed upon those criteria was noted.

2.2.3.2. Sharing the scientific knowledge – 2nd workshop

Several investigations were carried out in the farmers' agroforestry fields. However, some of the results had not been presented to the farmers, to this end; a 2nd workshop was organized.

The researchers presented and discussed the main objectives, methodologies, results and conclusions with the farmers. Among the themes and topics were the origin of the experimentation with agroforestry systems, diagnostics and design of the agroforestry systems, geoprocessing and land occupation around the State Park of Serra do Brigadeiro, soil management and erosion, nutrient cycling, problems and hypotheses in science, etc.

2.2.3.3. Analyzes and conclusions – 3rd, 4th and 5th workshops

Three workshops (half a day each) were held to present and analyze the results of the systematization and to draw conclusions. Obviously, new information was gathered in each workshop and was incorporated and analyzed as result of the systematization. Each workshop had the same goals, but the participants differed. Farmers participated in two workshops, organized in different municipalities, to facilitate the participation of the farmers. The extensionists from CTA-ZM participated in the third workshop. The different workshops for extensionists and farmers intended to highlight different understandings of the process.

a) Workshops with the farmers

The results of the systematization were presented to the farmers using cards, posters and diagrams. In these workshops we used Venn diagrams (Geilfus 2000) to analyze the institutional relations established during the experimentation. First the farmers listed the key organizations and key persons that influenced the experimentation. Each name was written on round cards of various sizes. The biggest card, representing the agroforestry systems, was placed on the floor, and the other cards were placed one by one around it. The distance to the card representing the agroforestry systems denoted the proximity of the organization or person to the agroforestry systems. The size of the cards denoted the importance of the organization or person for the experimentation.

b) Workshop with the extensionists

The extensionists received a preliminary report of the systematization to be read before the workshop and to be discussed during the workshop. In the workshop, we discussed the general understanding of agroforestry systems by each participant. We presented some definitions of agroforestry systems from the literature as well as the definition by the farmers to initiate the discussion.

2.2.3.4. Learned lessons – 6th workshop

As a synthesis of all processes we organized a report of the systematization with the results and preliminary lessons or recommendations. This material was presented and discussed with farmers and extensionists in the sixth workshop for a final analysis and discussion of the results as well as for drawing lessons from the experience. Nineteen farmers, three extensionists from CTA-ZM and four researchers participated in the workshop. The workshop was organized in three parts: symbolic re-construction of an agroforestry system, b) discussion of the principles of sustainable agriculture in an oral presentation, and c) lessons or recommendations.

To extract lessons or recommendations, the participants were organized in four groups. Four texts were extracted from the preliminary report of the systematization and made available to the participants. The topics in the texts were: a) design and management of the systems and the plant species used, b) connections among agroforestry systems and the other agroecosystems; c) methodology and participation of the farmers involved in the experimentation with agroforests; d) diversification of the production, market, environmental services, sustainable attributes and their broad impacts. To make the process of reading and extracting lessons more dynamic, the texts were distributed separately in four sites (topics a-d). The groups moved from one site to the other. Each group wrote the lessons they extracted from the process on cards. The cards were left on the site and the next group was only allowed to read it after extracting its own lessons. In a plenary meeting, all the lessons were presented and discussed to reach an agreement.

After all the workshops, the research team re-wrote the report analyzing the experimentation process, and drawing the main conclusions (based on farmers information and scientific data). With suggestions of the 6th workshop, the research team prepared a diffusion plan and suggested the elaboration of informative materials, released for different target groups.

3. Results

3.1. Visits, interviews and flow diagram

The interviews and visits showed that the farmers had worked with agroforestry systems for more than 10 years, even during the interruption of technical support by CTA-ZM. The farmers had started the systems at the most degraded sites of their properties. The systems were designed and re-designed, many trees were removed and others were introduced during the experimentation, which led to differences among the systems. There were also differences in the management and the location of the systems within each property.

The systems represented in the flow diagram (Figure 3) were diversified, i.e., produced other products than coffee. Among the products were food for the family and animals (banana, cassava, avocado, inga, sugar-cane, popcorn), wood and firewood. According to the flow diagram, the main inputs into the systems were labour and organic fertilizer. The learning from the social networks was considered as output as well as input of the systems.

3.2. The systematization matrix

The main themes recognized by the research team were institutional intervention, participation of the family farmers and impacts. The sub-themes were the design and management of the systems, connection of the agroforestry systems with other agroecosystems of the property, environmental aspects (fauna, flora, soil, water, and climate), partnership, methodology for the implementation of agroforestry experiments, and market (Table 1). In the cells of Table 1, we show examples of raised questions. In total, we consulted 62 documents (theses, papers, reports, folders, etc). All material was screened according to the matrix cells (Table 1). For each cell, we wrote a summary of the information that could help to answer the questions related to that cell.

3.3. Revisiting the history –The historical calendar

Table 2 shows the main events recovered through the historical calendar. The history of the experimentation started at the end of 80’s. During this decade (80’s), redemocratisation of Brazil took place and the social movement became more active. The grassroot movement linked to the Catholic Church (Liberation Theology) contributed to the organizations of the farmers, including the Family Farmer Unions. CTA-ZM started working with these organizations, searching for alternatives to the green revolution technologies. One of the alternatives proposed was the use of green manure. A PRA carried out in Araponga pointed to soil quality as one of the main problems. To cope with this problem, CTA-ZM and partners from the UFV suggested experimentation with agroforestry systems, amongst other alternatives. After the PRA, the installation of the State Park of Serra do Brigadeiro in the region was being discussed. The agroforestry systems were proposed as a good technology to be used by the farmers, especially those living at the border of the natural park.

The farmers started experimenting with agroforestry systems. After one year of experimentation, an agronomist working with agroforestry systems in the Northeast of Brazil, started cooperating as a consultant of CTA-ZM. He suggested increasing the diversification of the systems, which means increase the number of species and individuals of trees in the coffee systems. This resulted in low productivity of the coffee due to competition for light, water and nutrients among trees and coffee plants. These problems were evaluated during and after a participatory monitoring carried out in Araponga. After the evaluation, the farmers received subsidy to maintain and modify their systems. In 2001, the farmers supported by CTA-ZM started a process of certification for organic coffee. For this process, information from the participatory experimentation with agroforestry systems was requested, for instance, how to improve soil fertility with local resources. This was the direct reason for organizing the systematization (Table 2).

Table 2: Historical Calendar of the Main Events of the Participatory Experimentation with Agroforestry Systems.

Years	Events
1980/1988	• Foundation of the Family Farmer Unions and grassroots movement.
1989	• CTA-ZM (Centre of Alternative Technologies of Zona da Mata, non-governmental organization) started on-farm experimentation with green manure.
1990-1993	• Participatory Rural Appraisal (PRA) in Araponga indicated soil conservation as one of the main problems. • CTA-ZM started a specific program on agroforestry.
1994	• Discussions related to the implementation of the State Park of Serra do Brigadeiro. • Start of participatory experimentation with agroforestry systems
1995	• External consultancy on agroforestry systems.
1996	• More tree species were included in the systems.
1996/1997	• Participatory monitoring • Agroforestry coffee production was low.
1998-1999	• Discussion of results of the monitoring and evaluation of agroforestry systems. • Farmers received subsidy to continue with agroforestry systems. • Modification of agroforestry systems.
2001-2002	• CTA-ZM stopped agroforestry program. • Start of organic coffee certification. • CTA-ZM decided to carry out systematization.
2003-2004	• Participatory systematization.

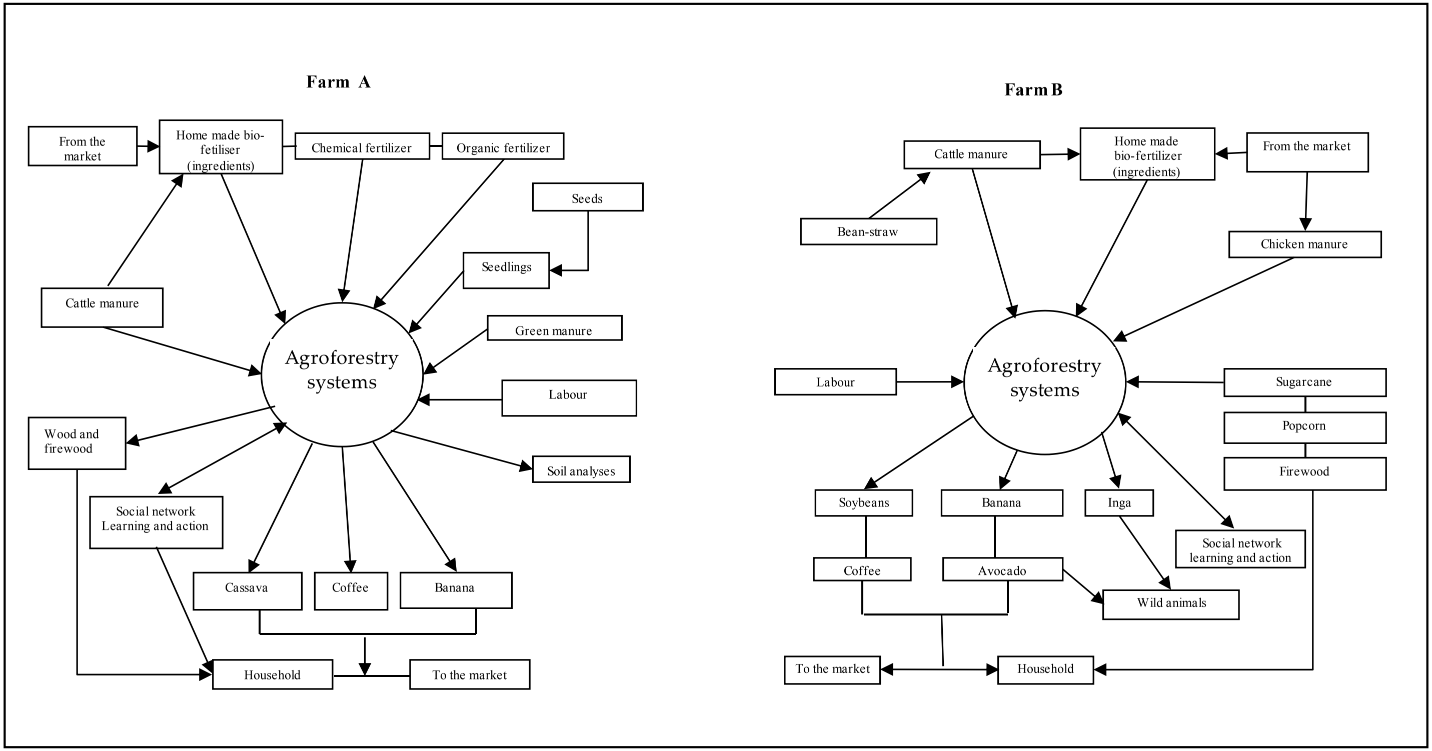


Figure 3: Flow diagrams of property 1 (in the municipality of Araponga) and property 2 (in the municipality of Divino) representing the outputs (arrows pointing at the central circle) and inputs (arrows pointing from the central circle) of the agroforestry systems in the Zona da Mata of Minas Gerais (Brazil).

3.4. Weighting, options and criteria matrices

The result of the weighting matrix, representing the themes within the phases is presented in Table 3. The phases or periods were a) awareness of the experimentation (before 1993); b) implementation of the agroforestry systems (from 1994 to 1995); c) increasing the diversification (from 1996 to 1998); d) evaluation and re-design of the systems (from 1999 to 2002) and; e) systematization of the experience (from 2003 to 2004). The main themes highlighted by the farmers were: a) the amount of trees present in the agroforestry systems, b) soil quality, c) costs, d) coffee production and e) coffee quality.

Table 3: Weighing Matrix. Columns Represent the Periods, Lines Are Themes Related to the Agroforestry Systems Experimentation.

Theme	Period				
	... 1993	1993-1995	1996-1998	1999-2000	2001-2004
Amount of trees	●●	●●●●●●	●●●●● ●●●●● ●●●	●●●●	●●●●●
Soil quality	●●	●●●	●●●●	●●●●●●●●	●●●●● ●●●●● ●●●●
Costs	●●●	●●●●● ●●●●●	●●●●●●	●●●●●●	●●●●●●
Coffee production	●●●● ●●●●●	●●●●● ●●●●●	●●●	●●●●●	●●●●●
Coffee quality	Not considered	●	●●●●	●●●●● ●●●●●●	●●●●● ●●●●● ●●●●●

● Represents the weight that farmers gave to each theme in each period by putting stones in the respective cells; each bullet (●) indicates a stone; more bullets signify more weight.

Besides the discussion during the construction of the weighting matrix, the synthesis of the information from the first workshop allowed us to better characterize phases of the agroforestry experiments (Table 3). Before 1993 (the awareness phase) there were few or no trees intercropped with coffee. The quality of the soil was not good. The costs were due to external inputs and labour. The most important event in this phase was the PRA carried out in Araponga

(Table 2). From 1993 to 1995 (the implementation phase), the amount of trees increased. In this phase, several meetings and field work were organized to learn about agroforestry systems. The production and quality of the coffee were the same as in the previous period. From 1996 to 1998 (phase of increasing diversification), the amount of trees increased even more than the period before. There was a negative effect on coffee production, and the labour and costs necessary to manage the system also increased. On the positive side, according to the farmers, soil quality and coffee quality also increased.

The phase of increasing the diversification led to the use of more plant species in the coffee fields, including some exotic species unknown to the farmers (for instance, elephant grass). The idea was to speed up the biomass production and to increase nutrient cycling through pruning. The principles of succession and management of the species were profoundly discussed. Most of the discussions and suggestions were given to the farmers in the field, however, the input of the farmers was not acknowledged sufficiently. Therefore, the participation principles were not fully followed during this phase. While increasing the diversification, the labour demand increased. In this phase, coffee production diminished, mainly due to competition. Moreover, the species used were mainly for biomass production and did not serve as food or commercial purposes.

From 1999 to 2000, the systems were evaluated and re-designed. During a participatory monitoring, the farmers evaluated the systems. The problems due to increasing diversification were raised and everybody was critical about the number of tree species to be used. It was clear that modifications were necessary. It was also clear that a new round of modifications should be better discussed in groups and that the local knowledge should be better valued. However, the ecological principles learned from the phase of increasing diversification were of high importance and was acknowledged by the farmers during the systematization. The farmers asked for a subsidy to continue the experimentation. The Environmental Ministry, through a federal governmental program called “Subprograma de Projetos Demonstrativos do Tipo A” (PDA), granted a project to subsidize the farmers. To receive the subsidy, farmers and CTA-ZM agreed upon some criteria, such as the will to keep the agroforestry systems experimentation. To this end, a definition of agroforestry systems was given by the farmers: agroforestry systems should have three strata, a high stratum of diversified trees, a middle stratum (bushes), including coffee, a low stratum (herbs), and including spontaneous vegetation, green manure and annual crops.

During the redesigning phase some tree species less suitable for intercropping with coffee were removed. During this period production diversified and, according to the farmers, soil and coffee quality improved. Costs, mainly due to labour, were still high and coffee production increased somewhat (Table 3).

From 2001 to 2004 (systematization of the experience) the number of trees on the properties increased, as well as, according to the farmers, the soil and coffee quality. The learning with the agroforestry systems experiment triggered the farmers to plant or to allow spontaneous trees growing in other agroecosystems of the farms. Costs stabilized and coffee production was considered good, although it was less compared to the first period of the experimentation. The production depicted by the farmers refers to the production per hectare. The density of coffee plants in some cases was less in agroforestry systems than in full-sun coffee. Considering 2000 coffee trees per hectare, some farmers stated that they produced the same amount in both systems (around 720 kilos per hectare). At least four farmers reported increase in the amount and quality of water in the springs after changing the management of the systems.

During the construction of the matrix of options and criteria the farmers listed around 80 tree species used in their agroforestry systems. The matrix allowed highlighting the knowledge acquired by the farmers through observation of native and exotic tree species intercropped with coffee plants. The most common were *Inga subnuda, Senna macranthera, Persea americana, Cecropia hololeuca, Musa sp., Solanum argenteum, Ovenia dulcis, Aegiphila sellowiana, Luehea grandiflora* and *Zeyheria tuberculosa.* The main functions of the trees in the systems were soil cover, nutrient cycling, food (for humans and animals), wood for small construction, firewood, shade and attraction of wild animals.

The diversification of agroforestry systems was important for increasing food security and sovereignty and the income of the families, as the farmers reduced the amount of external inputs and purchased food products. Moreover, the farmers considered more diversified food and the abandonment of pesticides as key factors for better health. This also means that less money was spent on medicine, an indirect way to increase income. All together, these are indicators of livelihood improvement.

The design and management of the agroforestry systems were specific for each property, but some criteria for tree selection could be generalized, for instance, the tree species have to be compatible with the coffee crop, produce high amounts of biomass, require low input of labour and should diversify the production.

3.5. Sharing the scientific knowledge

The workshop pointed at some of the successes and challenges of the research on family agriculture, as well as the benefits and problems of agroforestry systems. One of the challenges was to carry out research with farmer participation at all phases of the research.

3.6. The Venn Diagram

From the Venn diagram, we grouped the types of social relations with institutions or groups constructed during the experimentation process into three categories: partner, ally and opponent (Figure 4). In some cases, the relations with an institution or person differed among groups of farmers. This was due to the specificities within the region. For instance CPT (Comissão Pastoral da Terra - a grassroot organisation) is not active in some municipalities. In other municipalities, farmers have more problems with pesticides (such as intoxication) that are sold in local markets.

The farmers considered the CTA-ZM, the Soil Science Department, the grass roots organizations (CEBs - Comunidade Eclesial de Bases and CPT) and the Family Farmer Unions as partners. Partners contributed during the entire process and were in favour of the agroforestry systems. Allies were defined as the ones who were in favour of the agroforestry systems but contributed sporadically. The farmers included as ally the Federal Program (PDA), which subsidized the experimentation; the consultant during the phase of making the systems more complex; the Regional Association of the Farmers from Zona da Mata; and the Ford Foundation that gave financial support to the agroforestry program of CTA-ZM. Opponents did not support the experimentation and in some situation discouraged it. One group of farmers included the State Institute for Forestry as opponent, because of conflicts created due to use of protected areas. The protected areas are, for instance, the tops of the hills and slopes steeper than 45°. The agricultural farmers have historically used some of these areas, because of a lack of land, but law forbids this.

Recently, there was a modification of the law that allows family agriculture to use the protected areas for agroforestry systems under specific conditions. Farmers also considered the multinationals Bayer and Monsanto as opponent, because they produce and sell pesticides, which create dependency and are harmful for environment and health. The agroecological farmers do not use pesticides, which they consider as an improvement of the quality of life.

3.7. Workshop with the extensionists

Because of the problems in the phase of increasing the diversification, the extensionists were skeptical of agroforestry and were surprised that some farmers continued with their experimentation. During the discussion, they recognized the importance of agroforestry for agroecological management of family farming systems in the Zona da Mata.

The workshops with the farmers and extensionists were important to evaluate the results presented by the research team. In general the results were considered consistent and correct. For instance, there was agreement on the phases of the systematization. However, some results were modified. For instance, the research team considered the external consultancy that led to more complex systems as a negative event, whereas the farmers classified it as positive.

The research team suggested several materials for the diffusion of the main results, lessons and recommendations from the systematization, each for a different target group. Among the materials, folders, bulletins and videos were elaborated. Lectures and posters were presented in conferences, workshops and seminars. Courses were given for different audiences. Several visits were paid to the farmers' agroforestry systems.

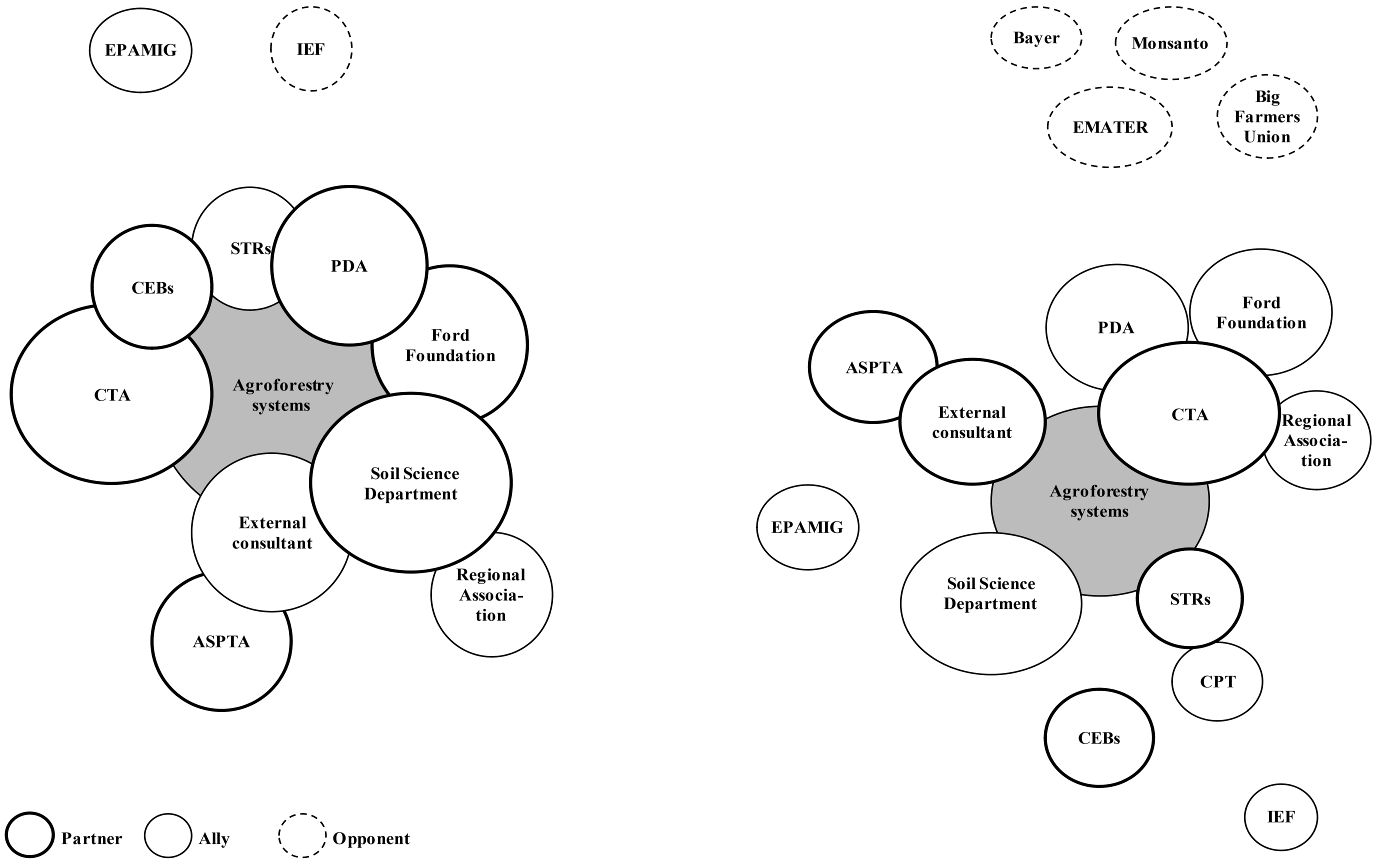


Figure 4: Venn diagrams of institutional relations identified during the participatory experimentation with agroforestry systems. Acronyms: EPAMIG: State Research Council of Minas Gerais; CEBs and CPT: grassroot movements; STRs: Agriculture Family Farmers Unions; IEF: State Institute for Forestry; PDA: Federal Demonstration Program; CTA-ZM: Centre of Alternative Technologies of Zona da Mata; ASPTA: Alternative Technologies Program Consultants.

3.8. Learned lessons

The main learned lessons (considered conclusions) were: a) the agroforestry systems increased biodiversity, diversified the production and reclaimed abandoned or unproductive areas, b) after some years of experimentation the coffee productivity can equal that of full-sun coffee systems, c) there was more equity: the community benefited from the agroforestry systems because there was improvement of environmental services such as soil quality and water quality and quantity, d) there was stability and resilience: even when the farmers did not get good results they kept their experimentation and could revert the negative results into positive results later on, e) with the diversification there was more autonomy of the farmers, because they did not rely only on coffee; and e) the participatory methodology used in the experimentation was flexible, allowing changes wherever the farmers wanted.

The main five recommendations are presented in Box 1. The farmers have to pay attention to some criteria to select trees to be intercropped with coffee plants; it is important to establish partnerships to develop agroforestry systems; the academic researchers to study the agroforestry systems are welcome but they have to be participative and, with special criteria, the agroforestry systems can be used by family farmers even in protected areas, because the systems increase biodiversity and protect the environment.

Box 1. The main recommendations emanating from the participatory systematization of long term experimentation with agroforestry systems.

- The farmers have to pay attention to criteria to select trees to be intercropped with coffee crops, in particular compatibility of the tree with the coffee crop, the degree of diversification of the production provided by the trees, the amount of biomass produced by the trees and the amount of labour necessary to manage the trees.
- It is important to establish partnerships to conduct innovative and complex experimentation with agroforestry systems;
- The academic research carried out on the farms has to be done in a participatory way; farmers have to be involved in all phases of the research, from the problem statement to the discussion of the results.
- The experiments pointed out that agroforestry systems are suitable for family farmers in protected areas. Therefore, modifications in the law to that end are welcomed and the experience with agroforestry systems developed in the Zona da Mata can contribute to those modifications.

4. Discussion

The participatory systematization served to highlight the learning with agroforestry experimentation by the participants and to understand the dynamics of the process of experimentation locally and regionally. The participatory construction of the historical calendar (Table 2) allowed all participants to see the whole picture and to identify the important points of experimentation. Together, it was easier to recover the process and to share impressions, learnings and doubts, whereas it would be impossible for single individuals to remember all the details. It was thus possible to understand that the specificities of each experience consequently led to a heterogeneity of problems but also of solutions as argued by Moors et al. (2004). The construction of the weighting matrix (Table 3) helped to share information and to reflect on the experimentation. Nasi (2010) states that farmers and stakeholders must be aware that uncertainties exist, especially in systems driven by external forces such as climate and human demands. Therefore, the management of each agroforestry system needs to be flexible, taking into account local and regional temporary circumstances.

The workshops allowed a better understanding of the biophysical-chemical processes in the soil related to the agroforestry systems, aboveground interactions, as well as socio-political influences, which can either contribute to, or obstruct the advance of environmental friendly agriculture. Therefore, the workshops enlarged knowledge on agroecological management and its impacts at the local and regional scales. With the experimentation, farmers and scientists learned and shared their knowledge with others during meetings, visits or courses promoted by CTA-ZM, by the Farmers' Unions and by the University. This process contributed to the creation of new knowledge, in a social learning process (Jiggins 2001). The experimentation at a small scale was a way to learn a new technology, used by the farmers to modify the management of the entire property. The effective integration of indigenous knowledge (Walker et al. 1995) facilitated the learning of the agroforestry technology by the farmers. For instance, the participatory experimentantion with agroforestry systems triggered the farmers to plant or to allow spontaneous trees growing in other agroecosystems of the farm. In doing so, more knowledge was created and shared with others, feeding another cycle of learning.

Chambers (1989) states that farmers deal well with challenges imposed by complex land use systems such as agroforestry systems. Their skill is developed during their continuous interaction with the complex environment. Observation of environmental characteristics, of responses to specific changes in agroecosystems, and of livelihood aspects are kept in the living memory of farmers and become of high relevance to the management of the agroecosystems (Barrios and Trejo 2003). The use of appropriate methods, as used by the research team during the systematization process, that trigger the participation of the farmers, can help them to document, analyze, and predict ecological and land use changes (Rocheleau 1994). At the same time these methods help the scientists to gather and use the generated information to co-create, with the farmers, new knowledge.

The social learning process and the participation in the design, monitoring, evaluation and adjustment of the agroforestry systems were essential for the continuity of the experimentation process. The participatory process enabled the farmers to continue with the agroforestry systems even when encountering difficulties, allowing agroforestry to show its potential. According to Sanchez (1995) agroforestry systems can be efficient, productive, and ecologically sustainable, but they have to be adopted and maintained over long time periods to contribute to sustainable land use.

Agroforestry was a new technology for both the farmers and the extensionists. As innovation is a social process in which users ‘socially construct’ new technology (Douthwaite et al. 2003), the social learning approach (Blackmore 2007) used was the key to the success. In the process of learning, the academic research was useful to support farmers’ innovation and practices to improve the management of their agroecosystems.

According to Holliday (2006), every interpretation based on a systematization of an experience should give theoretical and practical conclusions. Although the experimentation in this study differed among fields and farms, we were able to generalize practical lessons (considered as conclusions) and recommendations from the systematization, based on the principles of sustainable agriculture, which are productivity, equity, stability and resilience, autonomy and flexibility (Altieri and Nicholls 2002; Miranda 2002). However, the ecosystem services provided by the agroforestry systems, such as reducing soil degradation (Dominati et al. 2010), have to be critically evaluated. Such studies have been carried out or are in progress, e.g., on soil (Cardoso et al. 2003) and water (Ferrari et al. 2010) quality, the diversity of fruit and non-fruit trees (Siqueira 2008) and coffee productivity (Miranda 2002).

Understanding an innovation is a prerequisite to effective adaptation in terms of real farmers’ needs (Reed 2008). Thus, the systematization of local innovations created room for interacting social and ecological knowledge and practical skills of the adopters and scientists. On the one hand, participation in the innovation process and environmental knowledge sharing were essential ingredients in mobilizing and empowering farmers. On the other hand, extractive and interactive approaches helped to elucidate the questions remaining to be answered. For agroforestry practitioners to gain substantial information, having “treatments” or “plots” of agroforestry systems on their own farms for them to compare with other agroecosystems is of great value. These plots can be useful to share insights with other people and can serve as a starting point to engage these people in landscape management (Erdmann 2005).

More fully participatory experimentation in agriculture will encounter a combination of local challenges and opportunities, shared knowledge on ecological, economic and social processes linked to distinct interest of stakeholders to both improve the livelihoods and to reverse biodiversity loss and environmental degradation (Parrotta 2010). Therefore, farmers and institutions with traditionally distinct methods of acquiring and testing knowledge, both aiming at developing sustainable land use practices, can produce rich insights of mutual interest through collaboration. Consequently, this partnership becomes able to identify convergences, complementarities, and conflicts of interest that affect stakeholders and the environment.

The systematization does not finish when the final report is delivered. The results, lessons or conclusions have to be disseminated. Relative to mainstream behavioral scientists, action researchers have special needs and obligations in dissemination their findings (Sommer 2009). Dissemination involves constructing awareness of recommended solutions among future users. It involves decisions on when, to whom, and in what way to distribute technologies, supply new inputs, and teach new skills to potential users (Johnson et al. 2003). Based on the results of the systematization, new agroforestry systems were implanted by farmers and new research projects were developed by scientists. We attribute these, at least in part, to the dissemination plan, proposed by the systematization team and developed by CTA-ZM and the University.

5. Conclusions

The systematization of participatory experimentation in agroforestry systems was effective in several aspects: a) it allowed to elaborate a methodology for participatory systematization, b) it improved the methodology of design, implementation and management of on-farm participatory experimentation and c) it created possibilities for the reflection and learning about agroforestry systems by farmers, extensionists and researchers.

The PRA tools used were important to gather information in a dynamic way, but even more important in allowing the participation and the reflection of all persons involved. A matrix of themes and subthemes was an important tool to guide the process of systematization and to make it more objective.

The participatory systematization as proposed here serves to synthesize the main findings and to extract lessons from agroforestry systems experiments. Therefore it is more than a process to list the negative or positive result as pointed out in some system evaluations. Rather, it is a tool to foster innovation.

Acknowledgements

The authors thank the farmers for sharing this experience, the Brazilian sponsors FAPEMIG (Fundação para o Amparo da Pesquisa do Estado de Minas Gerais), for financial support, CAPES (Coordenação de Pessoal de Ensino Superior) for a scholarship to the first author and Arne Janssen, Paul Hebinck and Lijbert Brussaard for useful comments and corrections on an earlier version of this paper. The research was carried out in one of the eight benchmark areas of the agroBIODIVERSITY network of DIVERSITAS, the International Organization for Biodiversity Science (http://www.agrobiodiversity-diversitas.org/).

Chapter Three

Selection of native trees for intercropping with coffee in the Atlantic Coastal Rainforest biome

Helton Nonato de Souza [1], Irene Maria Cardoso[2a], José Martins Fernandes[3], Flávia Carvalho Pinto Garcia[3], Verônica Rocha Bonfim[4], Alvori Cristo Santos[5], Eduardo de Sá Mendonça[6]

[1]Department of Soil Quality, Wageningen University, PO Box 47, 6700 AA Wageningen, The Netherlands
[2]Department of Soil and Plant Nutrition, Federal University of Viçosa; Brazil, Campus UFV, 36571000
[3] Department of Plant Biology, Federal University of Viçosa, Brazil, Campus UFV, 36570000
[4] Centre of Alternative Technologies of Zona da Mata, Viçosa, Brazil, PO Box 128, 36570000
[5]Departament of Rural Socio Economic Studies, Paraná, Brazil
[6] Department of Plant Production, Federal University of Espírito Santo, Alegre-ES, 29500000, Brazil

[a] Corresponding author: irene@ufv.br; phone: +51-3138991045; fax:+51-31318992648).

Published in Agroforestry Systems 80:1-16 (2010)

Selection of native trees for intercropping with coffee in the Atlantic Coastal Rainforest biome

Abstract

A challenge in establishing agroforestry systems is ensuring that farmers are interested in the tree species, and are aware of how to adequately manage these species. This challenge was tackled in the Atlantic Coastal Rainforest Biome (Brazil), where a participatory trial with agroforestry coffee systems was carried out, followed by a participatory systematization of the farmers experiences. Our objective was to identify the main tree species used by farmers as well as their criteria for selecting or rejecting tree species. Furthermore, we aimed to present a specific inventory of trees of the Leguminosae family. To collect the data, we reviewed the bibliography of the participatory trial, visit and interviewed the farmers and organized workshops with them. The main farmers' criteria for selecting tree species were compatibility with coffee, amount of biomass, production and the labour needed for tree management. The farmers listed 85 tree species; we recorded 28 tree species of the Leguminosae family. Most trees were either native to the biome, or exotic fruit trees. To design and manage complex agroforestry systems, family farmers need sufficient knowledge and autonomy, which can be reinforced when a participatory methodology is used for developing on-farm agroforestry systems. In the case presented, the farmers learned how to manage, reclaim, and conserve their land. The diversification of production, especially with fruit, contributes to food security and to a low cost/benefit ratio of agroforestry systems. The investigated agroforestry systems showed potential to restore the degraded landscape of the Atlantic Coastal Rainforest biome.

Keys words: participatory trial, agroforestry systems, agroecological management, family farmers

1. Introduction

The merit of agroforestry systems in reducing land degradation is widely accepted. This is especially important in the Atlantic Coastal Rainforest Biome in Brazil (Figure 1), one of the most endangered and fragmented habitats in the tropics (Myers et al. 2000). For instance, in the basin of the Rio Doce, approximately 1 million ha of forest remains, covering less than 15% of the total basin, most of it fragmented (Vandermeer and Perfecto 2007). The agricultural systems bordering these fragments are based on green revolution technologies and include full-sun coffee (*Coffea arabica L.*) or pasture, both of which probably impede inter-fragment migration of most organisms (Vandermeer and Perfecto 2007). In contrast, agroforestry systems could be used as buffer zones among tropical rainforest fragments and as migration corridors by interconnecting forest fragments (Vandermeer and Perfecto 2007; Harvey et al. 2008; McGinty et al. 2008).

Agroecologists recognize that agroforests mimic natural ecosystems. In doing so, agroforests increase the efficiency of use of sunlight, soil nutrients and rainfall, enhance biodiversity, promote soil quality, protect crops, and increase productivity (Altieri and Nicholls 2000). The loss of soil quality is one of the main problems faced by family agriculture in the Zona da Mata (Figure 1), located in the basin of the Rio Doce. This problem was pointed out in a Participatory Rural Appraisal (PRA) carried out in 1993 by the non-governmental organization Centre of Alternative Technologies of Zona da Mata (CTA-ZM) in partnership with farmers' organizations (mainly unions and associations) and the Federal University of Viçosa (Cardoso et al. 2001).

To overcome this problem, the farmers proposed techniques like the use of green manure and the management of spontaneous herbaceous vegetation for soil cover. In turn, personnel from the NGO (CTA-ZM) and university proposed and carried out a participatory trial with agroforestry systems. Although the coffee crop has favourable characteristics for agroforestry, full-sun coffee systems are predominant in Brazil, including in our study region, and farmers usually lack experience with agroforestry coffee systems (Cardoso et al. 2001).

Farmer education and trial are more important for the development of agroforestry systems than for monoculture cropping systems (Douthwaite et al. 2003; Mercer 2004). Agroforestry systems are knowledge-intensive and require the involvement of the farmer at all stages of their development (Mekoya et al. 2008). This learning process is only possible through diverse methodologies and a participatory trajectory, which formed the backbone of the trial carried out by CTA-ZM and partners in the Zona da Mata.

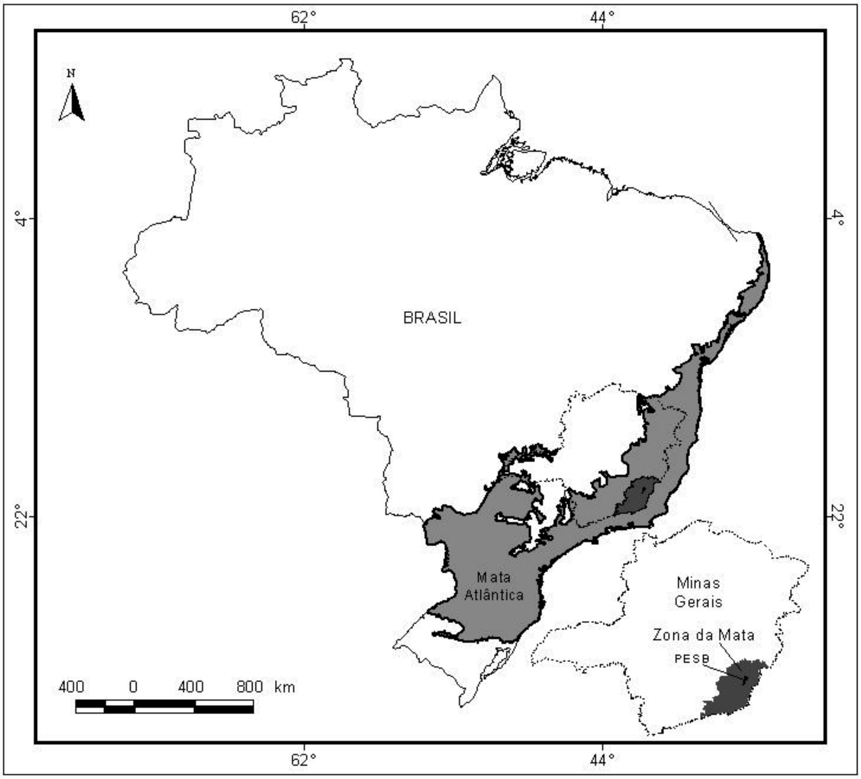


Figure 1. The Zona da Mata region, Minas Gerais State, Brazil. (PESB = Serra do Brigadeiro State Park)

The trial was necessary to develop and adapt agroforestry systems technologies to local conditions in order to effectively increase the productivity of agroecosystems and simultaneously preserve the environment. The general objectives in developing agroforestry systems were to (i) revert soil degradation, (ii) produce diversified products, and (iii) promote the use of native tree diversity. CTA-ZM and partners assisted the farmers in the design, implementation, monitoring, evaluation, and re-design of the experiments in a continuous learning process (Cardoso et al. 2001).

When implementing agroforestry systems, the farmers were encouraged to use native trees from the Atlantic Coastal Rainforest. To contribute to nature conservation, it is important to incorporate regionally vulnerable or threatened species rather than focusing on exotic or domesticated species (Méndez et al. 2007). Indeed, many farmers prefer local instead of exotic species (Mekoya et al. 2008). However, it was unknown which native tree species were most suitable in meeting the above-mentioned objectives.

Understanding the criteria needed to select trees is important in designing sustainable agroforestry systems because tree species differ in terms of their intercropping suitability. Based on their experience, farmers often have valuable ideas about these criteria. However, such knowledge is rarely investigated or reported (Soto-Pinto et al. 2007). Thus, the objective of this paper is to present farmers' criteria for selecting or rejecting tree species for their agroforestry systems as well as to report the main tree species used by farmers in the Zona da Mata. Furthermore, we present a specific inventory of trees of the Leguminosae family in order to extend the farmers' information. Leguminosae are one of the major angiosperm tree families worldwide, providing food, timber, and firewood and several environmental services like fixing nitrogen, a nutrient that limits production in tropical ecosystems. They are therefore important for the productivity of the agroecosystems and the economy and livelihood of farmers' families (Lewis and Owen 1989).

In order to analyze tree species used by farmers and their criteria for selecting or rejecting tree species, a participatory systematization was carried out (Souza 2006) after 10 years of trial (Franco 1995; Guijt 1999; Carvalho and Ferreira-Neto 2000; Franco 2000; Cardoso et al. 2001). The farmers involved in the participatory systematization were among those who started the agroforestry trial. Here, systematization is understood as systematic organization; the act of organising something according to a system (Oxford Advanced Learner's Compass dictionary) or a rationale (www.wordreference.com). We gathered, organized, and synthesized the knowledge and experience acquired by the farmers throughout the trial period. We used a participatory approach, in which farmers were involved in a process of reflection and analysis.

2. Materials and Methods

2.1. The study site

The Zona da Mata has a tropical highland climate with an average temperature of 18° C, average precipitation of 1500 mm $year^{-1}$, and 2-4 dry months per year. The area is hilly, with slopes ranging from 20% to 45% and altitudes from 200 m to 1800 m (Golfari 1975). Oxisols are the main type of soils; they are deep and well-drained, but acidic and poor in nutrient availability. The combination of deep soils with hilly slopes has led to the formation of several springs and streams. Brazilian law protects and restricts the agricultural use of the areas on hilltops, steep areas, stream margins, and areas surrounding springs (Brasil, 1965). In the Zona da Mata, this includes most of the landscape (Freitas et al. 2004). Although protected, the farmers continue to use these areas, not always in ways that conserve the landscape and biodiversity.

This region has a long history of soil degradation. Land cover has passed through a cycle that started in the mid of the 19th century with Atlantic Coastal Rainforest being replaced by full-sun coffee plantations. This broke the nutrient cycling in the system, causing erosion and nutrient loss via harvesting, thus drastically reducing soil fertility. Farmers occupied new areas in search for fertile land for coffee, which aggravated deforestation and degradation. Meanwhile, pasture and staple food crops (maize, beans and others) replaced coffee in the old fields (Valverde 1958; Dean 1995). Nowadays, pasture and full-sun coffee, often inter-cropped with maize and beans, are the most common agroecosystems in the Zona da Mata. The main cash crop is coffee, which is cultivated on approximately 200,000 ha (IBGE 2005). Other crops include sugarcane, cassava, fruits, and vegetables (Ferrari 1996; Cardoso et al. 2001). Most agroecosystems in the region have low productivity due to the long history of (increasingly) intensive soil use with practices not well adapted to the environment. In spite of this, production by family agriculture has maintained its vital importance within the region (Ferrari 1996). As the remaining forest fragments are protected, farmers cannot occupy new areas and have to search for alternative types of land use and management to cope with environmental degradation. One of these alternatives is agroforestry, which has recently become permitted by law (Ministério do Meio Ambiente 2006), to be used by family agriculture in the protected areas mentioned above. However, in the Zona da Mata, family agriculture was ahead of the law and started trials with agroforestry far before it was formally allowed.

From 1994 to 1997, 39 on-farm agroforestry experiments were established in 11 municipalities of the Zona da Mata. These municipalities are adjacent to the “Serra do Brigadeiro” State Park (Figure 1), one of the most important protected areas in the region, which was established in 1996 and measures approximately 10000 ha. Another reserve which is partially in the region is the Caparaó National Park. The agroforestry experiments involved 33 small-scale farmers, 37 of the experiments focused on coffee and 2 were with pasture. The experiments were established in degraded full-sun coffee (spaced at 3 x 1.5 m) fields (Cardoso et al. 2001). The average area of each agroforestry system was 0.45 ha (se = 0.14), ranging from 0.11 to 1 hectare (Franco 2000). The total area per farm was mostly less than 20 ha. Trees were planted between coffee plant rows or resulted from regeneration. The age of the coffee fields in which the experiments were started varied, but was in general less than 10 years. When the experiments were established, tree and shrub densities were very high, for instance, in one farm it reached 920 seedlings/ha, in order to maximise biomass production (Cardoso et al. 2001).

2.2. Systematization of the trials

In total, 17 family farmers (and 17 farms) from 7 municipalities (Araponga, Miradouro, Eugenópolis, Espera Feliz, Divino, Carangola and Tombos) were involved in the systematization process. Not all 33 farmers who started the agroforestry trial could be contacted or were available to participate in the systematization. However, we considered the families that participated representative of the 33 farmers who started the trial. The methodology of the systematization was adapted from Diez-Hurtado (2001). It comprised of organising and synthesising the bibliography on the trial, consisting of 62 documents (theses, papers, reports, folders, etc); visits to and observations of the agroforestry systems; interviews and a workshop with the 17 farmers, 5 technicians, and 6 scientists who participated in the trial. Techniques from the PRA were used in the workshop, specifically the matrix of options and criteria (adapted from Horn and Stür 2003).

2.2.1. Visits and interviews

We visited and interviewed the farmers (other members of the family participated in the interviews when possible) using semi-structured interviews (Oliveira and Oliveira 1982). For this purpose, we prepared general guidelines using the following subjects: general impressions of the agroforestry systems, characteristics of the tree species (deciduousness, fruit production, wood quality, and biomass production), characteristics of the trial site (slope, history of soil degradation and improvement), whether the tree species was kept or removed from the agroforestry systems and motivation to maintain or remove them, the production of the coffee plants and the trees, the design (space among the trees and position in relation to the coffee plants), and management of the agroforests (seedlings, seeds, natural regeneration, pruning - when and how), and management and quality of the soil (erosion, organic matter and soil cover). We interviewed the farmers on their properties and jointly observed their agroforestry systems with respect to the design, soil coverage, tree species characteristics, and coffee quality (Souza 2006).

2.2.2. Matrix of options and criteria

To identify the criteria used by the farmers to select trees to intercrop with coffee, a matrix of options and criteria (adapted from Horn and Stür 2003) was used in a workshop with 17 participating farmers (Table 1). The farmers included trees into the matrix that, according to their experience, were the main trees used in the agroforestry system. The farmers also listed the tree characteristics that they considered valuable for the agroforestry system. The names of the trees (considered as “options”) used in the trial and the main characteristics (“selection criteria”) of the trees were listed and written on cards. These cards were placed in the columns (options) and in the rows (criteria) of the matrix. The number of farmers that agreed upon those criteria was noted in the cells of the matrix. The higher the numbers the more farmers recognized the tree characteristic when intercropped with coffee. Empty cells or cells with low numbers indicate that none or few farmers valued the criterion in relation to a certain species, often because they did not have experience with the species in their agroforestry systems, in some case because they did not agree with the criterion. It was not possible to separate the latter two cases because of the methodology used to construct the matrix (only the farmers who agreed were recorded).

2.3. Inventory of Leguminosae

To identify the Leguminosae tree species, we collected plant material (leaves, fruits, and flowers) in 7 agroforestry systems in the municipality of Araponga. The owners of the agroforestry systems were among the 17 participants of the participatory systematization. As the species do not flower at the same time and the flower is the most important organ for species identification, we sampled plant material monthly during one year. Plant materials were herborised (Bridson and Forman 1999) and deposited in the collection of the VIC Herbarium (Plant Biology Department, Federal University of Viçosa). Species identification was based on the morphology of the collected plants and taxonomic literature and checked through comparison with collection material of the VIC Herbarium. For genus identification we used the classification system adopted by Lewis et al. (2005). For species identification, we used taxonomic reviews of the sampled genera.

2.4. Economic benefit

To compare the economic benefit of agroforestry and full-sun coffee systems, we carried out a survey of both systems. The information was gathered during the systematization process. For this comparison, we re-interviewed three farmers who started the trial with agroforestry systems and participated in the systematization. We also interviewed 5 farmers who cultivated only full-sun coffee. We questioned the farmers on the density of coffee trees per hectare, the production of coffee per tree, the price per bag of coffee and the production costs per hectare. The results were based on years of maximum coffee production because coffee plants are bi-annual (years of good production are interspersed with years of lower production). This problem occurs less in the agroforestry systems, but it was not considered in our comparisons of full-sun coffee with agroforestry coffee. We also obtained the production, the costs and the price of the commercialized products (mainly fruits) of the agroforestry systems. Based on these data, we scored the benefits as the money earned by the farmers when selling coffee without discounting the costs. Economic benefits are presented as the cost/benefit ratio.

3. Results

3.1. Visits, interviews, and matrix of options and criteria

The information obtained through visits, interviews, and the workshop, resulted in a list of 85 tree species or genera used in the agroforestry systems (Table 1). Most trees were native of the Atlantic Coastal Rainforest (55 species or genera, 65% of the total). Of the 30 exotic species, 20 (67%) were fruit trees. From the native trees, 39 (71%) were also found in forest fragments or observed in regenerating spots nearby agroforestry systems (Table 2).

Table 1: Matrix of criteria (tree species characteristics) and options (tree species) constructed with the farmers, with the aim to select trees to use in agroforestry coffee systems, Zona da Mata, Minas Gerais, Atlantic Coastal Rainforest, Brazil. Numbers in the cells refer to the number of farmers out of 17 who mentioned the tree characteristics.

	Criteria (tree characteristics)						
Options (trees)	Compatible[a] with coffee	Biomass production	No need of pruning	Food production[b]	Use as wood and fire wood	Compatible[a] with pasture, or fodder	Attract insects
Aegiphila sellowiana	7	12		6	12		12
Bombax marginatum	10	4	3	7			3
Carica papaya	3		1	3			
Cecropia sp (embaúba)	1	1	1	1	2	1	1
Dalbergia nigra	2	4	5		5	4	4
Eriobotrya japonica	1			3	3		3
Hovenia dulcis	4	3	4	4	3	2	3
Inga spp.	10	11	5	15	12	4	5
Musa paradisiaca	9	11		16			4
Persea americana	8	2	3	8		5	
Senna macranthera	6	8	1	5	11	2	
Solanum mauritianum	17	17	7	7	12	5	3
Spondias lutea	1			4			
Toona ciliate	2	2	5		5	1	

[a] Compatibility indicates that the tree is good to intercrop with coffee or pasture; [b] Food for human consumption, or for domestic and wild animals; blank cells indicate that farmers did not mention this criterion.

Table 2. Family, species and common Portuguese names of native and exotic trees used in agroforestry systems, Zona da Mata, Minas Gerais, Atlantic Coastal Rainforest, Brazil.

Family	Species (common names)	Origin	Neighbouring forest fragments or regenerating spots
Anacardiaceae	*Mangifera indica* L. (manga)	E*	
	Schinus terebinthifolia Raddi (aroeirinha)	N	Yes[a]
	Spondias lutea L. (cajá manga)	E*	
Annonaceae	*Annona muricata* L. (graviola)	E*	
	Annona squamosa L. (fruta-do-conde)	E*	
	Rollinia dolabripetala A.St.-Hil. (araticum)	N*	Yes[a]
Apocynaceae	*Aspidosperma polyneuron* Müll. (guatambu)	N	Yes[bc]
Araucariaceae	*Araucaria angustifolia* (Bertol.) Kuntze (pinheiro-brasileiro)	N	
Arecaceae	*Bactris gasipaes* Kunth (pupunha)	E	
	Cocos nucifera L. (coco-da-bahia)	E*	
	Euterpe edulis Mart. (palmito-jussara)	N	Yes[d]
	Syagrus romanzoffiana (Cham.) Glassman (coco-babão)	N	Yes[d]
Asteraceae	*Eremanthus erythropappus* (DC.) MacLeish (candeia)	N	Yes[abe]
Bignoniaceae	*Jacaranda macrantha* Cham. (caroba)	N	Yes[ab]
	Sparattosperma sp. (cinco-folhas)	N	
	Tabebuia impetiginosa (Mart. *ex* DC.) Standl. (ipê-roxo)	N	Yes[d]
	Tabebuia chrysotricha (Mart. *ex* A. DC.) Standl. (ipê-mulato)	N	Yes[abc]
	Tabebuia serratifolia (Vahl) G. Nicholson (ipê-amarelo)	N	Yes[d]
	Zeyheria tuberculosa (Vell.) Bureau (ipê-preto)	N	Yes[d]
Bixaceae	*Bixa orellana* L. (urucum)	N	
Cannabaceae	*Trema micrantha* (L. Blume. (crindiúva)	N	Yes[a]
Caricaceae	*Carica papaya* L. (mamão)	E*	
Casuarinaceae	*Casuarina equisetifolia* L. (casuarinas)	E	
Ebenaceae	*Diospyros kaki* L. f. (caqui)	E*	
Elaeocarpaceae	*Muntingia calabura* L. (calabura)	E	
Euphorbiaceae	*Alchornea triplinervia* (Spreng.) Müll. Arg. (pau-de-bolo)	N	Yes[be]
	Croton urucurana Baill. (adrago)	N	Yes[a]
	Joannesia princeps Vell. (cotieira)	N	
	Hyeronima alchorneoides Allemao (liquerana)	N	Yes[bc]
	Mabea fistulifera Mart. (canudo-de-pito)	N	Yes[d]
Lamiaceae	*Aegiphila sellowiana* Cham. (papagaio)	N	Yes[ae]
	Vitex montevidensis Cham. (maria-preta)	N	
Lauraceae	*Persea americana* Mill. (abacate)	E*	
Leguminosae	*Anadenanthera peregrina* (L.) Speg. (angico-vermelho)	N	Yes[d]
	Calliandra houstoniana (Mill.) Standl. (caleandra)	E	
	Caesalpinia pluviosa DC. (sibipiruna)	N	
	Cassia ferruginea (Schrad.) DC. (canafístula)	N	Yes[cf]
	*Erythrina verna*Vell. (pau-abóbora)	N	
	Erythrina speciosa Andrews (mulungu)	N	
	Hymenaea courbaril L. (jatobá)	N	
	Inga edulis Mart. (ingá)	N	Yes[cf]
	Dalbergia nigra (Vell.) Benth. (jacaranda-caviúna)	N	Yes[f]
	Enterolobium contortisiliquum (Vell.) Morong (orelha-de-macaco)	N	Yes[d]
	Machaerium stipitatum (DC.) Vogel (canela-de-velho)	N	Yes[f]
	Machaerium nyctitans (Vell.) Benth. (jacarandá-bico-de-pato)	N	Yes[bef]
	Piptadenia gonoacantha (Mart.) J.F. Macbr. (jacaré)	N	Yes[f]
	Schizolobium parahyba (Vell.) S.F. Blake (breu)	N	Yes[d]
	Senna macranthera (Collad.) H.S. Irwin & Barneby (fedegoso)	N	Yes[f]

Malpighiaceae	*Byrsonima sericea* DC. (massaranduva)	N	Yes[b]
Malvaceae	*Bombax marginatum* (A. St.-Hil., Juss. & Cambess.) K. Schum. (castanha-mineira)	E*	
	Ceiba speciosa (A. St.-Hil.) Ravenna (paineira)	N	Yes[c]
	Luehea grandiflora Mart. (açoita-cavalo)	N	Yes[ac]
Melastomataceae	*Tibouchina granulosa* (Desr.) Cogn. (quaresmeira)	N	Yes[ac]
Meliaceae	*Cedrela fissilis* Vell. (cedro)	N	Yes[ce]
	Melia azedarach L. (cinamomo)	E	
	Toona ciliata M. Roem. (cedro-australiano)	E	
Moraceae	*Artocarpus heterophyllus* Lam. (jaca)	E*	
	Morus nigra L. (amora)	E	
Moringaceae	*Moringa oleifera* Lam. (moringa)	E	
Musaceae	*Musa paradisiaca* L. (banana)	E*	
Myrsinaceae	*Rapanea ferruginea* (Ruiz & Pav.) Mez (pororoca)	N	Yes[a]
Myrtaceae	*Campomanesia xanthocarpa* (Mart.) O. Berg (gabiroba)	N*	Yes[e]
	Eugenia malaccensis L. (jamelão)	N*	
	Eugenia uniflora L. (pitanga)	N*	
	Myrciaria jaboticaba (Vell.) O. Berg (jaboticaba)	N*	
	Psidium araca Raddi (araçá)	N*	
	Psidium guajava L. (goiaba)	N*	
	Syzygium jambos (L.) Alston (jambo)	E	
Pinaceae	*Pinus* sp. (pinus)	E	
Rhamnaceae	*Hovenia dulcis* Thunb. (ovenia)	E*	
	Colubrina glandulosa Perkins (só-brasil)	N	Yes[d]
Rosaceae	*Moquilea tomentosa* Benth. (oiti)	N	
	Eriobotrya japonica (Thunb.) Lindl. (ameixa)	E*	
	Pyrus communis L. (pêra)	E*	
	Prunus persica (L.) Batsch (pêssego)	E*	
Rutaceae	*Citrus* sp (limão-cravo)	E*	
	Citrus sp (mexerica)	E*	
	Citrus sinensis (L.) Osbeck (laranja)	E*	
	Citrus sp (turanga)	E*	
	Dictyoloma vandellianum A.H.L. Juss. (brauninha)	N	Yes[d]
Sapindaceae	*Litchi chinensis* Sonn. (lichia)	E*	
Solanaceae	*Solanum lycocarpum* A. St.-Hil. (lobeira)	N	Yes[d]
	Solanum mauritianum Scop. (capoeira-branca)	N	Yes[d]
Urticaceae	*Cecropia* sp (embaúba)	N	Yes[a]
Verbenaceae	*Citharexylum myrianthum* Cham. (pau-de-viola)	N	

* fruit trees; N = Native of Atlantic Coastal Rainforest, E = Exotic; Yes = found in the neighbouring (distance ranging from a few meters to hundreds of meters) forest fragments or regenerating spots, according to [a]Siqueira (2008), [b]Saporetti-Júnior (2005), [c]Soares et al. (2006), [d]authors' observation, [e]Ribeiro (2003) and [f]Fernandes (2007); empty cell = no information found in the literature.

The main criteria and indicators for selecting trees to use in the agroforestry coffee systems that were given by the farmers during the visits and interviews and especially during the construction of the matrix (Table 1) are summarised in Figure 2. Two hierarchical levels could be defined. The main criterion (first hierarchical level) for selecting a tree species was the compatibility with coffee. Indicators of compatibility were the depth of the tree roots and phytosanitary aspects of the coffee trees. Incompatible species had superficial roots or caused sanitary problems to the coffee (for instance, the coffee leaves would become yellow). If compatible with coffee, other criteria and indicators (second hierarchical level) were also considered (Figure 2), mainly: a) the amount of biomass produced, b) the labour needed to manage the trees, and c) diversification of the production.

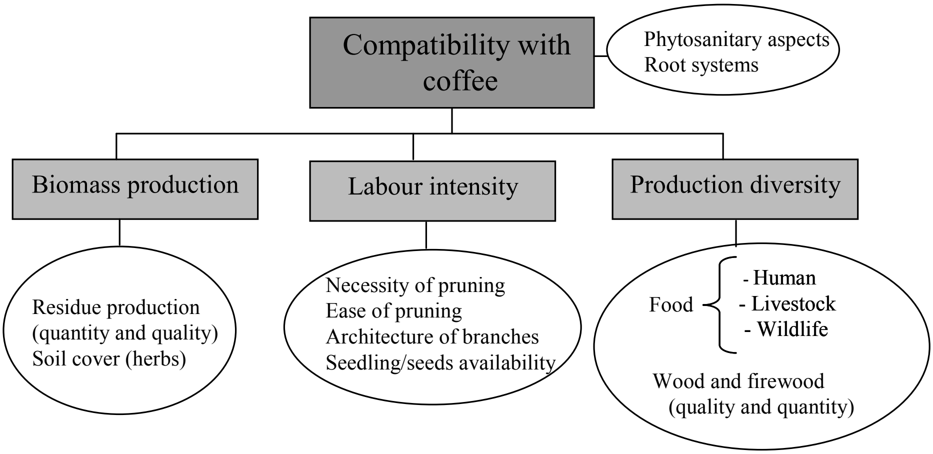


Figure 2. Criteria (boxes) and indicators (circles) used to select trees used in agroforestry coffee systems of the Zona da Mata region, Minas Gerais State, Brazil. The first box presents the main criterion or the first hierarchical level to select a tree, which is compatibility with coffee.

The main indicator for biomass production was the amount of residue produced, which includes senescent or pruned material, and soil cover, which includes the herbaceous stratum. Besides the management of trees, taking care of the herbaceous stratum is also important for the production of biomass, for soil cover, and for food production. This was done either through the introduction of species (for instance sweet potato and Leguminosae as green manure) or the management of spontaneous vegetation (so-called weeds). The farmers did not use herbicides to manage the spontaneous vegetation, but trimmed it manually or mechanically.

With respect to labour input, it was important for the farmers to use species of which seedlings or seeds could be easily obtained and species that did not need pruning or were easy to prune. The architecture of the branches was also considered important; the branches should not rest on the coffee plants. If they did, the branches should be pruned in order to avoid damaging the coffee plants. When trees were planted in the coffee fields, the seedlings were sometimes taken from naturally regenerating spots outside the coffee fields, often from fragments of secondary forest. The use of deciduous species was preferred because these do not need to be pruned, except for the lowest branches. Pruning, when necessary, was done during the dry season (winter, from June to September).

Diversification of the agroforestry systems was indicated by the quality and quantity of food produced for humans, cattle, pigs, poultry, and native fauna, and the production of wood for rural buildings, fences, and fuel. If compatible with coffee, at least some, but not all of the other criteria had to be met for the species to be accepted. For instance, banana and avocado were included because they produce fruits even though they are not deciduous.

Of the initial 85 species (Table 2), Table 3 shows 22 tree species and their characteristics according to the criteria and indicators mentioned in Figure 2. Most of these species and their characteristics were mentioned by the farmers during the construction of the matrix of criteria and options (Table 1), but the table also includes some information gathered during the visits to the systems and the interviews. This information refers specifically to the species *Erythrina* sp., *Zeyheria tuberculosa,* and *Luehea grandiflora*, present in some of the best managed agroforestry systems, and to the rejected species *Annadenanthera peregrina*, *Croton urucurana, Piptadenia gonoacantha,* and *Schizolobium parahyba*. During the interviews and visits, many farmers remarked that the latter species are incompatible with coffee because they have superficial roots that would desiccate the soil. However, some farmers kept them in the agroforestry systems because they can serve as wood and firewood. *P. gonoacantha* is often cut down before it is full-grown and used as firewood, thus avoiding competition with coffee. *A. peregrina* and *S. parahyba* are sometimes left in the systems to be used as wood (Table 3). *Solanum mauritianum* is used in agroforestry systems, but their low branches have to be pruned to avoid touching the coffee leaves, which would otherwise generate sanitary problems for the coffee.

Besides the tree characteristics presented in Figure 2, other tree characteristics, such as attraction of insects, were used by the farmers to evaluate the species (Table 1). Although insect attraction was mentioned by 9 farmers (Table 1), it is not a decisive criterion for inclusion of trees unless the species is attractive to honeybees. In this case, the criterion is related to diversification of food production (i.e. honey).

Most of the 22 species (64%) listed in Table 3 are native to the Atlantic Coastal Rainforest. Most exotic trees (85%, 6 species) were fruit trees. Most of the native species or genera (64%) of Table 2 were found in nearby forest fragments or regenerating spots. Among these species, *Aegiphila sellowiana*, *Cecropia* sp*., L. grandiflora, Senna macranthera, S. mauritianum,* and *Z. tuberculosa* are intercropped most with coffee. Among the 22 species, 10 (45%) produce fruits that are edible by humans or wildlife, and 11 (50%) were reported to be used for wood or firewood.

At the beginning of the trial, tree densities were higher. During the trial period, the farmers re-designed the agroforests, and set the density to around 100 trees ha^{-1}. However, the variation among agroforests was considerable, depending on the amount of natural shade in the fields, which, in turn, depends on environmental characteristics such as slope. The space among trees depended on the size of the tree crowns, which should not touch each other. In general, the systems had more than ten different species per ha; here again, there was considerable variation among systems.

Table 3: Tree species and the characteristics pointed out by the farmers to select trees to be included in agroforestry coffee systems, Zona da Mata, Minas Gerais, Atlantic Coastal Rainforest, Brazil.

Tree Species	Tree Characteristics					
	Compatibilty with coffee	Good biomass production	Easy management	Necessity of Pruning	Production	
					Fruits	Wood/firewood
Aegiphila sellowiana	Yes	Yes	Yes	No	Yes[**]	Yes
Anadenanthera peregrina [a]	No					Yes
Bombax marginatum [b]	Yes	Yes	Yes	No	Yes	
Carica papaya [b]	Yes			No	Yes	
Cecropia sp	Yes	Yes		No	Yes[**]	Yes
Croton urucurana [a]	No					
Dalbergia nigra	Yes	Yes		No		Yes
Eriobotrya japonica [b]	Yes				Yes	
Erythrina speciosa	Yes	Yes	Yes	No		
Erythrina verna	Yes	Yes	Yes	No		
Hovenia dulcis [b]	Yes	Yes	Yes	No		
Inga spp	Yes	Yes	Yes	No	Yes[**]	Yes
Luehea grandiflora	Yes	Yes	Yes	No		Yes
Musa paradisiaca [b]	Yes	Yes	Yes		Yes	
Persea americana [b]	Yes	Yes		No	Yes	
Piptadenia gonoacantha [a]	No					Yes
Schizolobium parahyba [a]	No					Yes
Senna macranthera	Yes	Yes		No		Yes
Solanum mauritianum	Yes	Yes	Yes	No	Yes**	Yes
Spondias lutea [b]	Yes			No	Yes	
Toona ciliata [b]	Yes	Yes	Yes			Yes
Zeyheria tuberculosa	Yes	Yes	Yes	No		

[a] Trees with superficial roots; [b] exotic trees; ** mainly for wild animals; Empty cells indicate that the farmers did not mention this criterion. For common names of the species, see Table 2.

3.2. Inventory of Leguminosae

We found 28 species of Leguminosae trees in 7 agroforestry systems (all with an area smaller than one hectare) (Table 4). Except for one species (*Leucaena leucocephala*), all were native to the Atlantic Coastal Rainforest. The most diversified systems had 11 species within the Leguminosae family and the least diversified had 5 species. *P. gonoacantha* was found in 6*, Inga edulis* and *S. macranthera* were found in 5, *Inga subnuda*, *Machaerium nyctitans,* and *Platypodium elegans* were found in 3 surveyed agroforestry systems. The other species were found either in one or two agroforestry systems. Trees of the *Inga* genus were found in all 7 surveyed agroforestry systems.

The Leguminosae family contained the highest number (15) of species or genera tested by the farmers during the trial period (Table 2). On the one hand, only 2 Leguminosae species (*Calliandra calothyrsus* and *Caesalpinia peltophoroides*) listed in Table 2 were not encountered during the inventory, on the other hand, the inventory yielded more Leguminosae species than mentioned by the farmers, which means that the number of species may increase beyond the 85 listed (Table 2) in a more specific survey. Among the 22 main tree species intercropped with coffee (Table 3), the farmers listed 4 species (*Dalbergia nigra*, *Erythrina speciosa, Erythrina verna*, and *S. macranthera*) and 1 genus (*Inga* spp.) of Leguminosae. Three out of the four rejected species (Table 3) are Leguminosae (*A. peregrina, P. gonoacantha,* and *S. parahyba*). Although rejected, all of them were found in the agroforestry systems (Table 4).

From the legume species identified in the agroforestry systems, 17 are known to fix nitrogen and 16 of them were native, mainly from the genera *Machaerium*, *Erythrina* and *Inga* (Table 4). *S. macranthera* (found in 5 out of 7 agroforestry systems) does not fix nitrogen according to the literature (Table 4).

Twenty legume trees species were sampled in two forest fragments neighbouring the 7 agroforestry systems where the Leguminosae inventory was done (distance ranging from a few meters to hundreds of meters) (Fernandes 2007). From the total, 11 species also occurred in the agroforests, including *S. macranthera, Inga* spp., and *D. nigra* (Table 4). *S. macranthera* and *Inga* spp. are among the main species used in the agroforestry systems (Table 3). *D. nigra* is an endangered species from the Atlantic Coastal Rainforest (Drummond et al. 2005); it was found in 2 agroforestry systems (Table 3) and in 2 fragments.

Table 4. Leguminosae trees surveyed in seven agroforestry systems (AF), Zona da Mata, Minas Gerais, Atlantic Rainforest, Brazil.

Subfamily and scientific name	**Common name**	**Number of AF^{1}**	**Nodulation^{2}**
Caesalpinioideae			
Apuleia leiocarpa (Vogel) J.F.Macbr.	Garapeira	2	No^{ab}
Caesalpinia echinata Lam.	Pau-brasil	1	Yes^{b}
Cassia ferruginea (Schrad.) DC. ^{3}	Canafístula	2	No^{b}
Copaifera langsdorffii Desf.	Pau-de-óleo	1	No^{bc}
Hymenaea courbaril L.	Jatobá	2	No^{abc}
Pterogyne nitens Tul.	Jacaranda	1	-
Schizolobium parahyba (Vell.) S.F. Blake	Breu	1	No^{bc}
Senna macranthera (Collad.) H.S. Irwin & Barneby ^{3}	Fedegoso	5	No^{bc}
S. multijuga (Rich.) H.S.Irwin & Barneby ^{3}	Farinha-seca	1	No^{bc}
Mimosoideae			
Albizia cf. polycephala (Benth.) Killip ex Record	Farinha-seca	1	Yes^{b}
Anadenanthera peregrina (L.) Speg.	Angico	1	Yes^{c}
Enterolobium contortisiliquum (Vell.) Morong	Orelha-de-macaco	1	Yes^{c}
Inga cylindrica (Vell.) Mart. ^{3}	Angá-feijão	1	-
I. edulis Mart. ^{3}	Angá-de-metro	5	Yes^{a}
I. sessilis (Vell.) Mart. ^{3}	Angá-ferradura	1	Yes^{b}
I. subnuda subsp. *luschnathiana* (Benth.) T.D.Penn.	Angá-serra	3	Yes^{a}
Leucaena leucocephala (Lam.) de Wit ^{4}	Leucena	2	Yes^{d}
Piptadenia gonoacantha (Mart.) J.F. Macbr. ^{3}	Jacaré	6	Yes^{bc}
Pseudopiptadenia contorta (DC.) G.P.Lewis & M.P.Lima	Jacarandá-amarelo	1	-
Papilionoideae			
Andira surinamensis *(Bondt) Splitg. ex Pulle*^{3}	Angelim	2	Yes^{a}
Dalbergia nigra (Vell.) Benth.^{3}	Jacaranda-Caviuna	2	Yes^{ac}
Erythrina speciosa Andrews	Mulungu	1	Yes^{a}
E. verna Vell.	Pau-abóbora	1	Yes^{ab}
Machaerium brasiliensis Vogel ^{3}	Bico-de-pato	2	Yes^{a}
M. nyctitans (Vell.) Benth.	Jacarandá-bico-de-pato	1	Yes^{a}
M. nyctitans (Vell.) Benth. ^{3}	Bico-de-pato	3	Yes^{abc}
M. stipitatum (DC.) Vogel	Canela-de-velho	1	-
Platypodium elegans Vogel	Jacarandá-branco	3	Yes^{b}

3.3. Economic benefit

The comparison between agroforestry and full-sun coffee systems is presented in Table 5. The amount of coffee harvested and the costs to produce it were less in agroforestry systems than in the full-sun coffee systems. Due to the diversification, the agroforestry systems allowed more products to be harvested and commercialised, such as avocado (*Persea americana*) and banana. The diversification and the lower costs of production resulted in a lower cost/benefit ratio for agroforestry systems (0.23) than for full-sun coffee systems (0.55).

Table 5. Comparison among full-sun and agroforestry coffee systems, Zona da Mata, Minas Gerais, Brazil.

Coffee	**Full-sun**	**Agroforestry**
Density (trees/ha)	2650	2050
Production (kg/tree)	0.79	0.62
Price (R$/bag – 60 kg)	120	120
Benefit (R$/ha)[a]	4187.00	2542.00
Costs[b] (R$/ha)	2300.00	750.00
Net benefit (R$/ha)	1887.00	1792.00
Cost/benefit	0.55	0.29
Other products of agroforestry (R$/ha)[b]		701.50
Net benefit including other products	1887.00	2493.50
Costs/ benefit (%)	0.55	0.23

[a]R$ = Brazilian real; [b] Products such as papaya, banana, citrus, mango, avocado, guava, jack fruit, palm heart and ficus fruit.

4. Discussion

In our region, the criteria to select trees to be used in the agroforestry coffee systems and the way to manage the trees was developed during 10 years of participatory trial. The participatory systematization contributed to clarification of farmers' criteria to select tree species and aspects of the management of the agroforestry systems. The use of native and or fruit trees provided important ecosystems services to the farmer families and helped them in restoring and preserving native forests.

The participatory trial allowed the construction of new knowledge and capacities and an understanding of the ecological processes involved in the agroforestry systems. Agroforestry systems are complex and their management requires more knowledge than full-sun coffee systems (Mercer 2004). In the trial, the farmers defined objectives, decided about the design and management, experimented, analyzed, and modified the agroforestry systems (Cardoso et al. 2001). The farmers controlled the process of decision-making and management and understood the objectives of the experiments. Therefore, they continued the experiments even when facing several difficulties during the long-term trial and found solutions to overcome these difficulties (Souza 2006). They had to design and re-design their agroforestry systems and many trees were removed, whereas others were introduced (Souza 2006). In our experience, the autonomy of the farmers in conducting the experiments resulted in a large diversity of design and management options, leading to specific agroforestry systems for each farmer.

Despite the specificity, the criteria for selecting trees were similar to all farmers and will apply to a wider range of environments, although they may result in the choice of other species. Selection of appropriate species is key to success of agroforestry. The species have to fulfil the requirements of different environmental niches and needs of the farmers (Scherr 1991). Some criteria found in our study are similar to those found in Chiapas, Mexico (Soto-Pinto et al. 2007), such as impact on coffee yield, amount of litter, impact on pests and diseases, additional goods, and services offered by trees. However, in contrast to farmers in Zona da Mata, farmers in Chiapas preferred non-deciduous trees (Soto-Pinto et al. 2007), probably because of the preference of Chiapas farmers for more intensely shaded coffee. In addition in Mexico, tree species incompatible with coffee are sometimes retained by the farmers because of their usefulness as food, timber, firewood, provision of medicines, and for other domestic purposes (Soto-Pinto et al. 2007).

The deciduous characteristic is important in the Zona da Mata because coffee needs more light during the flowering period (Morais et al. 2003), which is in the dry period (winter). In this season, several trees from the Atlantic Coastal Rainforest (semi-deciduous forest – classification of Veloso 1991) lose their leaves and pruning of the crown is not necessary, thus saving labour. The root system was also judged important and was one of the indicators raised by the farmers to explain the incompatibility of certain species with coffee. Fine coffee roots (less than one mm in diameter) are concentrated in the first few centimetres of the soil (Cuenca et al. 1983). Therefore, fine tree roots have to be deeper than the coffee roots to avoid competition for water and nutrients. However, Jaramillo-Botero (2007) could not find competition for water and nutrients between *S. parahyba* (an incompatible species, Table 3) and coffee, and suggested allelopathy between the two species to explain the incompatibility.

The preference for native and/or fruits trees (Tables 2 and 3) is the result of the strategy of CTA-ZM and partners to specifically promote the use of native species and the diversification of production. The natural regeneration within the agroforestry systems and availability of genetic materials (seeds or seedlings) in the region give more autonomy to the farmers. Consequently, the farmers are dependent on the presence of forest fragments nearby. The effects of forest fragments and agroforestry systems on each other are twofold. On the one hand, forest fragments are important as a genetic source for the agroforestry systems, working as a seed bank or seedling reservoir. Hence, most of the species found in the agroforestry systems were also found in the forest fragments and in regenerating spots nearby (Tables 2 and 4). Among the most common species recommended, *A. sellowiana*, *L. grandiflora*, *S. macranthera*, *S. mauritianum*, and *Z. tuberculosa* spontaneously occurred in the agroforestry systems, indicating that either seeds were present in the soil or that seeds were dispersed from other spots. With respect to dispersal, fruits from *A. sellowiana* and *S. mauritianum* are eaten by wild animals (Table 3) and all of the above-mentioned trees were observed nearby agroforestry sites (Table 2), suggesting the potential of seed dispersal.

On the other hand, agroforestry systems are important for conservation of regional biodiversity (Salgado et al. 2006), as the agroforestry systems mimic the forest fragments with respect to the strata of vegetation and the related microclimate. As a result, the use of the endangered *D. nigra* in two agroforestry systems can help the conservation of this species and may result in seed dispersal from the agroforestry systems into the forest fragments. Thus, agroforestry systems have the potential to interconnect forest fragments, to serve as buffer zones of tropical rainforests (Vandermeer and Perfecto 2007; McGinty et al. 2008) and even as nursery for endangered species. Moreover, the availability of wood for fuel and building from the agroforestry systems decreases the pressure on forest remains. Therefore, agroforestry systems, as developed by the farmers in Zona da Mata, meet demands in terms of production and environmental services (Altieri and Nicholls 2000; Harvey et al. 2008; Rice 2008), contribute to the conservation of species occurring in nearby reserves, have the potential to contribute to the sustainability of ecosystems, and can be used as a reference for policy makers to improve the regulation of the use of the protected areas in the region.

The agroforestry systems in the Zona da Mata were more diverse than in other Brazilian agroforestry systems. For instance, Santos et al. (2004) found 15 Leguminosae tree species in 7 agroforestry systems in the Amazon region, and Vivan (2000) found 6 species of Leguminosae in one agroforestry system in the south of Brazil. The use of different tree species with different characteristics is important in areas with large variation in the environment, related to hilly landscapes, different pedoforms, and different solar exposure, such as the Zona da Mata (Freitas et al. 2004). Moreover, it is important in family agriculture, which needs multi-use and multi-function crop fields to constantly diversify production, reduce costs and increase economic benefits (Table 5). For instance, the use of nitrogen-fixing trees may reduce costs of fertilisation. One *Inga* tree can produce 33 kg of senescent leaves per year, with a total of 710 g of nitrogen (Duarte 2007). The nitrogen can be released and used by the coffee, depending on the mineralisation rate.

Although of huge value, there is little literature available on the characteristics of most of the tree species of the Atlantic Coastal Rainforest. To the best of our knowledge, most of the species were never reported as intercropped with coffee before. To help in the design and management of agroforestry systems and to increase the use of native species in agroforestry, research has to be carried out to study the environmental services provided by the trees. Their potential is not restricted to shading the coffee systems, but also associated with the enhancement of other ecosystem services such as increasing soil quality, and water quantity and quality (Jose 2009). Besides the management of trees, managing the herbaceous strata is also important in agroforestry systems for production of mulch for soil cover and nutrient recycling, and for the diversification of the production.

The diversification of production, especially with edible fruit trees (Tables 2 and 3), contributes to food security and to a lower cost/benefit ratio of the agroforestry systems compared to full-sun coffee systems. Part of the higher production costs of full-sun coffee systems is due to the use of external inputs; at least three times more fertilizer is used in full-sun coffee than in agroforestry coffee systems (Cardoso et al. 2001). The use of herbicides is common in full-sun coffee, but absent in the agroforestry coffee systems. However, more in-depth studies on the economic aspects of agroforestry systems are necessary.

Considering that all trees listed in Table 3 are compatible with coffee, we suggest that the best 5 tree species to intercrop with coffee are *A. sellowiana, Inga* spp., *M. paradisiaca, S. macranthera,* and *S. mauritianum*, because they scored highest (Table 1) in the second hierarchical level of criteria mentioned in Figure 2. We also recommend *P. americana* (avocado) because of its high value as food for the family and animals and as a cash crop (Table 5). Moreover, *Erythrina* sp., *Z. tuberculosa,* and *L. grandiflora* were highly recommended by farmers with more experience with management of agroforestry systems, and we recommend *D. nigra* because it is an endangered species. However, these are only suggestions; the criteria and indicators established by a group of farmers are undoubtedly useful to other farmers, but the farmers' systems cannot be copied. Each farmer has to be able to adapt the choice of tree species and their management to the necessities of his or her system.

5. Conclusions

Selection of appropriate tree species is key to the success of agroforestry. The use of tree species with different characteristics is important in family agriculture, which needs multi-use and multi-function cropping systems, offering several ecosystem services, such as shade, improvement of soil quality, pollination, and diversification of products. In order to profit from the ecosystem services provided by the trees, the ideal is to use the diversity of native trees as much as possible.

To manage complex systems such as is agroforestry, family farmers need to have sufficient autonomy to design, modify and adapt their systems. This autonomy is only possible if they have sufficient knowledge, which can be acquired when the methodology used to develop on-farm agroforestry systems is based on participation, allowing reflection and the exchange of knowledge among farmers, technicians and scientists.

Agroforestry systems have the potential to rehabilitate the degraded landscape such as in the Zona da Mata. With the agroforestry systems, it is possible to connect important remains of Atlantic Coastal Rainforest in the region, such as the Serra do Brigadeiro State Park and the Caparaó National Park. However, policy-makers have to recognize this potential and develop actions to use it.

6. Acknowledgements

The authors thank the farmers and their organizations for sharing this experience, the Brazilian sponsors FAPEMIG (Fundação para o Amparo da Pesquisa do Estado de Minas Gerais), for financial support, CAPES (Coordenação de Pessoal de Ensino Superior) for a scholarship to the first and third author, Arne Janssen, Mirjam Pulleman and Lijbert Brussaard for useful comments and corrections on an earlier version of this paper, and two anonymous reviewers for constructive comments.

Chapter Four

Protective shade, tree diversity and soil properties in coffee agroforestry systems in the Atlantic Rainforest biome

Helton Nonato de Souza[1,a], Ron G.M. de Goede[1], Lijbert Brussaard[1], Irene M. Cardoso[2], Edivânia M.G. Duarte[2], Raphael B.A. Fernandes[2], Lucas C. Gomes [2] and Mirjam M. Pulleman[1]

[1]Dept. of Soil Quality, Wageningen University, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[2]Department of Soil and Plant Nutrition, Federal University of Viçosa; Brazil, Campus UFV, 36571000

[a] Corresponding author: QMSW 4, lote 3, Apto 103 – Setor Sudoeste – Brasília-DF - Brazil
CEP 70.680-400 Email: heltonnonato@yahoo.com.br

Published in Agriculture, Ecosystems and Environment 146: 179-196 (2012)

Protective shade, tree diversity and soil properties in coffee agroforestry systems in the Atlantic Rainforest biome

Abstract

Sustainable production and biodiversity conservation can be mutually supportive in providing multiple ecosystem services to farmers and society. We aimed to determine the contribution of agroforestry systems, as tested by family farmers in the Brazilian Rainforest region since 1993, to tree biodiversity and evaluated farmers' criteria for tree species selection. In addition, long-term effects on microclimatic temperature conditions for coffee production and chemical and biological soil characteristics at the field scale were compared to full-sun coffee systems. A floristic inventory of 8 agroforests and 4 reference forest sites identified 231 tree species in total. Seventy-eight percent of the tree species found in agroforests were native. The variation in species composition among agroforests contributed to a greater γ-diversity than α-diversity. Monthly average maximum temperatures were approximately 6°C higher in full-sun coffee than in agroforests and forests. Total soil organic C, N mineralization and soil microbial activity were higher in forests than in coffee systems, whereas the chemical and biological soil quality in agroforests did not differ significantly from full-sun coffee after 13 years. Given its contribution to the conservation of biodiversity and its capacity to adapt coffee production to future climate change, coffee agroforestry offers a promising strategy for the area.

Key words: coffee, agroforestry, tree biodiversity, climate change adaptation, soil quality, Brazilian Atlantic Rainforest

1. Introduction

High input agriculture as developed during the last decades has focused mainly on increasing the production of marketable products (Evenson et al., 2003). Despite successes in terms of agricultural productivity on a global scale, these developments have been accompanied by soil degradation, biodiversity decline and environmental pollution with negative feedbacks on food security and farm incomes at local scales (Perfecto and Vandermeer; 2008). The decline in biodiversity has disrupted ecological interactions and dramatically increased the reliance of agricultural production on external inputs. In contrast, diversification of agroecosystems to enhance agrobiodiversity and ecological processes can simultaneously support biodiversity conservation and the delivery of a range of supporting, provisioning and regulating ecosystem services that enhance the sustainability and resilience of agricultural systems (MEA, 2005; Knoke et al., 2009) and the surrounding landscape (Bennett et al., 2007; Kibblewhite et al., 2008).

Farmers in the Zona da Mata of Minas Gerais state, located in the Brazilian Atlantic Rainforest, have been facing problems of soil degradation, decreased production and declining biodiversity. The Atlantic Rainforest is a biodiversity hotspot (Myers et al., 2000) that is highly fragmented due to historic agricultural expansion. Only 12% of native vegetation remains, more than 80% of the fragments is <50 ha and the average distance between fragments is 1440 m (Ribeiro et al. 2009). Seventy percent of Brazil's human population lives within this biome.

The Zona da Mata is an important coffee producing region (CONAB, 2009). Conventional agricultural activities on the steep slopes have caused serious soil erosion and soil quality problems. Moreover, climate change scenarios for the Zona da Mata predict that temperature conditions will make large parts unsuitable for coffee growing by 2050 (Assad et al., 2004). As in the rest of Brazil, coffee in the Zona da Mata has mainly been cultivated in full-sun systems. In several other countries, however, coffee has traditionally been cultivated under a diverse canopy of local tree species. These trees provide shade (Moguel et al., 1999) and create microclimate conditions commensurate with the ecophysiology of the coffee plant (DaMatta, 2004). Moreover, the tree cover protects the soil against erosion and provides a continuous input of organic matter to the soil. The soil quality in tropical agroecosystems depends to a large extent on biomass production, plant residue inputs (Tian et al., 2007) and litter residence times (Hairiah et al. 2006) that provide soil protection and food for soil organisms, contribute to improved soil structure, soil moisture retention and nutrient supply (Kibblewhite et al., 2008).

Starting in 1993 a group of coffee growers, in collaboration with local NGOs and researchers, have implemented and monitored experiments with agroforestry coffee systems (AF) (Cardoso et al., 2001). AF can be defined as a form of multiple cropping of annual or perennial crops intercropped with trees (Somarriba, 1992). The successful adoption of agroforestry systems depends on their proper design, including tree species selection, and management. Therefore, it is necessary to have a better understanding of how locally available natural resources and local and scientific knowledge can be combined to develop systems that allow for coffee and food production and provide multiple ecosystem services at the same time (WinklerPrins et al., 2003). This also requires monitoring of the long-term effects of agroforestry versus full-sun coffee systems (SC) on biodiversity conservation, soil quality and ecosystem services across scales from the coffee field to the wider landscape. Here, we propose that scientific data will make up for the general lack of documentation and understanding of (local) strategies and experiences and will serve as guidance for regional and global policies (Harvey et al., 2008).

The objectives of our study were 1) to evaluate farmers' criteria for selection of tree species in AF systems; 2) to determine the contribution of coffee agroforestry to regional tree biodiversity conservation; 3) to determine the contribution of agroforestry systems to microclimatic conditions for coffee production in the Zona da Mata, as compared to full-sun coffee systems and neighboring reference forest fragments on the same farms; 4) to determine the effects of agroforestry on soil chemical and biological soil characteristics, as compared to full-sun coffee systems and neighboring reference forest fragments on the same farms, and to assess leaf litter quality of locally selected AF tree species.

Objective 1 required a descriptive, retrospective study, which is not open to hypothesis formulation. As to the other objectives, we hypothesized:

H1: the majority of the trees in coffee agroforests are native tree species, and also occur in surrounding reference forest fragments (refers to objective 2).

H2: AF moderates microclimate fluctuations compared to SC, thereby reducing mean daily maximum temperatures, which makes coffee production more resistant to temperature rise resulting from climate change (refers to objective 3).

H3: Chemical and biological soil characteristics are improved under AF as compared to SC and these improvements are related to leaf litter quality (refers to objective 4).

2. Materials and methods

2.1. Study area

The study area is located in the Zona da Mata (ZM), Minas Gerais State, Brazil. Since the nineteenth century the rainforest has been replaced by agriculture (mainly coffee production) due to favorable climate and market conditions (Dean 1995). Few forest fragments have been conserved as forest reserves while coffee plantations extend to the top of the hills. As a result, biodiversity and natural soil fertility have severely declined (Dean, 1995; Padua, 2002). Full-sun coffee (Coffee arabica L.) and degraded pasture are scattered across the landscape surrounding hundreds of small and isolated forest fragments (Ribeiro et al., 2009; Teixeira et al., 2009). Two protected areas are located in the region, the Serra do Brigadeiro State Park (PESB, by its Portuguese acronym, 14984 ha) and the Caparaó National Park (26200 ha) (Figure 1).

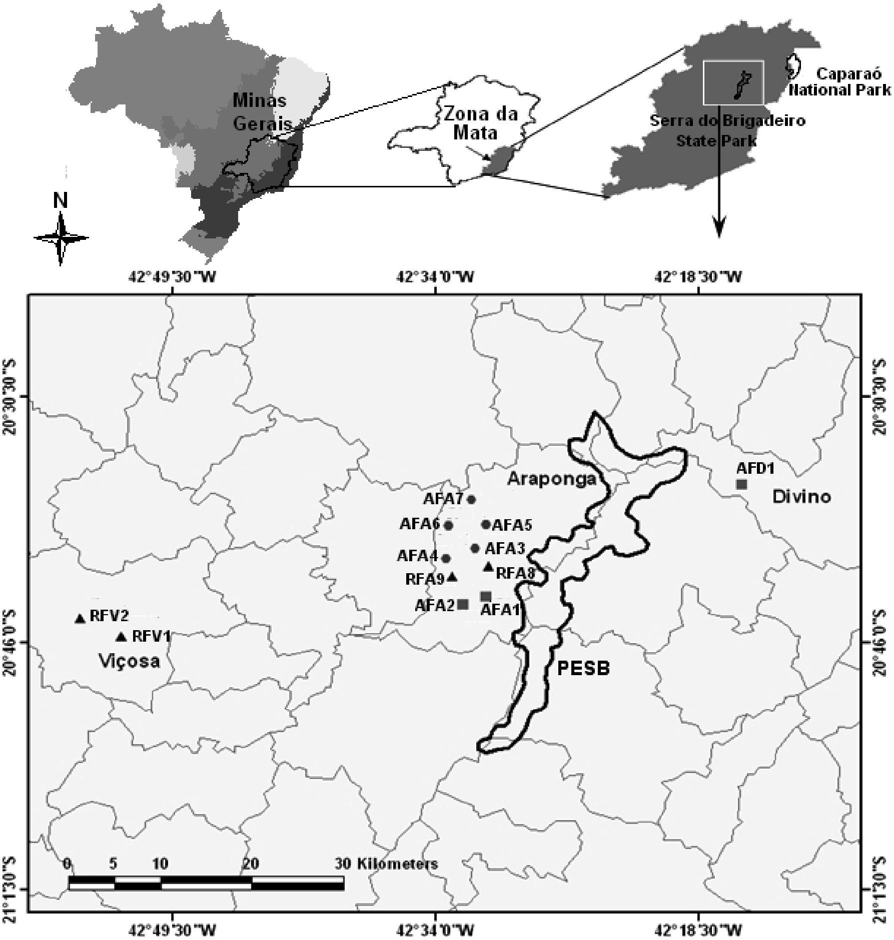


Figure 1: Location of the study sites in different municipalities of the Zona da Mata of Minas Gerais state: Viçosa (reference native forest fragments RFV1 and RFV2), Araponga (agroforests AFA1 to AFA7 and native forest fragments RFA8 and RFA9) and Divino (agroforest AFD1). The black line in the bottom map indicates the limits of the Serra do Brigadeiro State Park (PESB). The boundaries of the Caparaó National Park are shown in the upper map).

The Zona da Mata region has a tropical highland climate. The average temperature is 19°C and the average precipitation is 1300 mm, with 2-4 dry months per year (Figure 2). In general, the slopes range from 20 to 45%, and the altitude ranges from 200 to 1800 m asl (Golfari, 1975). Nowadays, around 18% of the population lives in rural areas. Forty-two percent of the farms in the region are smaller than 10 ha, and are managed mainly by family farmers (IBGE, 2000). Agriculture is characterized by continuous cultivation and conventional farming practices. Pasture and full-sun coffee, often inter-cropped with maize and/or beans, are the most important agricultural land uses. Other crops are sugarcane, cassava, fruits and vegetables. Use of agrochemicals such as fertilizers, lime, biocides and growth inductors are common, which reaches up to 54% of the total costs for coffee production.

Dominant soil types are Oxisols which are deep, well drained, acid and poor in nutrients (FAO, 1985). More information about pedology, agriculture and sociology of the Zona da Mata region can be found in Cardoso et al. (2001).

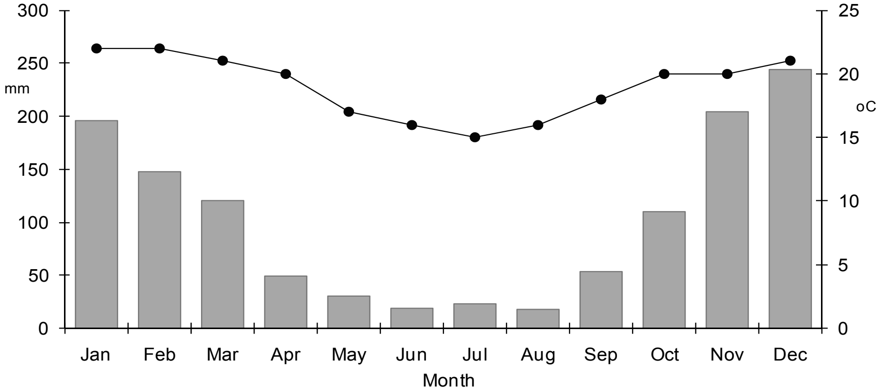


Figure 2: Mean monthly temperatures (bars) and total monthly rainfall (dots) in the Zona da Mata, Minas Gerais state, Brazil (1960-1990; data source: www.inpe.br).

2.2. Study sites

From 1994 to 1995, 37 on-farm agroforestry (AF) experiments were established by farmers across 7 municipalities bordering the Serra do Brigadeiro and Caparaó National Parks. The AF plots had an average size of 0.5 ha and were established on the most degraded soils within the farms, often presenting sheet erosion due to the historic land use. Among these 37 farms we selected our study sites, following four steps. From the 37 farms, 17 took part in an evaluation study. The evaluation consisted of several meetings where farmers, technicians and researchers gathered information about the composition and management of AF and to reflect on its impact on soil quality and productivity (Souza, 2006). Eight out of these 17 AF experiments and four reference forests (RF) were selected to to compare tree diversity and composition, as indicated by objective 1 of this study. The 8 AFs were best examples in terms of productivity and biodiversity, according to the evaluation by farmers and technicians (Souza, 2006) (Figure 1). Two RF fragments were located in Araponga (50 years old, with a size of 4 ha and located at a distance of 1 to 5 km from the AF experiments) and two in Viçosa (15 and 30 years old, with a size of 5 ha and located at a distance of 60 to 100 km from the AFs). The forest fragments were selected because of the availability of botanical studies, and because they were representative examples of different successional stages of secondary forest on abandoned agricultural land in the Zona da Mata (Marangon et al., 2003).

For a detailed study on microclimate and soil quality aspects at the field scale, as proposed by our objective 3, we selected a subset of 3 farms, out of the 8 farms that were used for the floristic study. Each of these 3 farms comprised 3 different systems within the farm boundaries: an agroforestry system (AF), full-sun coffee cultivation (SC) and a reference forest fragment (RF). The AF and SC systems were side by side, within 300 m distance from the RF. All three systems were comparable in terms of slope and solar incidence. The AF and SC systems had been established at the same time, between 1993 and 1995, and coffee plants were in the same growing stage. The RFs were on average 30-40 years old, had a size of 0.5-1.0 ha, and had a history of agricultural use. The farmers represented comparable conditions in terms of labour availability and economic endowment (Miranda, 2002). The location of the various research sites is given in Figure 1.

The AFs consisted of plantations of selected tree species in close association with coffee plants (*Coffea arabica* L.) on former arable land or degraded pastures. SC differs from AF mainly in terms of the absence of trees and shrubs (other than coffee) and the rate of chemical fertilizer used (Souza, 2006). Sometimes manual tillage was used in both systems. Due to local agreements, dating back to more than 20 years ago when the agroecological transition process started in the Zona da Mata, biocides have vanished from both coffee systems on all the participating farms. The RFs were kept on the farms in accordance with Brazilian environmental law. The trees reached up to 20 m in height. The RFs used for the floristic comparison were not the same fragments as the ones kept within the farms.

Location and slope of the coffee fields were measured using GPS (Garmin eTrex H, 10 m of precision) and clinometers. The farms and systems differed in terms of the slope, size of the SC, AF and RF systems, the density of coffee plants, the composition of the AFs, and coffee production (Table 1).

.

Table 1: Characteristics of the three selected farms in Zona da Mata, Brazil.

Sites	Farm		Farm A1			Farm A2			Farm D1		
	Location	(GPS)	20º 41' S ; 42º 31' W			20º 42' S ; 42º 31' W			20º 33' S ; 42º 11' W		
	Altitude	(m asl)	1062			1040			1160		
Systems[1]			AFA1	SCA1	RFA1	AFA2	SCA2	RFA2	AFD1	SCD1	RFD1
Area	size	(ha)	0.15	0.75	2.00	0.72	0.77	3.00	0.27	0.45	1.00
	slope	(%)	33	33	40	75	70	70	35	35	42
	former use		rice cultivation for 10 years	rice cultivation for 10 years	annual crops	eavily eroded coffee field	eroded coffee field	forest	cut forest and pasture	cut forest and pasture	forest
Fertilization	N-P-K (20-5-20)	g.plant^{-1}.yr^{-1}	200	200	0	0	180	0	100	150	0
	Cow manure	(Mg.yr^{-1}/field	0	0	0	2.9	0	0	10^5	0	0
	Lime	(g. m^{-2}/plant)	200^3	200^3	0	20^4	40^4	0	950^6	0	0
Coffee plants	Density	(#.ha^{-1})	3300	3300	-	1670	2600	-	2200	2200	-
	Spacing	(m)	3.0 x 1.0	3.0 x 1.0	-	4.0 x 1.5	3.2 x 1.2	-	3.0 x 1.5	3.0 x 1.5	-
	Age	(yr)	12-14	12-14	-	12-14	12-14	-	10-14	10-14	-
	Production	(kg ha^{-1})^2	1650	1350	-	313	1320	-	1644	1602	-
Trees and crops		(#.ha^{-1})	380	0	not counted	370	0	not counted	257	0	not counted
	Main species, Besides coffee plants	Current (2008-2009)	*I. sessilis .I subnuda* guava, papaya, citrus,	-	Secondary succession	*P.americana,* sugarcane, lemon, banana + fruits/crops	-	Secondary succession	banana, orange, cassava and lemon	-	Secondary succession
		Past (1994-2004)	*Hovenia spec., Colubrina spec., Pennisetum spec., Inga* spp., fruits (guava, papaya, citrus, avocado*)*	-	Secondary succession	*A.sellowiana, P.americana*	-	Secondary succession	*Luehea* spec., banana, orange, cassava and lemon	-	Secondary succession
		(#/.ha^{-1})	~20	0	Not counted	~20	0	Not counted	~40	-	Not counted
	Current pruning		December to March	-	-	December to March, low branches in July	-	-	December to March	-	-

[1] AF: agroforestry system, SC: full sun coffee system, RF: reference forest, A1 and A2 in Araponga and D1 in Divino municipality; [2] three year average (2007, 2008 and 2009); [3] total applied in 1999, 2001, 2004 and 2006; [4] applied annually; [5] total applied during the organic cultivation from 2003 till 2006; [6] applied in 1997.

The farm activities depended on the types of crops, number of farm workers and the season of the year. At farm A1, the soil in AFA1 and SCA1 was fertilized in 1994 with 100-150 g of NPK (4-18-8) per coffee plant and limed to recover soil fertility. The coffee plant density and fertilization were similar in both systems (Table 1). At Farm A2 trees were mostly planted in lines between the coffee plants to control erosion, and severely pruned. SCA2 was installed immediately down slope of AFA2 and had the same historical land use. The coffee planting density was 56% higher in SCA2 than in AFA2. Liming rates were twice as high in SCA2 as in AFA2. At farm D1, AFD1 and SCD1 were established where forest had been converted to pasture for several years (exact time unknown) and further to coffee cultivation. The main goals of the establishment of AFD1 were soil protection and diversification of production. AFD1 was intercropped with coffee. From 2003 till 2006, AF received 10 Mg of cow manure over a period of 4 years. In 2007 950 kg of limestone was applied in AFD1.

2.3. Sampling and data collection

2.3.1. Interviews

Information on the characteristics of the farms, management of the coffee systems and uses of the trees (objective 2) was obtained through semi-structured interviews between February 2008 and January 2009. While a map of the farm was drawn to locate each farm component, we asked the farmer about physical features of the property and the reasons for choosing the exact places for crops (annuals or perennials), buildings, pastures and roads. The structure and composition of agroforestry systems (AF) and sun coffee (SC) systems were gathered during excursions to the systems while undertaking the questionnaires on the influence on soil quality and coffee production, distances, height, and shade between trees and crops. The types of farm operations and time spent on different farming activities, and the type and amount of inputs and outputs in each system were collected during field visits and a calendar of field operations was created for each farm. Selected characteristics of the farms are presented in Table 1.

2.3.2. Tree species

Data on floristic composition (objective 1) of AFA1 until AFA7, RFA8 and RFA9 (in Araponga) were collected by Fernandes (2007) and Siqueira (2008). Tree composition in RFV1 and RFV2 (in Viçosa) was identified by Ribas et al. (2003) and we identified the floristic composition of AFD1 (in Divino). For identification of the RFs in Viçosa, twenty plots of 10x20 m, corresponding to a total area of 0.40 ha, were delineated and all trees with circumference ≥ 5 cm at breast height (1.3 m) were identified (Ribas et al., 2003). In the AF plots with an average size of 0.38 ha (ranging from 0.15 to 0.72 ha), all trees were counted and identified. In Araponga, observations on flowering and fruiting and sampling of botanical material of all trees were done monthly, from February 2006 to May 2007, in the two RFs and seven AFs (Fernandes, 2007; Siqueira, 2008). In AFD1 (Divino) species identification was based on the morphology of collected plants, taxonomic literature, consultation with specialists and comparison with collection materials of the VIC Herbarium of the Federal University of Viçosa. Matrices of presence and absence of tree families and species were made. The floristic composition was evaluated through cluster analysis and is presented in a dendrogram as described in paragraph 2.8. Taxonomic richness at species level was calculated by counting the number of different tree families and species found in each plot.

2.3.3. Microclimate

Thermometers for recording of maximum and minimum temperatures (Digilab) and rain gauges (0-130 mm/m^2, Walmur) were installed in the agroforestry (AF), sun coffee (SC) and reference forest (RF) systems at the three farms. One device per system was placed at a height of 1.0 m above the soil surface. Data were collected by the farmers, every 2-3 days during from January 2007 to January 2008.

2.3.4. Soil quality

Soil samples were collected at 0-10 and 10-20 cm soil depth during the dry season (end of June 2007 in A1 and A2; and August 2007 in D1). On each farm four sub-plots were established within each treatment. In each sub-plot four soil samples were taken between the coffee rows and bulked into one sample per sub-plot. Immediately after sampling, biological analysis was performed. The remaining soil was air-dried, sieved through a 2-mm sieve and stored at room temperature.

Soil texture was determined by the sieving and pipette method (Day, 1965). The soil pH was determined in water (soil:water ratio 1:2.5). Exchangeable cations (Ca^{2+}, Al^{3+}, Mg^{2+}) were measured after extraction with 1 mol L^{-1} KCl; K and P were extracted by Mehlich-1; H+Al was extracted with 0.5 mol L^{-1} $Ca(OAc)_2$ at pH 7.0 (EMBRAPA, 1997). The cation exchange capacity (CEC) and base saturation (%BS) were calculated using the concentrations of the exchangeable cations. Total organic C (TOC) was quantified by wet combustion with a mixture of potassium dichromate and sulfuric acid and subsequent titration with standardized $FeSO_4$ (Yeomans and Bremner., 1988). Total soil nitrogen (TN) was measured after sulfuric digestion followed by Kjeldahl distillation (Tedesco et al., 1995).

Measurement of soil respiration was based on the alkali absorption technique (Stotzky, 1965; Curl and Rodrigues-Kabana, 2001) and performed as follows: 100 g of fresh soil was placed in a plastic container. The moisture content was adjusted to 70% of field capacity by adding distilled water. The samples were incubated in a closed container at 25ºC. CO_2 was captured in a 0.5 mol L^{-1} NaOH solution and was quantified after 3, 5, 7, 9, 12, 16, 19, 23, 27, 31, 38, 45 and 48 days by titration with 0.25 mol L^{-1} HCl. From this incubation, samples (5 g) were taken weekly during seven subsequent weeks to determine N mineralization (Nmin). $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ were measured colorimetrically in a 1 mol L^{-1} KCl extract ((Kempers and Zweers, 1986; Yang et al., 1988). Microbial biomass C (Cmic) was determined by irradiation-extraction method, using a microwave (Ferreira et al., 1999). The conversion factor (Kc) used to convert extracted C to Cmic was 0.33 (Ferreira et al., 1999). The metabolic quotient (qMet) was estimated by dividing the mean values of $C\text{-}CO_2$ emission by Cmic (Franchini et al., 2007). The microbial quotient (qMic) was obtained by dividing Cmic by TOC.

2.3.5. Leaf quality

Based on their N, lignin and polyphenol contents, the leaf materials of selected tree species from the AF systems were classified into four quality classes according to Palm et al. (2001). These quality classes have been related to nutrient release patterns with important implications for soil fertility management in tropical agroecosystems. Seven trees selected by the farmers and cultivated currently in their AF with coffee to improve soil characteristics were used for this leaf quality study (objective 4). The tree species *Aegiphila sellowiana, Erythrina verna, Inga subnuda, Luehea grandiflora, Persea americana, Senna macranthera,* and *Zeyheria tuberculosa* were considered compatible with coffee, due to their amount and quality of biomass, food and fodder production and the ease of pruning (Souza et al., 2010). From each tree species fresh leaf material was collected in June 2006 from low, medium and high parts of the canopy and one composite sample per tree species was made. The leaf material was dried in a forced-air circulation oven (65°C, 72 h) and ground. Lignin, cellulose, hemicellulose and polyphenol contents were assessed by the acid-detergent fiber method (Goering et al., 1975). The soluble polyphenols were extracted through 50% aqueous methanol and determined colorimetrically using Follin-Denis reagent (Anderson et al., 1993). Nitrogen (N) was determined by the Kjeldahl method (Tedesco et al., 1995). For the species *Cassia ferruginea, Croton urucurana, Solanun variabile, and Piptadenia gonoacantha* leaf quality data were obtained from Mendonça and Stott (2003) who used the same methodology for sampling and analysis.

2.4. Statistical analysis

For the comparative analysis of species composition among agroforestry systems (AF) and reference forest (RF) fragments, cluster analysis using the Unweighted Pair Group Method with

Arithmetic Mean (UPGMA) was performed for the botanical dataset, using MVSP 3.13m software (MVSP, 2006). The Sørensen Index (SI) was calculated for each AF and RF fragment according to the formula $SI=2j/(a+b)$, where j is the number of species occurring at both sites, a is the number of species in site 1, b is the number of species in site 2 (Sorensen, 1948).

ANOVA with repeated measures was performed to test the effects of system on temperature over time, followed by Tukey's test ($p<0.05$). The three farms were considered as 3 replicates. SPSS Statistic 17 was used for microclimate data (SPSS, 2007) and PASW for soil data (PASW statistics 2009). The effects of system (AF, RF, SC) and site (farm A1, A2, D1) on soil quality parameters were tested using a Mixed Model with site and system as fixed effects and sub-plots as random effects. To account for the split-plot layout (system was nested within site) and the two levels of replication of the factor system (sites as real replicates; sub-plots as pseudoreplicates), subplots were nested within system and both were nested within site (Onofri et al., 2010). In case of statistically significant effects a pairwise comparison of means using a Bonferroni post hoc test ($p<0.05$) was applied. To meet the requirements for normality and homogeneity of variance, variables were transformed prior to statistical analyzes (1/x for qMet, Nmin, Silt, Total N; SQR for Ca, Mg, Al, Base saturation; and Log(x+1) for P and CEC).

To analyze the relationships between sites, systems and soil characteristics we used redundancy analysis (RDA) using CANOCO 4.0 for Windows (Ter Braak, 1986). Sites (A1, A2, D1) and systems (AF, SC, RF) were used as independent variables. The data set was log-transformed, centered, and standardized. All statistical analyzes were performed separately for the two soil depths (0-10 and 10-20 cm).

3. Results

3.1. Tree species composition among agroforests and forest fragments

The list of all species found in the agroforestry coffee systems (AF) and reference forest fragments RF is shown in Annex 1. A total of 231 tree species was found in the eight AFs (87 species) and four RF fragments (178 species). The tree species richness in the individual AFs ranged from 15-41 species and 12-20 families, which was lower than in the RFs (54-70 species and 24-28 families). The percentage of the total number of species found in the individual systems ranged from 6 to 18% for the AFs and from 23 to 30% for the RFs (Table 2). Overall, 38% of the tree species (33 species) that were present at least one of the AFs also occurred in at least one of the RFs. Seventy-eight percent (68 species) of the species in the AFs were native and 22% (19 species) were exotic. The percentage of species per individual AF system is listed in Table 2 and ranged from 21-53%.

Table 1: Number of tree families and tree species and the percentage of the total number of identified tree species in eight agroforestry coffee systems (AF) and four reference forest fragments (RF), in Zona da Mata, Brazil.

Item	AFA1	AFA2	AFA3	AFA4	AFA5	AFA6	AFA7	AFD1	RFA8	RFA9	RFV1	RFV2
# tree species	23	15	41	26	27	21	32	28	54	70	66	68
# tree families	16	12	20	17	14	13	13	20	24	26	25	28
% of total # tree species	10	6	18	11	12	9	14	12	23	30	28	29
% of RF species found	43	53	27	50	33	48	25	21	-	-	-	-

AFA1-AFA7 refer to the agroforestry systems located in Araponga, AFD1 is located in Divino; RFA8 and RFA9 are about 50 years old and are located in Araponga (not within the selected farms), RFV1 and RFV2 are 15 and 30 years old, respectively, and located in Viçosa.

The cluster analysis for tree species and families, which indicates the similarity among the 12 sites, distinguished two groups: one group is formed by the RFs and the other group is formed by the AFs (Figure 3).

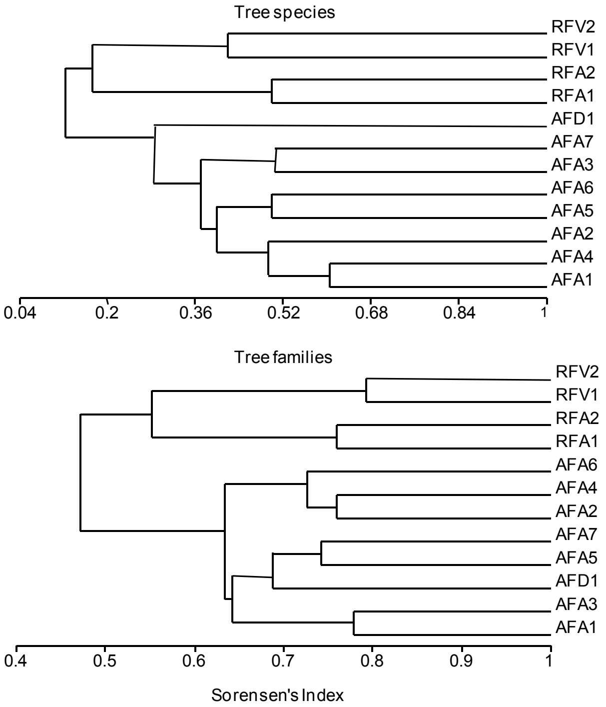


Figure 3: Cluster analysis dendrogram of floristic similarity (Sørensen's coefficient) from eight agroforestry systems (AFA1 to AFA7 in Araponga and AFD1 in Divino) and four reference forest fragments (RFV1, RFV2 and RFA8, RFA9) in the Seasonal Semideciduous Forest of the Atlantic Rainforest domain.

Among the RF fragments, there are two groups, separated by location (Figure 3). The similarity in tree species between the AFs and the RF fragments of our study, as expressed by the Sørensen Index (SI), was 13%.

3.2. Leaf material quality

The N content of the leaf materials ranged from 1.6 to 3.8%, lignin content (LG) ranged from 7.7 to 27.3% and polyphenol content (PP) ranged from 1.9 to 11.0% (Table 3). Quality class II (indicated to be used in combination with fertilizers) and class III (high LG and PP content, recommended to be composted before applying to the soil) were dominant with 4 species each, followed by class IV (recommended to be used as mulch for erosion control) with 2 species, whereas class I (nutrient-rich organic matter) was represented by one species (Table 3). The actual on-farm use of these tree species was as wood, soil cover, fertilizer and food/fodder.

Table 3: Residue category, use and leaf quality of common tree species used in coffee agroforestry systems in Zona da Mata, Brazil.

Residue categories[1]	Plant species	Uses[2]	N[3]	LG[4]	PP[5]
				%	
I	*Solanum variabile*[*]	w, sc	2.6	10.4	1.9
II	*Aegiphila sellowiana*	w, fe	3.8	18.2	4.9
II	*Erythrina verna*[6]	Fe	3.3	7.7	6.4
II	*Inga subnuda*[6]	fe, f, w	3.2	27.3	4.8
II	*Senna macranthera*[6]	fe, w	3.6	15.4	7.6
III	*Cassia ferruginea*[6]	sc, w	1.6	12.5	11.0
III	*Croton urucurana***	W	2.0	13.8	10.7
III	*Luehea grandiflora*	w, sc	2.0	13.6	8.3
III	*Zeyheria tuberculosa*	W	2.2	14.5	4.4
IV	*Persea americana*	f, w, sc	2.1	21.0	7.3
IV	*Piptadenia gonoacantha*[6**]	W	2.4	18.5	6.1

[1] Palm *et al.* (2001) ; [2] w: wood, sc: soil cover, fe: fertilizer, f: food/fodder, [3] N: nitrogen, [4] LG: lignin; [5] PP: polyphenols, [6] N-fixing trees.*nowadays classified as *Solanun mauritianum*; ** these species are no longer indicated as suitable to be intercropped with coffee in the region Souza et al. 2010).

3.3. System effects on temperature

The monthly average maximum temperatures differed significantly between systems ($p<0.001$). The sun coffee system (SC) consistently presented the highest mean daily maximum temperatures, which were 6.3 °C higher than in the reference forest (RF) and 5.4 °C higher than in agroforestry system (AF) when averaged across all months (Figure 4). The highest temperatures were reached in February and March (32 °C) and September and October (31 °C). There was no difference between RF and AF for monthly average maximum temperature ($p=0.79$). The mean daily minimum temperatures did not show significant differences among any of the systems ($p=0.12$).

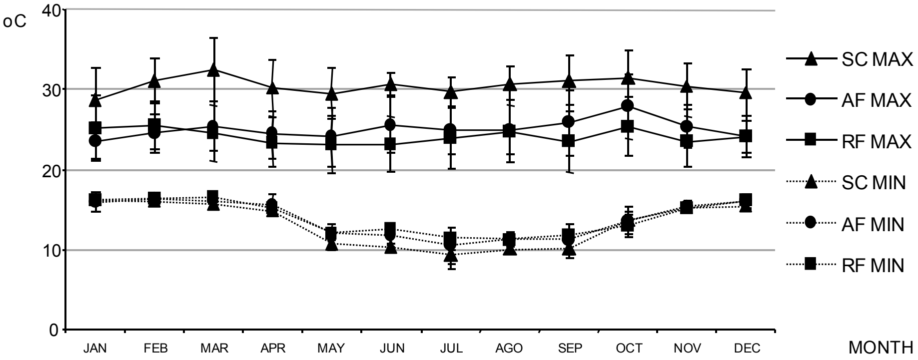


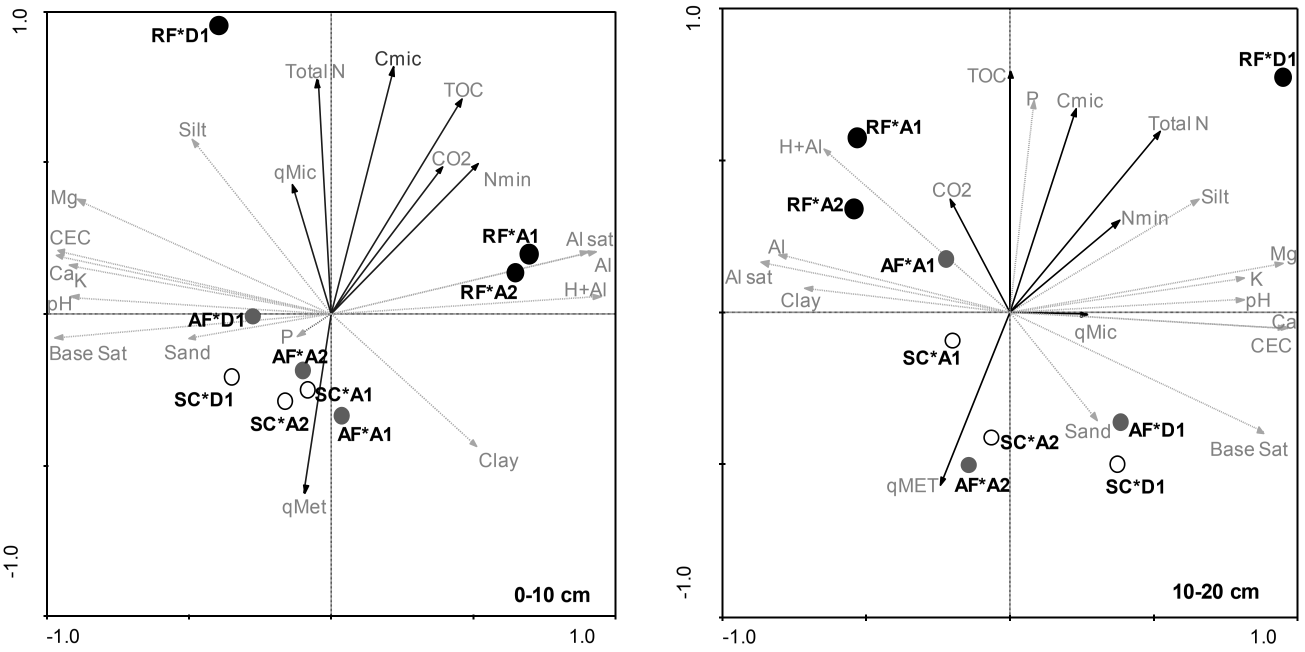
Figure 4: Monthly average maximum (MAX) and minimum (MIN) temperatures in reference forest fragments (RF), coffee agroforestry (AF) and full-sun coffee (SC) systems. Average data collected at three different farms in 2007/2008. Bars represent standard errors.

3.4. System effects on soil parameters

The redundancy analysis that described the variation in soil chemical and biological properties (response variables) as a function of the experimental variables site and system separated the farm in Divino from the two farms in Araponga (axis 1), and secondly, the reference forests (RF) from the coffee systems (sun coffee, SC and agroforestry system, AF). These results were consistent for both soil depths (Figure 5). The displayed graph explained 64% and 58% of the variance in soil factors and 79% and 77% of the variance in the fitted soil factors for the 0-10 cm and 10-20 cm soil depth, respectively. The sum of all canonical eigenvalues was 0.805 and 0.751 respectively (Figure 5).

At 0-20 cm depth, the Divino site had a silty clay texture (28% clay, 22% silt and 50% sand), whereas the Araponga sites had a clay texture (44% clay, 12% silt and 44% sand). Moreover, potential acidity (H+Al) was lower (p=0.005) and base saturation (Base Sat) higher (p=0.018) at Divino (H+Al = 5.6, Base Sat = 52.1) than at Araponga (A1 : H+Al = 11.8 and Base Sat = 5.5; A2 : H+Al = 8.4 and Base Sat = 14.4).

At 0-10 cm soil depth, the chemical parameters potential acidity (H+Al) and total organic carbon (TOC), and the biological parameters microbial carbon (Cmic), nitrogen mineralization (Nmin) and microbial respiration (CO_2) were higher ($p \leq 0.05$) in RF compared to AF and SC (Table 4). None of the measured soil parameters distinguished the AF treatments from the SC treatments. Also at 10-20 cm soil depth, H+Al, TOC, Cmic and CO_2 were higher ($p \leq 0.05$) in RF compared to AF and SC.



Codes: System: RF, reference forest (black dots); AF, agroforestry system (grey dots); SC, full sun coffee system (open circles); location: A, Araponga and D, Divino; Soil biological parameters indicated as black arrows; soil physical and chemical parameters indicated as grey arrows. See Table 4 for the explanation of the abbreviations of the soil parameters.

Figure 5: Correlation biplot based on redundancy analysis (RDA) of the independent factors location and system and the dependent chemical and biological soil parameters at 0-10 cm and 10-20 cm soil depth at 3 farms in Zona da Mata, Minas Gerais State, Brazil.

Table 2: Average (n = 12) of soil parameters in reference forest (RF), agroforestry systems (AF), and full sun coffee (SC) at two soil depths, in Zona da Mata, Brazil.

Soil parameters	Units	RF	AF	SC	P-value
----------------------------- 0-10 cm -----------------------------					
Sand	%	47.9	48.9	48.1	0.602
Silt	%	16.3	12.2	14.4	0.981
Clay	%	35.8	38.9	37.5	0.662
pH H_2O	(1:2.5)	5.4	5.8	6.0	0.309
P[1]	mg.dm^{-3}	4.3	3.9	7.0	0.607
K[2]	mg.dm^{-3}	108.1	123.5	135.8	0.361
Ca[3]	cmol$_c$.dm^{-3}	4.5	4.1	4.3	0.662
Mg[4]	cmol$_c$.dm^{-3}	1.0	1.1	1.0	0.683
Al[5]	cmol$_c$.dm^{-3}	0.70	0.02	0.01	0.181
H+Al[6]	cmol$_c$.dm^{-3}	127.8	6.0	5.3	0.086
CEC[7]	cmol$_c$.dm^{-3}	5.8	5.5	5.7	0.444
Base sat[8]	%	27.4	48.4	51.3	0.183
Al sat[9]	%	54.47	0.45	0.19	0.112
TOC[10]	g.kg^{-1}	61 a	30 b	26 b	0.006
Total N[11]	%	0.55	0.25	0.24	0.115
Nmin[12]	mg.kg^{-1} .wk^{-1}	0.15 a	0.13 b	0.11 b	0.001
C mic[13]	µg.g^{-1}	839 a	383 b	332 b	0.028
CO_2[14]	mg.kg^{-1}.day^{-1}	1378 a	1060 b	921 b	0.018
q Mic[15]	%	14.7	15.9	9.7	0.932
q Met[16]	mg C-CO_2 mg^{-1} Cmic day^{-1} *100	0.57	1.24	1.01	0.092
----------------------------- 10-20 cm -----------------------------					
Sand	%	47.8	50.0	47.7	0.874
Silt	%	15.1	11.0	13.9	0.664
Clay	%	37.2	38.4	38	0.841
pH H_2O	(1:2.5)	5.4	5.4	5.4	0.994
P	mg.dm^{-3}	2.4	1.6	1.5	0.338
K	mg.dm^{-3}	100.4	65.2	88.7	0.742
Ca	cmol$_c$.dm^{-3}	2.8	1.6	1.7	0.970
Mg	cmol$_c$.dm^{-3}	0.9	0.5	0.3	0.918
Al	cmol$_c$.dm^{-3}	0.46	0.27	0.29	0.793
H+Al	cmol$_c$.dm^{-3}	11.02 a	7.56 b	7.26 b	0.021
CEC	cmol$_c$.dm^{-3}	4.02	2.28	2.28	0.933
Base sat	%	21.7	26.2	24.1	0.418
Al sat	%	53.99	17.72	18.71	0.144
TOC	g.kg^{-1}	42 a	22 b	19 b	0.019
Total N	%	0.38	0.18	0.18	0.162
Nmin	mg.kg^{-1} .wk^{-1}	0.15	0.11	0.12	0.269
C mic	µg.g^{-1}	545 a	312 b	195 b	0.009
CO_2	mg.kg^{-1}.day^{-1}	1088	867	815	0.060
q Mic	%	12.8	12.7	12.6	0.360
q Met	mg C-CO_2 mg^{-1} Cmic day^{-1} *100	0.78	1.37	1.37	0.072

Numbers followed by the same letters are not significantly different between systems according to the Bonferroni “t” test.

Codes: [1]Available Phosphorus, [2]Potassium, [3]Calcium, [4]Magnesium, [5]Aluminium, [6]Potential acidity, [7]Cation Exchange Capacity, [8]Base saturation, [9]Aluminium Saturation, [10]Total Organic Carbon, [11]Total Nitrogen, [12]Nitrogen mineralization, [13]Microbial biomass carbon, [14]Carbon dioxide evolution, [15]Microbial quotient, [16]Metabolic quotient.

4. Discussion

4.1. AF and tree diversity conservation

Diversified agroecosystems, such as the agroforestry systems studied here, can support the conservation of biodiversity in the surrounding landscape and *vice versa,* depending on their design and management (Moguel and Toledo, 1999; Cassano et al., 2009). The similarity in tree species between the AFs and the reference forest fragments of 13%, as expressed by the Sørensen Index (SI), is in the lower part of the range of 12-39% found by Scales and Marsden (2008) who reviewed species richness and abundance shifts in small-scale tropical agroforests. However, the design and management of the agroforestry systems (AF) were geared to the characteristics of each farm and the farmers' preferences which resulted in large differences in tree species composition (SI 29-61%) and taxonomic richness (15-41 species and 13-20 families) between farms. We found that 38% of the AF species was also found in (at least one of the RF fragments. At the same time, 20% of the native tree species found in AF was not detected in the RF fragments. This analysis partly confirms the first hypothesis as it was shown that the majority of the tree species used in AF was native, even though the percentage of AF tree that also occurred in RFs was below 50%. This is explained by the observation that some tree species, that were not detected in the RF fragments, but were present in the AF, such as *Aspidosperma* spec., *Joanesia* spec., *Caesalpina* spec., *Schizolobium* spec., *Anadenanthera* spec. and *Zeyheria* spec., belong to more advanced stages of succession or to climax rainforest. The RF fragments consisted of secondary forest on former agricultural land.

Our results thus demonstrate the potential of AF systems to contribute to the conservation of tree species diversity in tropical rainforest landscapes such as the Zona da Mata. As part of the 62% of native tree species that were not found in AF systems might represent a source of useful tree species for agroforestry systems. An important future challenge is therefore to source local ethnobotanic knowledge, and generate new knowledge on tree characteristics to optimize the use of trees in AF systems (e.g. to verify compatibility with intercropping).

The use of native trees in coffee AFs is not common elsewhere in Brazil. Instead, exotic leguminous trees and/or marketable timber trees are preferred (Jaramillo-Botero et al., 2007; Vieira et al., 2007). In local agroforests in Kigezi Highlands in Rwanda most (69%) cultivated tree species were also exotic (Boffa et al., 2009). In contrast, in coffee agroforestry systems in Guatemala, on average 70 native tree species per hectare were surveyed (Rice, 2008). In other Latin American countries such as Honduras, El Salvador, and Peru, native *Inga* spp. were found to dominate the agroforestry systems and most shade canopies included a mixture of three to six of these tree species (Schroth et al., 2004). Unfortunately, to our best knowledge, quantitative data on tree species composition in AF systems in Brazil is lacking. The results of our study show a much greater γ-diversity than α-diversity in AFs. Hence, different choices of farmers probably increase habitat diversity, which is important for conservation of the diversity of both trees and other groups of fauna and flora (Schulze et al., 2004; Philpott et al., 2008; Cassano et al., 2009). Bhagwat et al. (2008) found that the more complex AF systems in their studies had on average 60% greater species richness of birds, bats, herptiles, insects, macrofungi, mammals, plants, and trees than the forests.

4.2. Agroforestry for adaptation to climate change

The average annual temperature for sun coffee (SC), agroforestry system (AF), and reference forest (RF) was 22 ^{o}C, 20 ^{o}C, and 19 ^{o}C, respectively, which falls within the range of the optimum temperature for *Coffea arabica*, which is between 18 and 23 ^{o}C (Camargo, 1985). On a daily basis, however, the maximum temperature registered in SC reached maxima up to 38 ^{o}C. Exposing coffee plants continuously to extreme temperatures higher than 30 ^{o}C can cause a reduction in the coffee production due to depressed growth and occurrence of abnormalities such as yellowing of leaves (DaMatta, 2004; DaMatta et al., 2006). The difference between the mean daily maximum temperature in SC and the average in AF and RF was approximately 6 ^{o}C. This result fully supports our third hypothesis that AF would moderate extremes of high temperature, thereby creating a more adequate microclimate for coffee production than full-sun coffee. Some studies emphasized the negative influence of high temperatures on coffee quality and production. For instance, Muschler (2001) observed that coffee fruit weight and bean size under shade systems in Costa Rica were on average 50% higher than in unshaded coffee systems. All three farmers (A1, A2 and D1) reported that the coffee from AF acquired high beverage (better quality) that guarantees a better price than the coffee harvested in SC.

Morton (2007) reported that climate change will affect smallholder farmers and indigenous communities in particular. Our results indicate that agroforestry provides temperature regulation as an ecosystem service, thereby offering an adaptation strategy for small coffee growers in response to global warming, in line with previous studies (Beer et al., 1997). Agroforestry could significantly reduce the risk of loss of coffee production in Minas Gerais state, which is predicted to be as high as 92% by 2050 if the climate warms up with 5.8 ^{o}C (Assad et al., 2004), in Minas Gerais and other coffee growing regions such as the higher elevation regions of the southeast of São Paulo state (Junior et al., 2006).

4.3. Local strategies for the use of tree resources and its effects on soil quality

Agroforestry management in Zona da Mata is not a traditional practice and farmers learn and improve their systems by exchanging their main findings. Tree species diversity in the individual agroforestry system (AF) plots is determined by different underlying factors related to farm features, physiographic conditions, local knowledge on tree species traits and soil fertility management, and farmer preferences. Our third hypothesis was that chemical and biological soil characteristics are improved under AF as compared to sun coffee system (SC) and these improvements are related to leaf litter quality. We found only partial evidence for this hypothesis. The AF in location A1 was established at a degraded plot. The choice of tree species by the farmer was functional in selecting N-fixing species that improve soil fertility. In location A2, the AF was located on a very steep slope (>70%), legally characterized as a Permanently Protected Area (BRASIL, 2006). At this position the soil was severely degraded by erosion, requiring an efficient and rapid topsoil recovery. The main tree species selected were *P. americana* (class IV, dominant in AFA2) in combination with *A. sellowiana* (class II). The farmer motivated his choice by reporting that *P. americana* is a deeper rooting species, that produces a large amount of relatively slowly decomposing litter that will contribute to an increased soil cover, whereas the leaves of *A. sellowiana,* a tree species that does not need pruning, are decomposed much faster and contribute to soil fertility. As a result, soil erosion was controlled (pers. observation). In location D1, AF was introduced in a degraded pasture where already some secondary tree species were present. The farmer's decision was aiming at a high diversity of tree species to produce a variety of residue qualities to improve soil protection. The AFD1 farmer achieved this goal by selecting trees belonging to class II (*A. sellowiana*), class III (*C. ferruginea*, *L. grandiflora*, *Z. tuberculosa*) and class IV (*P. americana* and *P. gonoacantha*). The wood providing *P. gonoacantha* (class IV) can provide additional benefits for erosion control due to its slow decomposition. Furthermore, e.g. *C. urucurana* and *Z. tuberculosa* (class III) were used for wood production only, but can according to the residue category classification system of Palm et al. (2001) also be mixed to facilitate nutrient release.

Hence, most of the actual uses of the trees found in the three AF systems studied did not entirely correspond with the function of the categories of residue quality according to the classification of Palm et al. (2001). The farmers selected trees based on multiple criteria and trade-offs, whereas the Palm classification looks at a limited set of criteria such as decomposability and nutrient supply while ignoring market value, management requirements, seed availability, and compatibility with other plants, such as coffee. A previous study reported on the main criteria and indicators of farmers for selecting trees to use in the agroforestry coffee systems in Zona da Mata, including the compatibility with coffee plants (e.g. no competition and negative phytosanitary interactions), the amount of biomass produced, the labour needed to manage the trees, and diversification of the production (Souza et al., 2010). A multi-criteria decision support system would be needed for the farmers to enhance their options and improve their selection. Moreover, to further improve the residue category classification system of Palm et al. (2001), we propose to base the classification of leaf material on characteristics of freshly fallen litter and not on fresh leaves.

We found significant differences in soil characteristics between reference forest (RF) and both coffee systems, but not between agroforestry system (AF) and sun coffee system (SC). However, there is a clear trend in soil quality of AF being closer to RF than SC (Table 4), suggesting that soil quality in AFs is improving more than in SC. Differences in soil conditions between RF and the two coffee systems were related to organic matter content and soil microbial activity (higher TOC, Cmic, soil respiration and Nmin). H+Al was only higher in RF in the 10-20 cm soil layer, with a similar, but not significant trend in the 0-10 cm layer. Such differences, which were also found in other studies (Sena et al., 2002; Macedo et al., 2008), might be explained by higher inputs of organic matter and less soil disturbance in RF, and inorganic fertilizer application in AF/SC.

AF did not result in higher soil carbon contents than SC despite the higher litter returns in AF. In contrast, Youkhana and Idol (2009) found differences in soil C and N already three years after conversion from SC to AF. The lack of such effect in our study may be explained by the fact that the experimental plots in ZM were highly degraded at the start of the experiments and may need relatively long time or high OM inputs before soil improvement can be detected. There may still be room for improvement of the soil quality in the AF systems, e.g. through enhanced organic matter returns and reduced soil disturbance. However, more research is needed to improve our knowledge of the management of residue quality and their effects on soil C dynamics and soil nutrient cycling as essential to support ecosystem services in tropical AF, such as erosion control, carbon sequestration and soil structure maintenance.

Coffee production in AF can be as high as in SC, as was proven at two of three studied farms, and also of a better quality that led to an enhanced price on sales. Again the large variability across farms suggests that there is scope for improvement, e.g. through further farmer-to-farmer knowledge exchange.

5. Conclusions

Our comparison between reference forest fragments, agroforestry coffee and sun coffee revealed that:

- Agroforestry can support the conservation of native trees.
- Agroforestry systems can moderate high temperature extremes to the extent that agroforestry coffee production, unlike sun coffee, is resistant to expected near-future temperature increases resulting from climate change.
- Some soil quality parameters (Total Organic Carbon, Microbial Carbon, Soil Respiration and Nitrogen mineralization) showed higher values in reference forest fragments compared to agroforestry and sun coffee systems, and there was a trend towards improved soil quality in AF relative to SC.
- The selection of trees in agroforestry systems was based on multiple criteria and trade-offs, Local and scientific knowledge on native tree species and multi-criteria decision support systems would increase farmers' options to further enhance ecosystem services provided by agroforestry systems.

Based on the successful examples of agroforestry coffee systems, our study has shown the potential of agroforestry systems to reconcile coffee production with biodiversity conservation under climate change and to contribute to some regulating and supporting ecosystem services. We see much scope for better design of these systems, based on increased ecological literacy through continued participative work among scientists and stakeholders.

Acknowledgements

We thank the farmers for unconditional sharing of their knowledge on agroforestry; Maria Ivanilda de Aguiar for the soil texture data of A1 farm; Prof. Dr. Rogério Ferreira Ribas, Carolina Marotta, Livia Constancio Siqueira and Jose Martins Fernandes for the botanical surveys; Prof. Dra. Andreza Viana Neri (UFV) for help with the botanical analysis and interpretation; Eliana de Souza for the map (Fig. 1); and CAPES (Coordenação de Pessoal de Ensino Superior) for a scholarship to the first author. The research was carried out in one of the eight benchmark areas of the agroBIODIVERSITY network of DIVERSITAS, the International Organization for Biodiversity Science (http://www.agrobiodiversity-diversitas.org/).

6. Annex

Annex 1: Species of native and exotic trees used in agroforestry systems and found in the forest fragments, Zona da Mata, Minas Gerais, Brazilian Rainforest.

#	Family/Specie	Common name	Agroforests[1]	Fragments[2]
	ANACARDIACEAE			
1	*Mangifera indica* L.	Manga	D1,A3,A4,A5,A7	
2	*Schinus terebentifolius* Raddi	Aroeira-do-sertão	A1,A4	1
3	*Tapirira guianensis* Aubl.	Pau-pombo		1,2
4	*Tapirira obtusa* (Benth.) JD.Mitch	Pau-pombo		1
	ANNONACEAE			
5	*Annona cacans* Warm.	Araticum-cagão		2
6	*Annona muricata*		D1	
7	*Annona squamosa* L.		D1,A6	
8	*Ephedranthus* spec.			1
9	*Guatteria mexiae* R. & Fr.	Pindaíba		1
10	*Guatteria sellowiana* Schltdl.	Pimenteira		1
11	*Guatteria villosissima* A.St.-Hil.	Araticum-peludo		2
12	*Rollinia dolabripetala* A. St.-Hil.	Articum/Araticum	A1,A3	1
13	*Rollinia laurifolia* Schltdl.	Araticum-bravo		2
14	*Rollinia sericea* (R.E.Fr.) R.E.Fr.	Araticum-mirim		2
15	*Xylopia sericea* A.St.-Hil.	Pimenteira		2
	APOCYNACEAE			
16	*Aspidosperma* spec.	Peroba/Tambu	D1	
17	*Himatanthus phagedaenicus* (Mart.)	Sucuúba		2
18	*Peschiera laeta* Miers			2
	AQUIFOLIACEAE			
19	*Ilex breviscuspis* Reissek			1
20	*Ilex* L.			1
21	*Ilex theezans* Mar			1
	ARAUCARIACEAE			
22	*Aracucaria angustifolia* (Bertol.) Kuntze	Pinheiro	A3	
	ARECACEAE			
23	*Syagrus romanzoffiana* (Cham.)	Coco-babão/Jerivá	A5	2
	ASTERACEAE			
24	*Baccharis* spec.			2
25	*Eupatorium angulicaule* Sch.Bip.			1
26	*Eremanthus erythropappus* (DC.) McLeish	Candeia-miúda	A2,A4	1
27	*Gochnatia polymorpha* (Less.) Cabr.	Cambará		1
28	*Piptocarpha oblonga* Baker			1
29	*Piptocarpha sellowii* (Sch. Bip) Baker			1
30	*Vernonia densiflora* Gardner	Pau-de-fumo		1
31	*Vernonia diffusa* Less.	Vassourão-preto		2
32	*Vernonia polyanthes* Less.		D1	1
	BIGNONIACEAE			
33	*Adenocalymma subsessilifolium* DC.			1
34	*Cybistax antisyphilitica* Mart.	Pente-de-macaco		1
35	*Jacaranda macrantha* Cham.	Carobinha/Caroba	A1,A2	1,2
36	*Jacaranda microcalyx* A.H.Gentry			1
37	*Sparattosperma leucanthum* K. Schum.	Cinco-folhas		2
38	*Tabebuia chrysotricha* (Mart. Ex DC.) Standl.	Ipê-mulato	A3,A4,A6	1

39	*Tabebuia serratifolia*	Ipê-amarelo	D1	
40	*Zeyheria tuberculosa*	Ipê-preto	D1	
	BIXACEAE			
41	*Bixa orellana* L.	Urucum	A5	
	BORAGINACEAE			
42	*Cordia ecalyculata* Vell.	Poragaba		2
43	*Cordia sellowiana* Cham.	Chá-de-bugre		1,2
44	*Cordia alliodora* (Ruiz & Pav.) Oken.			1
45	*Cordia* spec.			2
	CANNABACEAE			
46	*Trema micrantha* (L.) Blume	Crindiúva/Candiúva	D1	1,2
	CARICACEAE			
47	*Carica papaya* L.	Mamão	A1,A3,A4,A6,A7	
	CHRYSOBALANACEAE			
48	*Hirtella hebeclada* Moric.	Azeitona-da-mata		2
49	*Hirtella selloana* Hook.			2
	CLETHRACEAE			
50	*Clethra scabra* Pers.			1,2
	CLUSIACEAE			
51	*Vismia brasiliensis* Choisy	Ruão		1
	CUNONIACEAE			
52	*Lamanonia ternata* Vell.	Três-folhas		1,2
	ELAEOCARPACEAE			
53	*Sloanea monosperma* Vell.	Sapopeba		2
	ERYTHROXYLACEAE			
54	*Erythroxylum pelleterianum* A.St.-Hil..	Cocão		2
	EUPHORBIACEAE			
55	*Alchornea triplinervia* Müll.	Irucurana		2
56	*Croton urucurana* Baill.	Sangra-d'água	A3	1
57	*Hieronyma alchorneoides*	Licurana		2
58	*Joannesia princeps* Vell.	Cutieira	A5	
59	*Mabea fistulifera* Mart.	Canudo-de-pito	A5	
60	*Manihot dulcis* Baill.	Maniçoba		2
61	*Maprounea guianensis* Aubl.	Carambola-da-mata		2
62	*Ricinus communis* (L.) Mull. Arg.	Mamona	A1,A3,A5,A7	
63	*Pera* spec.	Pera		1
64	*Sapium glandulatum* (Vell.) Pax	Leiteiro		2
65	*Sapium* spec.	Leiteira	D1	
66	FLACOURTIACEAE			
	Carpotroche brasiliensis Endl.	Canudo-de-pito		2
67	*Casearia decandra* Jacq.	Café-do-mato		2
68	*Casearia ulmifolia* Cambess.	Cafezinho		2
69	*Xylosma prockia* (Turcz.) Turcz.	Espinho-de-judeu		2
	GUTTIFERAE			
70	*Kielmeyera* spec.			2
71	*Rheedia gardneriana* Planch. & Triana	Bacupari		2
72	*Vismia martiana* Rechb. f.	Ruão		2
	LABIATAE			
73	*Hyptis cana* Pohl ex Benth.	Hortelã-do-campo		2
	LACISTEMACEAE			
74	*Lacistema pubescens* Mart.			2
	LAMIACEAE			

75	*Vitex montevidensis* Cham.	Maria-preta	D1,A5,A6	
	LAURACEAE			
76	*Endicheria glomerata* Mez			1
77	*Lauraceae* spec.	Canela		2
78	*Nectandra lanceolata* Nees & Mart. ex Nees	Canela-amarela	A3	2
79	*Nectandra opositifolia* Nees.	Canela		1
80	*Nectandra rigida* Nees	Canela		2
81	*Ocotea corymbosa* Mez	Canela-fedida		1,2
82	*Ocotea dicaricata* (Nees.) Mez	Canela		1
83	*Ocotea dispersa* Mez	Canelinha		2
84	*Ocotea spixiana* (Nees.) Mez	Canela		2
85	*Ocotea odorifera* (Vell.) Rohwer	Canela-sassafrás		1
86	*Persea microneura* Meisn.			1
87	*Persea americana* Mill.	Abacate	D1,A2,A3,A4,A5,A6,A7	
	LEG. CAESALPINIOIDEAE			
88	*Apuleia leiocarpa* J.F. Macbr.	Garapa	A6,A7	1,2
89	*Caesalpinia echinata* Lam.	Pau-brasil	D1,A3,A7	
90	*Cassia ferruginea* (Schrader) Schrader ex DC	Cássia	A1,A2,A4	1
91	*Copaifera langsdorffii* Desf.	Copaíba/Pau-d'óleo	A3,A7	
92	*Hymenaea courbaril* L.	Jatobá	A3,A7	
93	*Peltophorum dubium* Taub.	Farinha-seca		2
94	*Pterogyne nitens* Tul.	Aroeira-do-sertão	A3,A7	
95	*Schizolobium parahyba* (Vell.) S.F. Blake	Guapuruvu/Breu	A3,A5	
96	*Sclerolobium friburguense* Harms			1
97	*Sclerolobium rugosum* Mart. ex Benth.			1
98	*Senna* spec.	Fedegoso	D1	
99	*Senna alata*	Fedegoso-miúdo	A7	
100	*Senna macranthera* (DC. ex Collad.) Irwin & Barneby	Fedegoso	A1,D1,A2,A3,A5,A4,A7	1,2
101	*Senna multijuga* (Rich.) H.S. Irwin & Barneby	Farinha-seca	A3,A5	1
102	*Tachigali paratyensis* (Vell.) H.C.Lima			1
	LEG. MIMOSOIDEAE			
103	*Abarema obovata* (Benth.) Barneby & J.W. Grimes			1
104	*Albizia polycephala* (Benth.) Killip ex Record	Farinha-seca	A7	
105	*Anadenanthera peregrina* (L.) Speg.	Angico-vermelho	A3,A5	
106	*Anadenanthera colubrina* (Vell.) Brenan	Angico-branco		2
107	*Enterolobium contortisiliquum* (Vell.) Morong	Orelha-de-negro	A4,A6	2
108	*Inga cylindrica* (Vell.) Mart	Ingá	A4,A6	1,2
109	*Inga edulis* Mart.	Ingá-de-metro	A1,A2,A5,A6,A7	
110	*Inga leptantha* Benth.	Ingá		1
111	*Inga sessilis* (Vell.) Mart.	Ingá-ferradura	A1,D1,A4	1
112	*Inga striata* Benth.	Ingá		1
113	*Inga subnuda* (Benth). T.D. Penn.	Ingá-serra/Angá	A1,D1,A3,A4,A5,A7	
114	*Inga vera* Willd.	Ingá/Angá		2
115	*Leucaena leucocephala* (La.) de Wit	Leucena	A3,A4,A6,A7	
116	*Piptadenia gonoacantha* (Mart.) J.F. Macbr.	Pau-jacaré/Jacaré	A1,A2,A3,A4,A6,A7	1,2
117	*Plathymenia foliolosa* Benth.	Vinhático		2
118	*Pseudopiptadenia contorta* (DC.) G.P. Lewis & M.P. Lima	Angico-amarelo	A5,A6	2
119	*Stryphnodendron guianense* Benth.			2
	LEG. PAPILIONOIDEAE			
120	*Andira fraxinifolia* Benth.	Angelim		2
121	*Andira surinamensis* (Bondt) Splitg. ex Pulle	Angelim-doce	A3,A5,A6	1
122	*Dalbergia foliolosa* Benth.			1

123	*Dalbergia nigra* Allemao ex Benth.	Jacaraná-caviúna	A1,A3,A5,A7	1,2
124	*Dalbergia variabilis* Vogel	Jacarandá		2
125	*Erythrina speciosa* Andrews	Sumaúma	A3,A7	
126	*Erythrina verna* Vell.	Mulungu/Pau-abóbora	D1,A3,A7	
127	*Flemingia macrophyla*	Flemigia	A7	
128	*Hymenolobium janeirense* var. stipulatum (N.F. Mattos) Lima			1
129	*Indigofera suffruticosa*		A7	
130	*Machaerium acutifolium* Vogel			1
131	*Machaerium brasiliense* Vogel	Sangue-de-gato	A3,A4,A5,A6	1,2
132	*Machaerium hirtum* (Vell.) Stellfeld		A3,A7	1
133	*Machaerium nyctitans* (Vell.) Benth.		A1,A2,A4,A7	1
134	*Machaerium stiptatum* Vogel	Marmelim	A3,A7	
135	*Machaerium* spec.		A2	2
136	*Platymiscium pubescens* Micheli			2
137	*Platypodium elegans* Vogel		A1,A4,A5,A6,A7	
138	*Swartzia pilulifera* Benth.			1,2
139	*Swartzia* spec.			2
	MALPIGHIACEAE			
140	*Malpighia emarginata* Sessé e Moc. Ec Dc	Acerola	D1,A3	
141	*Byrsonima sericea* DC.	Massaranduva		1
142	*Byrsonima* spec.			1
	MALVACEAE			
143	*Bombax marginatum* K. Schum.		A3,A4,A5,A6	
144	*Luehea grandiflora*	Açoita-cavalo	D1	2
145	*Luehea divaricata* Mar	Açoita-cavalo	A2,A5,A7	
	MELASTOMATACEAE			
146	*Miconia cubatanensis* Hoehne			2
147	*Miconia sellowiana* Naudin	Jacatirão		2
148	*Miconia latecrenata* (DC) Naudin	Quaresminha		1
149	*Miconia pyrifolia* Naud.	Quaresminha		1
150	*Miconia urophylla* DC.			2
151	*Tibouchina granulosa* Cogn.	Quaresma	A1,A4	1
	MELIACEAE			
152	*Cedrela fissilis* Vell.	Cedro-nativo	D1,A3	
153	*Cabralea canjerana* (Vell.) Mart.	Canjerana		2
154	*Guarea kunthiana* A.Juss.	Andirobarana		2
155	*Trichilia lepidota* Mart.			2
	MONIMIACEAE			
156	*Siparuna guianensis* Aubl.	Folha-santa		2
157	*Siparuna reginae* A.DC.			2
	MORACEAE			
158	*Artocarpus heterophyllus* Lam.	Jaca	A3	
159	*Brosimum glaziovii* Taub.			2
160	*Ficus arpazusa* Casar.			1
161	*Ficus guaranitica* Chodat	Figueira-branca		2
162	*Maclura tinctoria* D.Don ex Steud.	Amoreira		2
163	*Morus nigra* L.	Amora-preta	A1	
164	*Sorocea bomplandii* (Baill.) Bürger, Lanj. & Boer	Folha-de-serra		2
	MORINGACEAE			
165	*Moringa oleifera* Lam.	Muringa	A3	
	MUSACEAE			
166	*Musa paradisiaca* L.	Banana	A1,D1,A2,A3,A4,A5,A6,A7	

	MYRSINACEAE			
167	*Rapanea ferruginea* (Ruiz et Pavon) Mez	Pororoca		1
	MYRTACEAE			
168	*Eucalyptus* spec.	Eucalipto	A6	
169	*Eugenia leptoclada* Berg			2
170	*Eugenia uniflora* L.	Pitanga	A3,A5	
171	*Eugenia* spec.	Pitanga		2
172	*Gomidesia* spec.			1
173	*Myrcia fallax* DC.	Jambo-vermelho		1,2
174	*Myrcia formosiana* DC.			1
175	*Myrcia rostrata* DC.	Jambinho		1
176	*Myrcia* spec.	Jambo		2
177	*Psidium cattleyanum* Sabine	Araçá-do-mato		2
178	*Psidium guajava* L.	Goiaba	A1,A4,A5,A6	
179	*Psidium rufum* D.C	Araça		1
180	*Syzygium jambos* (L.) Alston	Jambo	A3	
	NYCTAGINACEAE			
181	*Guapira opposita* (Vell.) Reitz	Maria-mole		2
	OCHNACEAE			
182	*Ouratea castanaefolia* Engl.			1
	PALMAE			
183	*Euterpe edulis* Mart.	Palmito	D1,A4,A7	
	PROTEACEAE			
184	*Euplassa organensis* (Gardner) I. M. Johnst.	Carne-de-vaca		1
185	*Roupala montana* Aubl.			1
	QUINACEAE			
186	*Lacunaria* spec.			1
	RHAMANACEAE			
187	*Colubrina glandulosa* Var. Reitzii	Sobrasil	A1	
188	*Hovenia dulcis* Thunb.	Uva-do-japão	A3	
	ROSACEAE			
189	*Eriobotrya japonica* (Thunb.) Lindl.	Ameixa-amarela	D1,A2,A3	
190	*Prunus persica* (L.) Batsch	Pêssego	A7	
	RUBIACEAE			
191	*Alibertia* spec.			2
192	*Amaioua guianensis* Aubl.	Carvoeiro		1,2
193	*Bathysa nicholsonii* K. Schum.			2
194	*Guettarda viburnoides* Cham. & Schltdl.	Angélica		1,2
195	*Randia armata* DC.	Limorana		2
196	*Rubiaceae* spec.			2
	RUTACEAE			
197	*Citrus limon* (L.) Burm. F.	Limão	A1,D1,A4,A5	
198	*Citrus reticulata* Blanco	Pocã/mexerica	A3	
199	*Citrus sinensis* L. Osbeck	Laranja	D1,A3	
200	*Dictyoloma vandellianum* A.Juss.	Sabugueiro-do-mato		1,2
201	*Hortia arborea* Engl.	Paratudo		1
202	*Zanthoxylum rhoifolium* Lam.	Maminha-de-porca	A1,A7	1,2
	SALICACEAE			
203	*Casearia arborea* (Rich.) Urb.			1,2
	SAPINDACEAE			
204	*Allophylus edulis* (A.St.-Hil..) Radlk. ex Warm.	Vacunzeiro		2
205	*Allophylus petiolulatus* Radlk. ex W.Muell.	Casca-solta		2

206	*Allophylus sericeus* Radlk.	Três-folhas		2
207	*Cupania* spec.		D1	
209	*Cupania vernalis* Cambess.	Pau-de-cantil		2
209	*Litchi chinensis* Sonn.	Lichia	A3	2
210	*Matayba elaeagnoides* Radlk.	Camboatá		2
	SAPOTACEAE			
211	*Chrysophyllum gonocarpum* (Mart. & Eckl.) Engl.	Guatambu-sapo		2
	SIMAROUBACEAE			
212	*Simarouba amara* Aubl.			1
	SOLANACEAE			
213	*Cestrum sendtnerianum* Mart. ex Sendtn.	Coerana		2
214	*Solanum cernuum* Vell.	Panacéia	A7	2
215	*Solanum cinnamomeum* Sendtn			1
216	*Solanum cladotrichum* Dunal			1
217	*Solanum leptostachys* Dunal			1
218	*Solanum pseudoquina* A. St. Hil.	Jessiana		1
219	*Solanum leucodendron* Sendtn.	Adrago		2
220	*Solanum mauritianum* Scop.	Capoeira-branca	A1,D1,A2,A4,A5,A6,A7	2
221	*Solanum robustum* H.Wendl.			2
222	*Solanum swartzianum* Roem. & Schult.			1,2
	THEACEAE			
223	*Gordonia semiserrata* (Nees.) Spreng.	Ameixa		1
	TILIACEAE			
224	*Triumfetta semitriloba* Jacq.	Carrapichão		2
	URTICACEAE			
225	*Cecropia glaziovi* Snethl.	Embaúba	A1,A2,A3,A4	1,2
226	*Cecropia hololeuca* Miq.	Embaúba-formiga		1,2
	VERBENACEAE			
227	*Aegiphila sellowiana* Cham.	Papagaio/Capoeirão	D1,A2,A4,A6	2,1
228	*Hyptidendron asperrimum* (Spreng.) R. M. Harley	Maria-mole		1
229	*Vitex sellowiana* Cham.	Tarumã		1,2
	VOCHYSIACEAE			
230	*Qualea cryptantha* Mart.			1
231	*Callisthene major* Mart.			1

---

[1] Agroforests: AF1, AF2 (located in Araponga) and AFD1 (located in Divino) are in the selected farms ; and AFA4-AFA7 are neighboring agroforests in Araponga.

[2] Total species found in reference forest fragments: 1: Araponga (RFA8 + RFA9), 2: Viçosa (RFV1 + RFV2).

Chapter Five

Strategies and economics of farming systems with coffee in the Atlantic Rainforest Biome

Helton Nonato de Souza[1a], Jan de Graaff[2], Mirjam M. Pulleman[1]

[1]Department of Soil Quality, Wageningen University, PO Box 47, 6700 AA
Wageningen, The Netherlands
[2]Land Degradation and Development Group, Wageningen University, P.O. Box 47, 6700 AA, Wageningen,
The Netherlands

[a] Corresponding author: QMSW 4, lote 3, Apto 103 – Setor Sudoeste – Brasília-DF - Brazil
CEP 70.680-400 Email: heltonnonato@yahoo.com.br

In press, available online DOI: 10.1007/s10457-011-9452-x, Agroforestry Systems

Strategies and economics of farming systems with coffee in the Atlantic Rainforest Biome

Abstract

In the Zona da Mata of Minas Gerais State, Brazil, family farmers are adjusting to agroecological principles to reconcile sustainable agriculture, livelihood improvements and biodiversity conservation. Starting in 1993, experimentation with coffee agroforestry was gradually initiated on an increasing number of farms (37 in total), resulting in the simultaneous management of sun coffee (SC) and agroforestry coffee (AF) plots. We aimed i) to identify factors that determine the farmers' selection of trees used in AF; ii) to describe the agroecological farms in transition; and iii) to perform an economic comparison between AF and SC. These objectives were addressed by combining data from botanical surveys in 1993/1994 and 2007, by interviews with farmers and by detailed data on the production value and costs of labour and material inputs. The results showed considerable diversity in farming strategies and management among the farmers. Early adopters of AF had diversified towards production of different marketable products. The use of native trees in AF for this purpose, and for restoration of soil fertility (e.g. leguminous trees), had increased since the start of the experiments, while exotic tree species were eliminated. Over a period of 12 years AF was more profitable than SC due to the production of a diversity of agricultural goods, despite somewhat higher establishment costs. Other ecosystem services delivered by AF, such as biodiversity and cultural services are currently not valorized. Payment schemes for environmental services could further improve the economic benefits of AF for family farmers and alleviate establishment and learning costs.

Key words: family agriculture, coffee agroforestry, productivity, profitability, ecosystem services.

1. Introduction

Poverty and food security depend on the functions and services that local ecosystems supply (Sala and Montes 2007, SSNC 2008). However, the ability of ecosystems to secure human well-being has declined (MEA 2005). Increasing food production while reducing the dependency on fossil fuels, protecting wildlife species and enhancing environmental quality is an important challenge for today's society. As an alternative to the current model that focuses primarily on maximization of production of agricultural goods, new forms of agriculture that strengthen the delivery of multiple ecosystem services (ES) are being advocated (Lundberg and Moberg 2008; Brussaard et al. 2010). Interdisciplinary science, agricultural management interventions and institutional development at local and global scales are needed for ecological intensification of agricultural production (Perfecto and Vandermeer 2008; Carpenter et al. 2009), but many questions concerning the trade-offs between economic and ecological benefits remain.

In developing regions family agriculture is usually based on low external inputs and therefore strongly linked to internal resources and ecological processes (Montes and Sala 2007). For these conditions farming practices based on agroecological principles (i.e. optimizing the recycling of biomass and nutrients and enhancing species and genetic diversity and beneficial interactions among biological components) in order to maintain productivity with minimal use of agrochemicals and other external inputs have been promoted (Egoh et al. 2008; Schroth et al. 2009). Agroecological practices have been advocated as technologies that can simultaneously offer environmental, social and economic benefits to human beings and support the conservation of wildlife (Harvey et al. 2008; Ouinsavi and Sokpon 2008). In particular, agroforestry (AF) can combine production functions with biodiversity conservation by connecting fragments of remaining natural forest in the landscape (Buck et al. 2006).

In the past, coffee in most areas in Latin America was grown under the shade of a diverse tree canopy, providing various environmental benefits. In years of low coffee prices (and relatively high fertilizer prices) the trees were allowed to provide more shade, while in years of high coffee prices the shade trees were severely pruned, more fertilizers were applied and higher coffee production was obtained. With the introduction of new high yielding coffee varieties (mid of 20th century) full sun coffee was more generally applied and this is particularly the case in Brazil. In more recent years renewed attention is paid to the environmental and biodiversity benefits of intercropping with multiple tree species and opportunities for certification of shade-coffee (Perfecto et al. 2005; Vaast et al. 2005).

However, on-farm studies of the economic aspects (including productivity, labour inputs and profitability) of AF are scarce and documentation of local knowledge on management strategies and tree selection is largely lacking (Molua 2005; Jose 2009). This type of knowledge would be crucial for scaling up AF coffee production and to inform agri-environmental and rural development policies (Molua 2005; Bennett and Balvanera 2007).

Our study focused on the Zona da Mata (ZM) region, located in the Atlantic Rainforest biodiversity hotspot (Myers et al. 2000) and characterized by the predominance of family farms. Sustainable agriculture is of vital importance for the ZM, where the side effects of the "green revolution" have caused severe environmental, agricultural and social problems (Ferrari 1996). Biodiversity loss in ZM is the result of a huge loss and fragmentation of forest cover of which only 12-14% remains today (Ribeiro et al. 2009; Teixeira et al. 2009). Participatory experimentation with agroecological principles has started in 1993, with the aim to enhance crop diversification, soil restoration, and biodiversity conservation on family farms. Furthermore, farmers, together with NGOs and university researchers started an agroecological transition process, making gradually adaptations on their farms converting them from the conventional approach to more ecologically based systems. As part of this experimentation AF coffee (*Coffea arabica L.*) systems have gradually been established on an increasing number of farms (37 in total; Souza et al. 2010, Cardoso et al. 2001).

Considering low external input systems and the relationships between biological components of an agroecosystem in terms of supplementarity, complementarity or competition (Conway 1987; Filius 1982), we hypothesized that AF systems have a higher productivity (here defined as the harvested products per unit of area) and profitability (defined as the gross margin per unit of area and per man day) than SC.

The aims of this study were to: i) identify factors that determine the farmers' selection of trees in agroforestry systems; ii) describe the family farming systems in agroecological transition and iii) perform an economic comparison between coffee agroforestry systems and conventional coffee production systems.

2. Materials and methods

2.1. Study site

The Zona da Mata (ZM) is located in the state of Minas Gerais (MG) and has a tropical highland climate. The average daily temperature is 18°C and the average precipitation is 1500 mm yr^{-1}, with 2-4 dry months. The slopes range from 20 to 75% and the altitude from 200 to 1800 m (Golfari 1975). The main soil types are Oxisols, which are deeply weathered, well drained, acidic and poor in available nutrients (Cardoso et al. 2003). Around 18% of the population in ZM lives in the countryside, mainly on family farms (IBGE 2000). The average farm size is 18 ha and 91% of the farms have less than 100 ha (IBGE 2000). The characteristics of agricultural production in ZM are: long-term land use, small-scale production systems, and conventional agricultural practices, mainly for coffee production and cattle.

In the nineteenth century the rainforest was replaced by agriculture, mainly due to favorable climate and market conditions for coffee production (Dean 1995). Few forest fragments are conserved as forest reserves and coffee plantations extend to the top of the hills. Such deforestation has caused loss of biodiversity and soil erosion, leading to drastic loss of soil fertility (Dean 1995).

Conventional full-sun coffee (SC) is the predominant type of coffee production. However, family farmers that have participated in a participatory project that has run since 1993 (Cardoso et al. 2001), have changed at least part of their land from conventionally managed systems to systems based on agroecological principles. One of these systems is coffee agroforestry (AF), in which coffee plants are intercropped with trees, shrubs and herbaceous plants. The main functions of the trees are protection of the soil against erosion, recycling of nutrients and diversification of production. AF and SC systems are managed side-by-side on the same farm.

2.2. Selection of the farms and farming systems for this study

Within ZM there is a group of about 600 families, distributed over 20 municipalities, involved in agroecological transition through collaboration with local non-governmental organizations (NGOs), farmers' organizations and research institutes (Cardoso et al. 2001). These farms serve as a platform for knowledge exchange and study of the effects of agroecological practices on productivity and profitability of farming systems and of the environmental services provided. From these 600 families, a group of 100 families belong to a "Monitoring Program on the Sustainability of Agroecosystems" conducted by the NGO Centre of Technologies Alternatives of Zona da Mata (CTA-ZM) and partners (CTA-ZM 2006) with the aim to document changes in management practices on the farms. From these 100 families, three sets of farms were included in the study presented here (Table 1).

The first group was formed by those farms on which botanical surveys were carried out in the AF plots in the early stage (1993/1994, 15 farms, group 1a) and approximately 13 years later (2007, 7 farms, group 1b). Although the overlap between the two groups is only two farms, the use of two sets of representative farms allows for the interpretation of changes in composition of coffee AF, by considering the existing data on tree species and their uses by local farmers over a long period of experimentation (objective 1).

Table 3: Study design for this paper considering the different groups of selected farmers, data sets used for each topic of investigation and the related objectives.

Group	Number of family farms	Data used	Topic of interest	Objective
		Botanical survey conducted in:	Determinant factors for the selection of trees to improve performance of regional agroforests	1
1[a]	15	1993/94		
1[b]	7	2007		
2	6	Farming activities, management, farm layout, inputs and outputs obtained through participatory techniques (interviews, flow diagram, maps)	Description of family farms in agroecological transition	2
3	3	Coffee production, labour (demand+ costs), sales, spending	Economic comparison between agroforestry and conventional systems	2 and 3

[a] Regional references of coffee agroforestry experiments established at initial phase

[b] Best regional performers of coffee agroforestry experiments at later stage of experimentation; in this group of 7, two farms of the group of 15 are included.

A second group of farmers implemented agroecological practices in the period 2003-2005 and was composed of 6 families (Farms 1-6; Fig.1), which volunteered (one family per municipality) to participate in a specific activity inserted in the monitoring program mentioned above, which should reveal “indicators of sustainability”.

A third group was formed by three families (Farms A1, A2 and D1; Fig. 1). These belonged to the early adopters of AF in ZM and started in 1993/1994 (Souza 2006). Information on farming practices and management from the second and third group (9 farms) were used to address objective 2.

For the economic comparison of AF versus SC systems (objective 3) we focused on the third group, the early adopters. These three farms maintained parallel long-term AF and SC experiments within each farm and were comparable in terms of slope and age of the coffee plants. These three families were living under similar social and economic conditions.

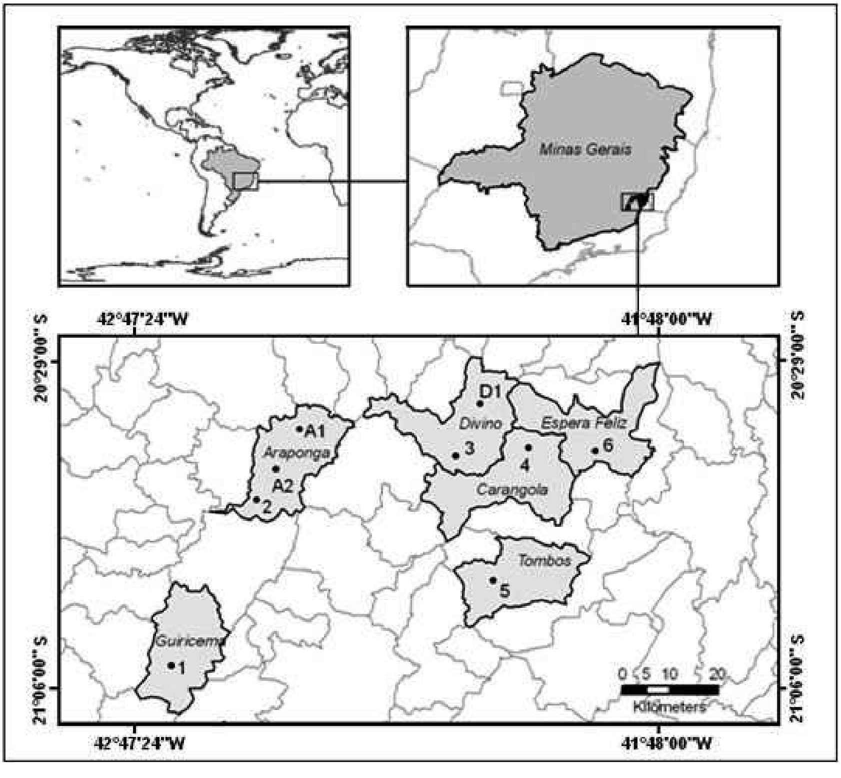


Figure 1. Location of the selected farms in six municipalities of the Zona da Mata (ZM), Minas Gerais state, Brazil.

2.3. Data collection

2.3.1. Changes in tree composition

Two botanical studies were used to assess the changes that occurred in tree family composition across the AFs established between 1993 and 2007. Franco (2000) conducted the botanical survey in 15 of the 37 initial AF experiments established in 1993-1994 and Siqueira (2008) studied the 7 best developed AF plots, as suggested by local farmers in 2007. The farms A1 and A2 were included in both surveys. Information on uses of trees was obtained through a participatory appraisal among farmers.

2.3.2. Farm characterization

The six farmers of group 2 recorded the data on consumption, production, income, farm layout and subsystems, crops, inputs, outputs and the annual calendar of farming activities and shared them during several meetings held between 2005 and 2006. The three farms of group 3 were visited in 2008 to obtain the same information. During the visits the flow diagram technique (Geilfus 2000) was used. The flow diagram provides an evaluation of all inputs and outputs of the agroecosystems, including both the material inputs and services and the products produced. It also allows the identification of the links of farming systems with the other agroecosystems of the property (Geilfus 2000). The diagrams were drawn by the families during the interviews. This was first done for each individual subsystem, and thereafter for the whole farm.

The nine farmers of groups 2 and 3 provided the results of the last soil analysis for the coffee plots (SC and AF) carried out in the labs of the Soil and Plant Nutrition Department of Federal University of Viçosa in 2005/2007. The range of soil characteristics of the farms is presented in Table 2.

Table 4: Range of soil characteristics for selected farms in Zona da Mata, Brazil

Farms	Period	pH$_{H2O}$	P	K	Ca	Mg	CEC[1]	B Sat[2]	OM[3]
		1:2.5	-- cmol$_c$.dm^{-3} --		---------- mg.dm^{-3} --------			%	%
Group 2*	2005/6	4.9-6.6.	0.4-7.6	29-161	0.3-5.4	0.2-1.7	7.2-19.0	6.3-85.0	2.7-5.3
Group 3**	2007	5.6-6.0	2.7-4.8	89-164	2.8-5.7	0.6-1.5	3.6-7.6	30.0-76.0	4.3-5.7

Codes:[1] CEC, Cation Exchange Capacity; [2] Base saturation; [3] OM: Organic Matter
*: Farms in agroecological transition (1-6); **: Farms of early adopters (A1, A2, D1)

The three farms of group 3 fell within the range of soil characteristics found for group 2 (Table 2). Group 3 (early adopters) presented less variation in nutrient and organic matter content and generally higher values than group 1 (Table 2).

2.3.3. Analysis of productivity and profitability

During the visits of farms A1, A2 and D1 in February and March 2008, more detailed information used for the economic comparison (objective 3) was also collected. The annual average production of the most important products over three years (2005-2007) was calculated based on the farmers' individual notes and the number of trees existing in each AF system was counted. Elevation and slope of the farms were measured with GPS and clinometers.

The steps used for the analysis of production costs are based on Duarte et al. (2004), in which the Production value A minus the costs (B+C+D+E+F+G) is equal to Gross Margin I. Hereunder more details are given for the respective items A until J:

A. *Total production values*: the production values were obtained by considering all marketable products produced during one year. The prices of these products were verified in the local market of Araponga and Divino during February and March 2008.

B. *Annuities of establishment costs* were calculated based on the activities (person days) and materials (material costs) required to establish the different coffee systems. One farmer belonging to the first group of 6 farms had accurately documented all activities related to the establishment of his SC and AF systems. We used his data to calculate the establishment costs over a period of three years. Based on the information provided by the farmers we set the length of the production cycle at 12 years for both systems.

C. *Labour for cropping* covers the annual activities required for the cash crop (coffee), other crops or products, and the production of compost. The prevalent daily wage rate in the region is R$ 20.00 a day or US$ 11.00 dollar (March 2010).

D. *Intermediate consumption* included all expenses for external inputs not produced on the farm (e.g. fertilizers, lime, bio-fertilizers, compost, bags, and boxes).

E. *Processing costs* were the total cost of post-harvest activities for all products on the farm. The costs of coffee drying on the ground was calculated at US$ 1.67 bag^{-1} (one bag = 60 kg) for coffee in the early processing stages called "café em coco" (Bliska et al. 2009).

F. *Overheads* were considered 2.5% of intermediate consumption following Bliska et al. (2009).

G. *Interest on circulating capital* was defined as 12% of the sum of intermediate consumption and overhead costs (Bliska et al. 2009).

H. *Total person days* is the time spent (including temporary workers) on farming activities.

Gross margin (GM) was calculated by deducting the variable costs and also some fixed costs (B + C + D + E + F + G) from the total production value (A). A distinction is made between "GM including labour" (I), whereby labour costs are also deducted and "GM excluding labour" (J) whereby labour costs are not deducted. The gross margin per person day is obtained by dividing "GM excluding labour", by the total number of person days. This can be compared with the prevalent wage rate.

3. Results

3.1. Tree composition and tree selection criteria at two different stages of implementation

During implementation of the initial AF experiments, the farmers together with a local NGO and university researchers, focused on the following factors when selecting trees for the AF systems: a) stability/risk alleviation, b) avoiding nutrient competition, and c) maintaining or increasing coffee production (Souza 2006). Changes in tree composition over time, since the start of the on-farm AF experiments in the early 1990's (Franco 2000) until 2008 (Siqueira 2008) are shown in Fig. 2. The respective uses of each tree family are indicated at the bottom of the graph and are based on the information provided by the farmers during semi-structured interviews (Fig 2). Several exotic tree species that were found in the AF systems in 1993/1994 were not present in the AF systems monitored in 2007 (e.g. Casuarinaceae, Ebenacea, Myrsinaceae, Pinacea and Caprifoliacea) (Fig. 2). Farmers reported that they had been eliminated because of their different requirements in terms of climate and soil conditions that led to increased competition with, or damage to, coffee plants. Tree families that provide multiple products, such as food, wood, green manure, medicine and other products (e.g. fibre, oil, seeds), were kept or added (e.g. Bignoniaceae, Rutacea, Myrtaceae, and Euphorbiaceae). Local availability and market opportunities are determining factors for selecting those trees with multiple uses.

The initial AF experiments on 15 family farms (group 1a) started with a minimum of 2 and a maximum of 72 tree species per AF plot, belonging to a total of 34 different tree families (Fig. 2). This wide range in the number of tree species reflects a high diversity of approaches by different groups of farmers due to the high uncertainty resulting from lack of experience. One group decided to start with planting few tree species to avoid risks. In the opposite extreme there was another group of farmers that decided to experiment with a large pool of tree species to be intercropped with coffee. Thirteen years later 7 family farms (group 1b) reported different criteria for selecting trees than those initially defined at the start of the project. Selected trees included then species that a) are compatible with the coffee crop; b) produce a good amount of biomass; c) are soft and easy to manage (e.g. cutting, pruning, transporting), and d) provide extra products such as food and animal feed, or e) stimulate wildlife, as reported during the interviews.

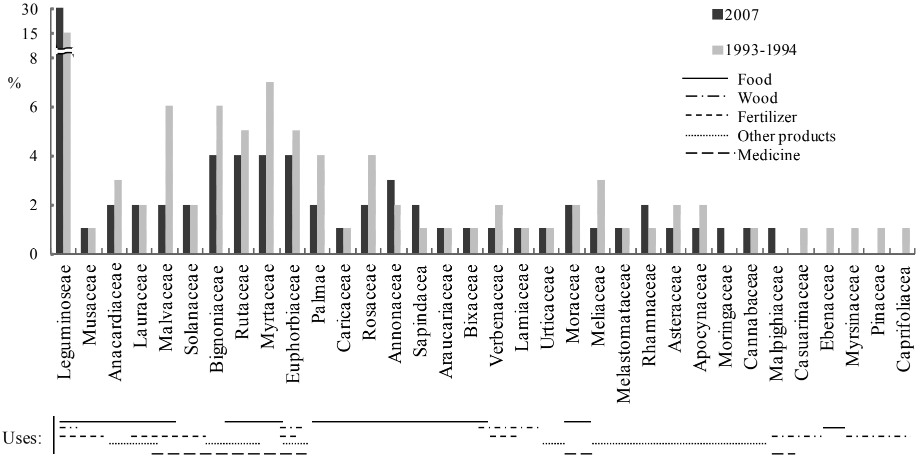


Figure 2. The proportional distribution and the uses of trees in AF systems as obtained from 15 and 7 farms, surveyed in 1993-1994 and 2007, respectively.

3.2. General characterization of the farms and their coffee systems.

A compilation of the individual flow diagrams (not shown) that was obtained for each of the 9 family farms of groups 2 and 3 demonstrated that all of them had diversified their farms as part of the agroecological transition, with the objective to make the different components of subsystems more closely connected and mutually supportive to reduce the need for external inputs. These 9 families represented a range of different farm settings in family agriculture in the ZM. The farm size ranged from 6 to 90 ha. The number of family members, indicative for labour availability, ranged from 2 to 7. Six families were land owners and three were tenants. The total area of coffee cultivation on the different farms ranged from 1.5-9.5 ha, corresponding to 4-47% of the total farm area. The density of coffee plants ranged from 2310 to 7500 ha^{-1} in SC and from 1785 to 5333 ha^{-1} in AF. The land owners, especially the early adopters of AF, had a more diversified farm in terms of the number of commercialized products and the presence of own forest (Table 5).

Table 5: General information about the six farms of group 2 and three farms of group 3 with their full-sun coffee (SC) and agroforestry (AF) coffee systems.

Items	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm A1	Farm A2	Farm D1
1. Municipality	Araponga	Divino	Tombos	Carangola	Guiricema	Espera Feliz	Araponga	Araponga	Divino
2. # of family members	2	2	4	5	4	7	4	2	2
3. Land tenure	tenant	tenant	tenant	owner	owner	owner	owner	owner	owner
4. Farm size (ha)	na	29	na	12	68	8.8	90	43	6
5. Total area of coffee systems (ha)*	1.6	1.6	1.5	1.8	2.7	2.8	9.5	8.7	2.8
a. Full-sun coffee (ha)	1.3	1.1	1.2	0.9	1.4	1.2	6.9	7.9	2.5
Density of coffee plants in SC (plants ha^{-1})	3230	3636	2833	4500	4545	7500	3465	2730	2310
Coffee production (kg.ha^{-1})	na	na	na	na	na	na	1350	1320	1602
b. Agroforestry coffee (ha)	0.3**	0.5	0.3	0.9**	1.3	1.6**	2.6**	0.8**	0.3
Density of coffee plants in AF (plants ha^{-1})	3333	1800	5333	4444	2308	1875	3465	1785	2310
Coffee production (kg.ha^{-1})	-	120	1080	450	1380	630	1650	313	1644
c. Year of adoption of AF	2005	2005	2005	2005	2004	2005	1993/4	1993/4	1993/4
6.Commercialized products	Beans Coffee Honey Propolis	Beans Coffee Eggs Livestock	Beans Cassava Coffee Maize Cassava flour	Banana Coffee Honey Livestock Vegetables	Beans Coffee Livestock Eggs Pumpkin Wood	Banana Beans Cassava Coffee Eggs Maize Peanut Sugarcane	Banana Beans Coffee Guava Maize Papaya Pumpkin Wood	Avocado Banana Beans Cassava Coffee Maize Sugarcane Wood	Banana Beans Citrus Coffee Maize Pumpkin Wood
7. Forest on farm	no	no	no	yes	yes	yes	yes	yes	yes

na = not available; * the size calculation was based on the coffee plant spacing (Farm 1-6 and A1 = 3 x 1 m, Farm A2 = AF 4 x 1.5 m, SC 3.2 x 1.2 m, Farm D1 = 3 x 1.5 m) plus 5% of the total to compensate space for internal roads; **part of it is certified for organic coffee production.

Table 6: Most relevant activities for both coffee systems carried out on the three farms over the year.

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A1	Weeding[2]			Fertilizing[12]	Coffee harvesting[12]				Liming[12]			Pruning trees[1]
		Chemical fertilizer application[12]				Harvesting beans[12]			Weeding[12]	Chemical fertilizer application[12]		
		Apply biologic fertilizer[12]		Cleaning[12]	Cleaning rows of crops[12]					Apply biological fertilizer[12]		
A2	Pruning trees[1]			Coffee management[12]	Coffee harvesting[12]					Sowing maize/beans [2]		
	Sowing beans/maize[2]				Biological fertilizer application[1]		Pruning trees[1]	Animal manure application[1]		Liming[12]	Weeding[1]	
				Routine[12]	Maize/beans harvesting[2]							
D1	Weeding [12]		Pruning trees[1]		Harvesting beans[12]	Coffee harvesting[12]				Liming[12]		Pruning trees[1]
	Apply biologic fertilizer[1]		Weeding [12]			Harvesting beans[12]				Apply biological fertilizer[12]		
	Pruning trees[1]		Apply biological fertilizer[1]							Animal manure application[1]		
			Sowing beans[12]								Weeding [12]	

[1] AF, [2] SC

Coffee was the main cash crop and different types of coffee plots were present at all the farms. On 7 out of 9 farms, the area under SC was higher (ranging from 0.9 to 7.9 ha) than the area under AF on the same farm (0.3 to 2.6 ha). Coffee planting density was distinctly higher in SC than in AF on four of the farms (farms 2, 5, 6 and A2), more or less similar on the other four farms (farms 1, 4, A1 and D1) and lower in SC than in AF on farm 3. The number of commercialized products and the presence of forest on the farm varied depending on land tenure. Based on the farms considered in our study, coffee production (parched) under AF ranged from 120–1644 kg.ha^{-1} and under SC (based only on the early adopters' farms) it ranged from 1320–1602 kg.ha^{-1}. For Farm 1 there was no AF coffee production in 2005 because that was the first year in which coffee was planted.

A large variety of crops was produced on each farm in AF areas. Food, firewood, water and construction materials are the most common needs for the family. Although such diversity contributes to local agrobiodiversity, it also increases labour intensity in the beginning, which was indicated as a constraint by 6 out of 9 farmers.

Forest within the farms is also called "reserve", following the Brazilian environmental law. However, wood and non-wood products can be harvested for family consumption only (e.g. honey, seed, medicines and fibre). Together with AF as a subsystem they represented the main source of wood for construction (Table 3).

3.3. Management of SC and AF coffee systems

More detailed information on coffee management was obtained for the three farms of group 3 (Table 6). On a yearly basis, the management activities could be divided into three main periods. From January to April, the activities included the first sowing of some annual crops, weeding, fertilizer application, tillage, and trimming. The harvesting of beans, maize, and cassava is done from May to July. From May till September, the main activities are to soil preparation, crop management (routine), foliar fertilization and the second sowing of beans and maize.

In AF the spontaneous vegetation is kept or trimmed, no pesticides or herbicides are used and limestone is applied biannually. The use, type and quantity of fertilizers depend on whether the AF coffee is certified for organic production or not. Family members do most of the field operations in the AF systems. The SC systems do not have trees shading the coffee. In this type of system liming is done biannually, fertilizers are applied annually and herbicides/pesticides are used when considered necessary. Some farms apply tillage and some farms do not. Some farmers intercrop the coffee with herbaceous plants (in few cases even with annual crops). It is common to employ temporary workers for field operations in the SC systems. Soil preparation includes limestone broadcasting and manure application. In some cases manual tillage is used, especially when maize is cultivated. All coffee systems are biannually limed and annually fertilized. The farmers spray homemade liquid compost called “supermagro”, as biological fertilizer in AF at least twice a year. Spontaneous vegetation in the coffee field is weeded at least twice per year, mainly in the period November to February, and residues are left on the soil surface. The pruning of the trees is done from December to March on all farms, but on farm A2 the bottom branches of the trees are also pruned in July.

3.4. Characteristics of selected SC and AF coffee systems used for economic evaluation

The specific characteristics of the AF and SC coffee systems of group 3 farms are shown in Table 7. The systems in each farm were established at similar elevation (ranging from 1040 m at farm A2 to 1160 m at farm D1). Slopes were steeper on farm A2 (75%) than on A1 and D1 (approximately 34%). The size of the coffee systems ranged from 0.45-0.77 ha for SC and 0.15-0.72 ha for AF.

Table 7: Characterization of the agroforestry and full-sun coffee systems of the three early adopters in the Zona da Mata, Brazil.

Systems	Elevation (m)	Slope (%)	Area (ha)	Coffee plantation				Trees
				Plants (# ha^{-1})	Spacing (m)	Age (yr)	Production* (kg.ha^{-1})	#/ha
AFA1	1062	33	0.15	3300	3.0 x 1.0	12-14	1650	380
SCA1			0.75	3300	3.0 x 1.0	12-14	1350	0
AFA2	1040	75	0.72	1700	4.0 x 1.5	12-14	317	370
SCA2			0.77	2600	3.2 x 1.2	12-14	1320	0
AFD1	1160	35	0.27	2200	3.0 x 1.5	10-14	1644	257
SCD1			0.45	2200	3.0 x 1.5	10-14	1600	0

* Considered the average over three years (2007, 2008 and 2009). Codes: AF: agroforestry, SC: full-sun coffee systems, A: Araponga, D: Divino.

The density of coffee plants was the same for both systems in the case of A1 and D1. In A2 the AF system had a lower planting density (1700 coffee plants ha^{-1}) than the SC (2600 coffee plants ha^{-1}) which resulted in 76% higher production per unit area for SC than for AF. In addition to this, the farmer stated that the location, where the AF was established, was a “cooler area” that always affected negatively the production performance. For this farmer, the main goal was to rehabilitate the area by controlling soil erosion. Any extra coffee production obtained from that area would be considered an advantage. On the farms A1 and D1 the coffee production per hectare was respectively 18 and 3% higher for AF than for SC (Table 5).

The AF systems contained on average 335 trees ha^{-1}, but they differed in taxonomic richness (Table 5) and composition, which is related to the history of land use and to the requirements of the farms. On farm A1 the area where AF and SC were implemented had been degraded after several years of rice cultivation, and coffee stopped to produce. In the beginning, soil was covered by grass species and the tree species *Hovenia dulcis* (uva-do-japão), *Glandulosa colubrine* (sobrasil), *Inga sessilis* and *Inga subnuda* were interplanted randomly with the coffee. On farm A2 the AF system was introduced to halt the advanced erosion process, which had removed the top soil and deposited the soil material to the lowest part of the farm where it had damaged the roads and farm buildings. The farmer planted some trees belonging to a pioneer succession and several fruit species, mostly avocado (*Persea americana)*. The farmer has harvested bananas, oranges, avocados, sugarcane and pumpkin from the AF. This system is converted into an organic system and the coffee plants have been rejuvenated once, in the beginning of the experiment. The system has a low density of coffee plants compared to the other two farms. Chemical fertilizers were not applied in this system.

The farmer of D1 planted some pioneer trees in his AF system and there were already some mature trees from secondary succession, such as *Zeyheria tuberculosa* (ipê-preto), *Tabebuia sp* (ipê-amarelo) and *Vitex montevidensis* (maria-preta). This area was originally an abandoned pasture. Bananas, oranges and avocados have been harvested from the AF. The trees also supply wood for construction, firewood, fencing and animal feed.

3.5. Production values and gross margins in AF and SC systems

The total production value was higher for all AFs (ranging from USD 4976 to 6281 ha^{-1}.yr^{-1}) in comparison to all SCs (ranging from USD 3534 to 4284 ha^{-1}.yr^{-1}) (Table 6). The production value for AF-D1 was about 20% higher than for AF-A1 and AF-A2. For SC-D1 the production value was about 17% higher compared to SC-A1 and SC-A2.

In AF-A2 other products than coffee, including banana, papaya, pumpkin, citrus, wood, and guava, made up 73% of the total production value. Banana, citrus, pumpkin, wood, and organic compost represented 30% of the total production value in AF-D1, whereas in AF-A1 the products banana, wood, avocado, cassava, sugarcane and organic compost represent only 14% of total value (Table 6).

Table 8: Production costs and gross margin per ha per year, based for the parallel agroforestry (AF) and sun-coffee (SC) systems on three farms in Zona da Mata, Brazil

ITEM	**AFA1**		**SCA1**		**AFA2**		**SCA2**		**AFD1**		**SCD1**	
	Person-days	$\text{R\$.ha,yr}^{-1}$	Person-days	$\text{R\$.ha,yr}^{-1}$	Person-days	$\text{R\$.ha,yr}^{-1}$	Person-days	$\text{R\$.ha,yr}^{-1}$	Person-days	$\text{R\$.ha,yr}^{-1}$	Person-days	$\text{R\$.ha,yr}^{-1}$
A. Total production value		9240		6507		8957		6362		11305		7712
A1. Coffee*		7953[a]		6507[b]		2403[c]		6362[d]		7924[e]		7712[f]
A2. Total other products		1287		-		6555		-		3381		-
B. Annuity establishment cost	17	591	16	495	12	431	12	392	15	517	12	423
C. Labour for cropping	114	2270	51	1010	96	1910	65	1300	125	2490	84	1670
D. Intermediate consumption		1153		1135		285		940		1532		1514
E. Processing costs	71	2257	33	1044	28	1225	32	1020	62	1914	39	1236
F. Overhead costs		29		28		7		23		38		38
G. Interest on circulating capital		59		58		15		48		79		78
H. Total labour input	202		99		136		109		201		134	
H1. Person days for coffee	132				70				111			
H2. Person days for other products	70				66				90			
I. Gross margin (incl. labour)		2881		2737		5085		2640		4735		2753
I1. Coffee production		3529		2737		475		2640		3867		2753
I2. Other products		-648				4610				868		
J. Gross margin (excl. labour)		6914		4698		7941		4813		8765		5450
J1. Coffee production		6169		5832		2012		5753		6090		6964
J2. GM per person day for coffee		47		59		29		53		55		52
J3. Other products		745				5929				2674		
J4. GM per person day for other products		11				90				30		

[1] R$ 1.00 = 0.55 dollar (01/03/10)

* Production (kg.ha^{-1}): a.1650, b. 1350, c. 317, d. 1320, e. 1644, f. 1600. The price per bag of coffee (60kg) was R$ 289 and only in AFA2 it was sold at R$ 455 (price of coffee organic).

The annuity of establishment costs was on average 17% higher for the AFs than for the SCs due to the increased labour for other crops (Table 6). Labour is the most expensive factor during this phase contributing on average 58% of establishment costs in both systems, over the first three years. The establishment costs of other crops are on average 11% of the total establishment costs (data not shown). The labour required for annual cropping was higher for AF than for SC, varying from 136 to 202 person days $ha^{-1}.yr^{-1}$ in AF, and from 99 to 134 person days $ha^{-1}.yr^{-1}$ for SC. The intermediate consumption values largely depended on the management, arrangement and level of external inputs of the farming systems (e.g. chemical fertilizers, lime, liquid compost, fuel and electricity cost). While AF-A1 (US$ 641 $ha^{-1}.yr^{-1}$), SC-A1 (US$ 631 $ha^{-1}.yr^{-1}$), AF-D1 (US$ 851 $ha^{-1}.yr^{-1}$) and SC-D1 (US$ 841 $ha^{-1}.yr^{-1}$) have quite similar expenses in both systems, in AF-A2 the intermediate consumption value is much lower (US$ 158 $ha^{-1}.yr^{-1}$) than in SC-A2 (US$ 522 $ha^{-1}.yr^{-1}$), mainly because no chemical fertilizers are used in AF-A2.

Regarding the processing costs, more labour is required for coffee than for other products (e.g. drying, bagging, post harvest preparation, transport). The costs of total material inputs depended on the type of crops, frequency of cultivation and care needed. The values were higher for AF on all three farms. They were considerably higher in AF-A1 (US$ 1254 $ha^{-1}.yr^{-1}$) than in SC-A1 (US$ 580) $ha^{-1}.yr^{-1}$ and in AF-D1 (US$ 1063 $ha^{-1}.yr^{-1}$) than in SC-D1 (US$ 687 $ha^{-1}.yr^{-1}$) and somewhat higher in AF-A2 (US$ 681 $ha^{-1}.yr^{-1}$) than in SC-A2 (US$ 567). Most of the products intercropped with the coffee cannot be stored and demand immediate processing when harvested (e.g. pumpkins, banana, green maize, papaya).

Despite the higher establishment, labour and processing costs for AF in comparison to SC, the gross margin, both including and excluding labour, was higher for AF than for SC on all three farms (Table 6) thanks to the higher overall production value of AF. The gross margin per person day for coffee was for all systems higher than the prevalent wage rate of US$ 11.00. The exception was the value of the gross margin per person day for other products in AF-A1 that has a lower value than the prevalent wage rate.

4. Discussion

4.1. Farmers' selection of trees in AF systems

For the majority of the farmers intercropping trees and coffee was quite a challenge initially due to lack of experience with AF in the region and the difficulties to select the suitable trees among many species available in the Brazilian Rainforest biome. By comparing tree species composition on farms between 1993-94 (group 1a) and 2007 (group 1b) we obtained insight in the developments of tree selection criteria with time. Although Group 1b only included two farms of group 1a, and a pure quantitative comparison is not possible, it is important to note that the 7 farms of group 1b, surveyed in 2008, were the “best performers” in the view of the farmers. Hence, in a general sense, the difference between the two groups reflects the selection of the tree families most compatible with regional coffee AF and other farmers’ needs.

The use of leguminous tree species had clearly increased between 1993-94 and 2007, whereas the contribution of exotic trees had decreased (Fig. 2). It is widely known that leguminous species are very beneficial to tropical agroecosystems because of the low natural soil fertility. A study carried out by Duarte (2007) in AF systems in ZM showed that *Senna macranthera*, *Erythrina verna* and *Inga subnuda* are N fixers and contribute to the fertilization of crops by supplying on average 0.4 $Kg.yr^{-1}$ of N per tree. In addition *S. macranthera* and *I. subnuda* produced the highest amount of leaf litter, thereby returning on average 52 kg. $tree.yr^{-1}$ of organic material to the soil. Jaramillo-Botero (2007) showed that the leguminous tree species *S. macranthera,* planted at a distance of 3 to 5 m from coffee trees had a positive effect on coffee production at the family farm in Araponga.

The plant composition in the AFs on the three farms studied for the economic analysis was correlated with farmers’ preferences based on market accessibility and environmental needs (e.g. soil fertility). The results point out the need for further investigations on a wide range of leguminous tree species to match farmers’ needs. This concerns mainly N fixing species. For example, farmers could select trees to increase N fixation among several available leguminous tree species. Such decision would help to increase the number of plants which contribute to N inputs, and at same time provide other uses for family consumption. It would also lead to further diversification in terms of tree species composition thereby enhancing the conservation of tree diversity in the landscape (Chapter 4 in this thesis).

4.2. Family farming systems in agroecological transition

The characteristics of the farms studied here were in line with the most common regional family size (4 to 6 members), and land tenure characteristics reported by Miranda (2002). These factors have a strong influence on farm management decisions and arrangements of the land and on which farming systems are adopted (Klingen 2009; Miranda 2002). Diversified farms and more connected subsystems took part of the agroecological transition aiming to reduce the need for external inputs. The outputs (e.g. crop residues, dung) of one farm component were used as an input for another component. In contrast, conventional coffee producers usually do not pay attention to interactions among subsystems, once they use chemical fertilizer. Ethnobotanical studies conducted on seven AF plots in the same region have identified more than nine different uses of trees on farms, including construction materials, firewood and medicines (Siqueira 2008; Fernandes 2007). Farmers reported that the productivity of forest and AF systems depended on soil conditions and their age, which influence the arrangement, composition and structure of these ecosystems. They were aware that time is needed to achieve best results for soil improvements as well as farm performance. That was the reason why farmers kept both AF and SC on the farm, so that they can make changes gradually.

4.3. Productivity and economics of AF and SC systems

Reflect on the coffee yields which were very variable depending on farmers strategies and preferences. Each farmer manages his own farm to keep productivity and profitability of the implemented systems, and therefore is a source of information for family agriculture. For farm A1, labour requirements were less for SC than for AF. The farmer preferred to focus on the coffee, because of the higher returns on investment and to invest less time in the production of other products. In D1, although it is diversified and produces several other products (e.g. wood, banana, citrus, beans), the total production costs are higher compared to the others. However, on the third farm (A2) the management approach adopted shows that long term planning is needed in order to deal with more complex agroecosystems. The farmer has been able to get his area certified according to an organic standard that allows him to get a higher price for his coffee production (60% higher). The diversification of products (avocados, bananas, cassava, wood, sugarcane) together with the strategy of farm-gate sales guarantees the farm stability during the period of reestablishment of the coffee production (after rejuvenation). For example, on farm A2, *P. americana* (Lauracea) produced on average 120 kg.yr^{-1} of avocado fruits per tree, thereby generating extra income for the family.

Considering production, all cases show a higher return to labour than the wage rate of US$ 11.00 per person day. The gross margin per person day for coffee production obtained from SC in A1 and A2 (US$ 33 and US$ 29 person day^{-1}, respectively) were higher than in AF (US$ 26 and US$ 16 person day^{-1}, respectively). Some reasons for this could be that more labour was required for investments in coffee production than in other products, that the products selected were less accepted in the regional market (e.g. guava, pumpkin) or that they had higher processing costs, reducing the revenues. The contrary was observed in D1 where the gross margin in AF (US$ 31 person day^{-1}) was higher compared to SC (US$ 29 person day^{-1}). A possible explanation for the higher production could be the fact that AF-D1 has received more organic fertilizers (cow manure, castor bean cake, residues of leguminous species, biofertilizer and cattle urine), as mentioned by the farmer. Higher soil fertility was found at this farm that may contribute to a better production in both coffee systems. In addition, AF-D1 had a lower density of intercropped trees and higher diversity of tree families. Furthermore this is the smallest farm, so more time could be spent on the other crops.

For risk reduction reasons it is advisable to have both coffee systems side by side, at least during the transitional/learning phase.

4.4. Ecosystem services and economic incentives

In current economic models, many ecosystem services are considered economic externalities by farmers, economists and society, and tend to be under-valued (Pagiola et al. 2007; Alavalapati et al. 2004). Farmers receive payments for the food, fiber and other goods they produce (categorized as provisioning services), but the real value of other ecosystem services (e.g. supporting, cultural, regulating services) is generally ignored or underestimated (Costanza 2000). For instance, a survey conducted in the surroundings of the Brigadeiro State Park showed that 1.44 m^3/month of firewood is consumed per family (Casali et al. 1997). Extrapolating this value to over 600 families involved in agroecological transition in ZM, this could save 10368 $m^3.yr^{-1}$, or 5456 trees a year from being cut elsewhere, outside these farms (12 years old tree: 6.0 x 0.30 m, calculated according to Brown et al. (1989)). In a study performed on agroforestry systems in Peru and Guatemala the consumption and sale of all non-coffee products accounted for 20-30% of the total value obtained from the agroforestry system and tree species that provided good fuel wood and construction materials were preferred by the farmers (Rice 2008). Among other ecosystem benefits is the reduction of soil and nutrient losses due to erosion (Franco et al. 2002), which contribute to a better water quality and quantity and Carbon sequestration to mitigate global climate change (Montagnini and Nair 2004).

With the advent of economic instruments such as Payment for Ecosystem Services (PES), these benefits could be internalized, ensuring that those services are taken into account monetarily (Pascual and Perrings 2007; Zbinden and Lee 2005). Most PES schemes focus on carbon sequestration, biodiversity and/or soil and water conservation (Pagiola et al. 2007). Some examples in Latin American countries are The Western Altiplano Natural Resources Management Project (Guatemala), a GEF-financed project (Venezuela), Hydrological Environmental Services program and BioCarbon Fund (Mexico), The Ecomarkets Project and biodiversity conservation (Costa Rica) and others under preparation (Dominican Republic, Ecuador, and El Salvador) (Pagiola et al, 2004).

According to PES schemes currently available in Brazil, groups of farmers could receive additional income when adopting soil and water conservation practices on their farms, up to a maximum of US$ 55.6 $ha.yr^{-1}$ (Chaves et al. 2004). These payments can be received for a maximum period of three years, which coincides with the period of additional expenses on (annuity of) establishment costs in AF when compared to SC. In addition, the time between AF adoption and reaping the benefits from the diversification can take several years. Ricci and Oliveira (2007) argue that in the first three years after adoption of AF farm income is substantially lower due to high costs, intensive labour, and the fact that trees do not yet provide any commercial benefits. The farmers that have adopted AF in ZM have done so without the payments, but only on a limited area.

Financial support during the first years following adoption may therefore be instrumental to upscaling AF especially for the poorer households, as was also pointed out by Pagiola et al. (2007).

PES schemes could provide such support if designed properly. In Costa Rica, for example, the largest part of the total PES is provided in the first and second year of adoption (Zbinden and Lee 2005). Monitoring is also required to ensure that land use changes generate the desired services as argued by Pagiola et al. (2007). Next to the provisioning services, that farmers in ZM have provided, efforts must therefore also be made to monitor and document the effects of AF on other types of ecosystem services such as biodiversity conservation, carbon sequestration in soils and tree biomass, and soil and water protection.

5. Conclusions

This paper described the strategies and economics of coffee farming systems based on studies among three groups of farmers, who are at different stages of the agro-ecological transition process. These groups of farmers reflected the diversity in terms of family size, farm area, land tenure and cropping systems, characteristic for family agriculture in the Zona da Mata. Based on our findings we conclude that:

1. There was a considerable diversity among the different farmers in their farming strategies and management of agroforestry and full-sun coffee production systems. This strongly affected the productivity and profitability of the systems and is thus an important source of information for further optimization of family agriculture.
2. Early adopters of AF had diversified towards production of different marketable products. The use of native trees in AF for this purpose, and for restoration of soil fertility (e.g. leguminous trees), had increased since the start of the experiments, while exotic tree species were eliminated.
3. The total production value for agroforestry systems was on average 43% higher than for full-sun coffee systems over a period of 12 years, despite somewhat higher establishment costs. The diversification of production renders additional income and offers a strategy for risk mitigation.
4. The agroforestry systems provide various ecosystem services in addition to agricultural goods. Future research should focus on the quantification and valuation of ecosystem services, as PES programs could help farmers to overcome establishment and learning costs when adopting AF.

Acknowledgements

We are grateful to the farmers for providing inspiring moments and sharing unconditionally their enthusiasm with agroecology; to the CTA-ZM (Centre of Alternative Technologies of Zona da Mata) for providing valuable data and information; to CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for providing a scholarship to the first author; to Daniel Orellana for the map. We thank Lijbert Brussaard for useful comments on an earlier version of the manuscript. This work was part of the agroBIODIVERSITY network of DIVERSITAS, the International Organization for Biodiversity Science.

Chapter Six

General discussion and conclusions

A better integration of agriculture with development, nature conservation and people's needs constitutes one of modern society's challenges. Diversifying agricultural systems appears to be a practical option to generate benefits for human beings and wildland biodiversity, contributing to the Millennium Development Goals. However, there are constraints, such as lack of incentive, lack of suitable technical assistance, and lack of applicable knowledge. Likewise, conflicts of interest for land use and soil quality management are important factors to be considered for the conservation and restoration of natural and managed systems.

Recently, the delivery of ecosystem services, indispensable for the maintenance of life, has emerged as a new perspective on combining food production and environmental protection, especially for family agriculture. In my thesis, I showed that implementing agroforestry systems (AF) for soil quality improvement and diversification of production has the potential to deliver a range of ecosystem services at different scales in the Zona da Mata of Minas Gerais state. Using a variety of indicators to assess ecosystem services (Table 1), I showed in particular that: integrated communitarian and institutional efforts support the transition to sustainable agriculture (Chapter 2); various selections of native trees are compatible with coffee production and contribute to conservation of tree biodiversity (chapter 3); agroforestry ameliorates microclimatic conditions for soil protection in comparison with sun coffee, although this is as yet only reflected as a trend in differences in soil parameters (chapter 4); and agroforestry increases family income through the diversification of products (chapter 5).

The importance of knowledge of agroforestry practitioners

In land use planning, soils are often considered of vital importance and farmers see soils as one of the main elements of farming. Local knowledge on soils is not only essential for the farmers themselves, but also for policy-making. When land use changes are desired for regional development, research, technical assistance and policies addressing biodiversity, soil conservation and economics can make use of local knowledge in order to understand some of the logic behind farmers' practices in soil management.

Table 9: Indicators to assess ecosystem services and respective chapters in this thesis in which they are discussed.

Service classification	**Service**	**Indicator**	**Related chapter**	**Measurement/units**
Supporting services	Soil structure maintenance	Aggregate size distribution	*	Size-classes: < 53 µm, 53-250 µm, > 250 µm
		Water-stability of aggregates	*	> 2mm, 2-1, 1-0.5, 0.5-0.25, 0.25-0.105, < 0.105 mm
		Mean weight diameter of aggregates	*	mm
	Humification	Humification coefficient	*	% of annual input, ratio among humic fractions
	Decomposition	Weight loss from litterbags	*	% weight loss/time unit
		Respiration in soil samples	4	µg CO_2/g/time unit
	Nutrient cycling	Litter quality (categories I, II, III, IV)	4	C/N ratio, polyphenols, lignin (chemically or by sensory observation)
		Microbial quotient	4	%
		Metabolic quotient	4	Amount of CO_2-C respired per microbial C/ time unit x 100
		Potential N mineralization	4	Amount/ Kg soil/ unit of time
		Dissolved organic nitrogen (DON)	*	Concentration in soil pore water
		Nutrient balance (N, P, K)	*	kg/ha/yr
		Nutrient use efficiency (NUE)	*	Net Primary Production (NPP) in kg per kg of nutrient, dry matter/nutrient unit/ time unit Ecosystem NUE= NPP/nutrient uptake x nutrient uptake/soil nutrient supply ($gm^{-2}d^{-1}/gm^{-2}d^{-1}$)
		P-availability	*	Various methods: Pi (Resin-Pi, $NaHCO_3$, NaOH, HCl); Po ($NaHCO_3$, NaOH)
		pH	4	Routine analysis
		Cation Exchange Capacity (CEC)	4	$cmol_c.dm^{-3}$
		Mycorrhizal inoculum of soil	*	No. of spores per volume of soil
		N fixation	*	Natural ^{15}N abundance, kg/ha
	Photosynthesis	Net primary productivity	4,5	Diameter at Breast Height (DBH), increase of trees/ha, area x productivity/ha
	Conserving genetic resources	Biodiversity (planned, unplanned)	3,4	Species richness and evenness

* Further research

Table 10: Indicators of to assess ecosystem services and respective chapters in this thesis in which they were identified and discussed (continued).

Service classification	**Service**	**Indicator**	**Relaterd chapter**	**Measurement/unit**
Provisioning services	Food/feed/wood etc. production	Harvested crop (coffee, other crops)	5	kg/ha/yr
		Animal products (meat, milk, honey, etc.)	*	kg/ha/yr
		Cattle/herd/human population density	*	No./ha
	Plant and animal breeding	No. of cultivars and breeds marketed	*	Number per property
		Medicinal plants and uses	*	Number per farm
Regulating services	C sequestration	Carbon balance	4	kg dry mass/tree, total Soil C
	Greenhouse gas control (GHG)	CO_2, N_2O, CH_4 production	*	metric tons of carbon equivalent, metric tons of carbon dioxide equivalent
	Temperature regulation	Temperature variability, average, min and maxi	4	ºC
	Erosion control	Sediment run-off	5	Kg/ha/year
		Litter quality (cover of soil)	4	N, polyphenosl, lignin
		Total vegetation cover	*	%
		Vegetation cover per plant functional type (PFT)	4	% (trees, coffee, grass)
	Water regulation	Porosity (macro and microporosity)	*	m^3/m^3
		Water balance	*	L/ha/yr
		Soil hydraulic conductivity	*	m/h
		Soil moisture content	*	%
	Water purification	Contaminants	*	Concentration
	Pollination	Insects visiting plants	*	# insects, # species of insects
	Biological control	Plant damage, disease and pest species	*	Number of plants and pests
Cultural services	Cultural heritage	Self-regulation (e.g. creation of land use patterns, land conquest, self organization)	2,5	No. of families involved
		Social networks	2	Density, architecture, partnerships

* Further research

Agroecological farmers consciously invest in their soils over the long term by means of organic matter management (e.g. through cover crops, tree litterfall, the use of manure and compost). Only practitioners of AF explicitly relate this type of improvement to their own management (Klingen, 2009). As a result, agroecological farms used as a regional strategy would generate positive effects such as independence from external markets through reduction of external inputs; and resilience to market price fluctuations through diversification of production (Chapter 5).

Small-scale farmers need to maintain their environment somehow in a sustainable way and they have extensive knowledge about it. Aquino et. al (2008) reported richness of groups of soil organisms under different production system and found that agrosilvipasture, crop-animal integration and agroforestry promoted better environments for biodiversity conservation. This demonstrates that in the Atlantic Rainforest biome farming systems at small scale play an important role beyond food production in nature conservation, by contributing to biodiversity and environmental protection.

Timeline and baseline

Several cycles of economic development contributed to the disappearance of almost 90% of Brazilian Atlantic Rainforest (Ribeiro et al., 2009). Dean (1995) reports that the first act that colonizers did when arriving in Brazil was to cut down a tree, the first part of a domino effect of destruction of forests. Ever since, the wood exploitation, mineral exploitation, sugar cane expansion, railway implementation and coffee cultivation consecutively have reduced rainforest cover in a period of more than five centuries. Engraved earlier (colonial period, XVIIIth century) by the lack of environmental policies, which could stop destruction and support environmental protection, and later (ending of XIXth century) with ambitious but inadequate strategies for development (Dean, 1995; Galindo-Leal and Câmara, 2005; Padua, 2002) including the Green Revolution. Many ways of preservation of natural resources failed. Therefore, the relevance of a long term experience in order to re-approximate natural and human values is a powerful instrument to understand a historical process of paradigm changes. It is very well known that changes in habits and custom for people and institutions do not occur in a short time. Moors et al. (2004) argue that at least one generation time of approximately 25 years is necessary to perceive fundamental changes in communities, and that a transition is a gradual and continuous process. Therefore, the case of coffee agroforestry system in Zona da Mata (ZM) region of the Brazilian Rainforest, as a bottom up initiative, provides an insightful field for people and institutions, mainly in recovering the importance of trees as an element to create more sustainable agroecosystems.

Tree traits: tools to cope with farm and landscape functions

Understanding the tree component is essential to ensure best performance in AF. The arboreal component regulates the majority of the ecosystem services such as soil conservation, nutrient recycling and provision of multiproducts (Chapters 3, 4 and 5). However, among the wide variety of trees in the Brazilian Atlantic Rainforest, farmers have selected 14 species so far, (plus *Musa paradisiaca*, banana, an exotic perennial herb with a tree-like appearance, without woody tissues) as the most compatible tree species to intercrop with coffee. A tree species can have multiple functions that are important criteria for selection by the farmers (Chapters 2 and 3). Nine tree species were indicated to attract insects, mostly pollinators. Coffee pollination is an important ecosystem service for coffee production in the region (De Marco and Coelho, 2004), provided by more than eight bee species; most of them make their nests on the branches of trees (Ferreira, 2008). Ethnobotanical studies conducted in family farms in ZM showed other uses of trees such as for tools, medicine, fertilizing and wood (Fernandes, 2007; Siqueira, 2008). Some exotic species have additional importance in AF to enhance food sovereignty and autonomy. Additional studies are needed to select the best varieties of avocado and guava for increased productivity and fruit quality and, at the same time, the right amount of shade for the best coffee-producing trees. There are many tree species for different purposes, which provide a good combination for AF and can be selected according to family preferences and local resource availability. By planning the local tree diversity, farmers contribute to increasing biodiversity (Altieri, 1999; Vandermeer and Perfecto, 1995). Consequently, planned biodiversity offers goods (e.g. fruits, wood) and benefits soil (e.g. organic matter decomposition, nutrient cycling), and environmental quality (e.g. ameliorates temperature, provides shade, creates aesthetic value). Hence, the importance of investigating native trees and their potential contribution to the functioning of the entire ecosystem is high. Their traits and direct uses should meet the circumstances of farmers' interests, willingness and vision, integrating individual systems within a farm to a regional context of sustainability.

An integral view - farms as benefits for the landscape

The agricultural property as part of a landscape is an individual and spatial unit, characterized as a dynamic system (Blatt et al., 2008), subjected to modifications, evolution and disturbances due to natural processes and human intervention (Boer and Dicke, 2005). The disturbances caused by human intervention due to the use of some unsuitable agricultural techniques (e.g. burning, tillage, biocides in steep areas) induce qualitative and quantitative modifications of soil, water and the environment (Boer and Dicke, 2005). Environmental quality is related to different factors in an agroecosystem, such as declivity, erosion, fertility, temperature, cultivation, vegetation, which interfere with several processes (soil biological, physical and biochemical interactions and transformations) (Brussaard et al., 2007; Kibblewhite et al., 2008).

The local farmers' former ideas of re-establishing soil quality through the implementation of more diversified farming systems (Cardoso et al., 2001; Carvalho and Neto, 2000) has encouraged hundreds of families to adjust their farming systems within the Zona da Mata region (Chapter 5). The decision of using an apparently simple technique, just enhancing the number of trees as used in the past by Brazilian indigenous people (Posey, 1985), has shown potential to locally deliver supporting services (e.g. nutrient cycling, soil formation and primary production), provisioning services (e.g. food, water, fiber, fuel provision), and regulating services (e.g. climate regulation). Although the positive impacts of the diversification of agroecosystems seem to be widespread, several questions remain, for instance, how to provide positive impacts at the landscape level on other ecosystem services. Therefore, an integral view on land use strategies through transdisciplinary collaborations among ecologists, economists and social scientists is necessary (Carpenter and Folke, 2006).

At the landscape level, the Zona da Mata region combines deep soil, hilly slopes with several springs and streams, coffee production systems and thousands of forest remains (Freitas, 2000; Teixeira et al., 2009). For promoting improvements in land use, the different landscape units require specific and integrative attention. The selected forest fragments served as a local and regional reference for, showing the tree diversity that can be attained after 40-50 years through natural regeneration of the rainforest. Forest fragments are the source of many environmental goods and services such as seeds, wood, clean water, pollinators, aesthetic beauty, etc. Considering the actual status of the Brazilian Atlantic Rainforest, which is highly fragmented by land use, the more diversified farming systems appear to be a solution for some important issues such as soil protection, the maintenance of food production, the creation of ecological corridors, the enhancement of agrobiodiversity and the reduction of biodiversity losses, meanwhile delivering more ecosystem services than monoculture. Most of the native forest fragments lie at high altitudes (Teixeira *et al.*, 2009). Considering climate change scenarios, coffee cultivation tends to move up-hill (Camargo, 2010), competing for space with the forest fragments and increasing the pressure on forest remains and natural habitats. On the other hand, highly diversified farms in the buffer zone around protected areas may reduce the pressure on forest remains (Clergue et al., 2005).

This study has shown that full-sun coffee systems (SC), as monoculture, still appear to be profitable due to the regional coffee market structure, even though providing only one type of product. Agroforestry provides more products, regulates temperature extremes, contributes to soil improvement and can connect forest fragments. The use of fertilizers is quite similar in both coffee systems, AF and SC, although livestock increasingly provides animal manure to replace external fertilizer in AF. At farm level, family farms have adopted more diversified and integrated subsystems. There is a reduction of pesticide use as reported by Klingen (2009) and Miranda (2002). Therefore, a combination of farmer awareness, spatial heterogeneity, and natural resources availability favors a more sustainable land use that matches with current ecoagricultural thinking (Buck et al., 2006).

Further research

Low input systems are both a reality and an alternative to high-input systems for family agriculture in the Zona da Mata region and should be better investigated for impact on different scales. However, the responses may not occur in the short term and for this reason long term monitoring of changes in indicators of ecosystem services is advisable. In this thesis I studied some of the indicators of ecosystem services and many others remain to be further investigated (Table 7). I suggest that future research focuses on the quantification and valuation of ecosystem services in agroforestry systems. Table 10 with a list of some indicators of ecosystem services (supporting, provisioning, regulating and cultural) can serve as a guide for assessment and monitoring.

The comparison between reference forest fragments, agroforestry coffee and full-sun coffee revealed the potential of AF to conserve local tree biodiversity and to increase total productivity per area. The used tree species are important in family agriculture for the provision of multiple ecosystem services and potentially can connect remnants of the Atlantic Rainforest. Selection of appropriate tree species is essential to the success and upscaling of agroforestry. Studies on tree species will further highlight the delivery of supporting services through soil quality, while generating understanding on provisioning and regulating services. For regional planning programmes, the potential of implementing payment schemes for ecosystem services might be an option for upscaling and increasing regional impact on biodiversity conservation. Therefore, the benefits of experimenting with agroforestry systems for the farmers and institutions go beyond the mere listing of the short-term negative or positive results. Studies on local social organization and landscape changes probably will identify more cultural services (e.g. sense of place, knowledge, and aesthetics) in the near future. Transdisciplinary studies may further demonstrate the benefits of more diversified systems based on communitarian efforts to enhance ecosystems services at all scales of society.

Conclusions

Agroforestry systems can be made to work for crop production and conservation of biodiversity in the context of family agriculture and the threatened status of the Brazilian Atlantic Rainforest. Continued participative work among scientists and stakeholders may help to increase the delivery of ecosystem services provided by agroforestry systems, next to just crop production, with potential to reduce the need for external inputs and to contribute to major local, regional and global objectives on sustainability and human well-being.

References

Alavalapati, J.R.R., Shrestha, R.K., Stainback, G.A. and Matta, J.R. 2004. Agroforestry development: An environmental economic perspective. Agroforestry Systems 61-62 (1):299-310.

Alfaro-Villatoro, M.A., Saggin-Júnior, O.J., Ricci, M.S.F., Silva, E.M.R., and Berbara, R.L.L. 2004. Produção de Café em Sistema Agroflorestal Embrapa Agrobiologia Documentos, 187, Seropédica.

Altieri, M.A. 1999. The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment 74:19-31.

Altieri, M.A. 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agriculture, Ecosystems & Environment 93:1-24.

Altieri, M.A. 2004. Linking ecologists and traditional farmers in the search for sustainable agriculture. Frontiers in Ecology and the Environment 2:35-42.

Altieri, M. and Nicholls, C.I. 2000. Agroecologia: Teoría y práctica para una agricultura sustentable. Red de Formación Ambiental para América Latina y el Caribe, Programa de las Naciones Unidas para el Medio Ambiente, México DF, México

Altieri, M.A. and Nicholls, C.I. 2002. Un método agroecológico rápido para la evaluación de la sostenibilidad de cafetales. Manejo Integrado de Plagas y Agroecologia, vol 64. Costa Rica.

Altieri, M.A. and Nicholls, C.I. 2003. Soil fertility management and insect pests: harmonizing soil and plant health in agroecosystems. Soil and Tillage Research 72:203-211.

Altieri, M.A. and Nicholls, C.I. 2008. Scaling up Agroecological Approaches for Food Sovereignty in Latin America. Society for International Development 51 (4):472-280. doi:doi:10.1057/dev.2008.68.

Altieri, M.A. and Koohafkan, P. 2008. Enduring Farms: Climate Change, Smallholders and Traditional Farming Communities Third World Network, Penang, Malaysia.

Anderson, J.D., Ingram, J.S.I., 1993. Tropical soil biology and fertility: a handbook of methods. CAB International, UK.

Aquino, A.M.., Correia, M.E.F. and Alves, M.V. 2008. Diversidade da Macrofauna Edáfica no Brasil, p. 143-170, *In* F. M. S. Moreira, et al., eds. Biodiversidade do Solo em Ecossistemas Brasileiros. Editora UFLA, Lavras, MG, Brasil.

Assad, E.D., Pinto, H.S., Zullo Jr, J., Helminsk Ávila, A.M., 2004. Climatic changes impact in agroclimatic zoning of coffee in Brazil (Impacto das mudanças climáticas no zoneamento agroclimático do café no Brasil)" Pesquisa Agropecuária Brasileira 39, 1057-1064.

Aquino, A.M., Correia, M.E.F., and Alves, M.V. 2008. Diversidade da Macrofauna Edáfica no Brasil, p. 143-170, *In* F. M. S. Moreira, et al., eds. Biodiversidade do Solo em Ecossistemas Brasileiros. Editora UFLA, Lavras, MG, Brasil.

Barberi, A., Carneiro, M.A.C., Moreira, F.M.S., Siqueira, J.O. 1998. Nodulação em Leguminosas Florestais em Viveiros no Sul de Minas Gerais. Cerne 4:145-153

Barrios, E. 2007. Soil biota, ecosystem services and land productivity. Ecological Economics 64:269-285.

Barrios, E. and Trejo, M.T. 2003. Implications of local soil knowledge for integrated soil management in Latin America. Geoderma 111 (3-4):217-231.

Beer, J., Muschler, R., Kass, D., and Somarriba, E. 1997. Shade management in coffee and cacao plantations. Agroforestry Systems 38:139-164.

Benbrook, C. 2009. Impacts of Genetically Engineered Crops on Pesticide Use in the United States: The First Thirteen Years, pp. 1-69 The Organic Center Vol. http://www.organic-center.org/reportfiles/13Years20091126_FullReport.pdf, November' 2009, available: ed. The Organic Center, Boulder - CO.

Bennett, E.M., and Balvanera, P. 2007. The future of production systems in a globalized world. Frontiers in Ecology and the Environment 5:191-198.

Bhagwat, S.A., Willis, K.J., Birks, H.J.B., and Whittaker, R.J. 2008. Agroforestry: a refuge for tropical biodiversity? Trends in Ecology & Evolution 23:261-267.

Blackmore, C. 2007. What kinds of knowledge, knowing and learning are required for addressing resource dilemmas? A theoretical overview. Environmental Science & Policy 10 (6):512-525.

Blatt, S.E., R.C. Smallegange, L. Hess, J.A. Harvey, M. Dicke, and J.J.A.v. Loon. 2008. Tolerance of Brassica nigra to Pieris brassicae herbivory. Botany 86:641-648.

Bliska, F.M.M., Vegro, C.L.R., Júnior, P.C.A., Mourão, E.A.B. and Cardoso, C.H.S. 2009. Custos de Produção de Café nas Principais Regiões Produtoras do Brasil. Informações Econômicas 39 (9):1-20.

Boer, J.G. and M. Dicke. 2005. Information use by the predatory mite Phytoseiulus persimilis (Acari: Phytoseiidae), a specialised natural enemy of herbivorous spider mites. Applied Entomology and Zoology 40:1-12.

Boffa, J.M., Turyomurugyendo, L., Barnekow-Lillesø, J.P., Kindt, R., 2009. Enhancing Farm Tree Diversity as a Means of Conserving Landscape-based Biodiversity. Mountain Research and Development 25, 212-217.

BRASIL. 1965. Código Florestal Brasileiro, Lei No. 4771, DOU 15 de setembro de 1965. Brasília, Brazil

BRASIL. 2006a. SNUC - Sistema Nacional de Unidades de Conservação da Natureza, pp. 56, *In* M. S.-. Brasília, (ed.), Vol. Lei. No. 9985, 18/07/00; Decreto No. 4340, 22/08/02, 5a. ed.

BRASIL. 2006b. RESOLUÇÃO CONAMA No. 369, pp. 50 - 151, *In* C. N. d. M. Ambiente., (ed.) Dispõe sobre os casos excepcionais, de utilidade pública, interesse social ou baixo impacto ambiental, que possibilitam a intervenção ou supressão de vegetação em Área de Preservação Permanente-APP. Publicada no DOU no 61, de 29 de março de 2006.

Bridson, D., Forman, L. 1999. The Herbarium Handbook. Royal Botanic Gardens, Kew, United Kingdom.

Brown, S., Gillespie, A.J.R. and Lugo, A.E. 1989. Biomass Estimation Methods for Tropical Forests with Applications to Forest Inventory Data. Forest Science 35:881-902.

Brussaard, L., de Ruiter, P.C., and Brown, G.G. 2007. Soil biodiversity for agricultural sustainability. Agriculture, Ecosystems and Environment 121:233-244.

Brussaard, L., Pulleman, M.M., Ouédraogo, É., Mando, A., and Six, J. 2007. Soil fauna and soil function in the fabric of the food web. Pedobiologia 50:447-462.

Brussaard, L., Caron, P., Campbell, B., Lipper, L., Mainka, S., Rabbinge, R., Babin, D. and Pulleman, M. 2010. Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. Current Opinion in Environmental Sustainability 2 (1-2):34-42.

Buck, L.E., Milder, J.C., Gavin, T.A., and Mukherjee, I. 2006. Understanding Ecoagriculture: a framework for measuring landscape performance. Department of Natural Resources, Cornell University, Ithaca, NY:54.

Buchy, M. and Ahmed, S. 2007. Social Learning, academics and NGOs: Can the collaborative formula work? Action Research 5 (4):358-377.

Camargo, A.P., 1985. Florescimento e frutificação de café arábica nas diferentes regiões cafeeiras do Brasil. Pesquisa Agropecuária Brasileira 20, 831-839.

Camargo, M.B.P. 2010. The impact of climatic variability and climate change on arabic cofee crop in Brazil. Bragantia v.69(N.1):239-347.

Cardoso, I.M., Guijt, I., Franco, F.S., Carvalho, A.F. and Ferreira Neto, P.S. 2001. Continual learning for agroforestry system design: University, NGO and farmer partnership in Minas Gerais, Brazil. Agricultural Systems 69:235-257.

Cardoso, I., Boddington, C., Janssen, B., Oenema, O., and Kuyper T. 2003. Distribution of mycorrhizal fungal spores in soils under agroforestry and monocultural coffee systems in Brazil. Agroforestry Systems 58 (1):33-43.

Carpenter, S.R., and C. Folke. 2006. Ecology for transformation. TRENDS in Ecology and Evolution 21:309-315.

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., DeFries, R.S., Daz, S., Dietz, T., Duraiappah, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., Reid, W.V., Sarukhan, J., Scholes, R.J. and Whyte, A. 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proceedings of the National Academy of Sciences 106 (5):1305-1312. doi:10.1073/pnas.0808772106.

Carvalho, A.F., and P.S.F. Neto. 2000. Evolving learning in designing agroecological farming systems with small-scale farmers in Zona da Mata, Brazil., p. 73-88, *In* I. Guijt, ed. Deepening the Basis of Rural Resource Management: Proceedings of a Workshop held at ISNAR. ISNAR - International Service for National Agricultural Research and Red Internacional de Metodología de Investigacíon de Sistemas de Produccíon, The Hague

Casali, V.W.D., Cardoso, I.M., Teixeira, M.C.C., Ferreira-Neto, P.S., Barbosa, W.A., Jucksch, I., Mendonça, E.S., Ferrari, E.A., Fernandes, E.I., Gjorup, G.B., Franco, F.S., Carvalho, A.F. and Mello, C.C. (1997) Parque Estadual da Serra do Brigadeiro: Percepção, Uso e Estratificação do Ambiente. Universidade Federal de Viçosa, Viçosa

Cassano, C., Schroth, G., Faria, D., Delabie, J., and Bede, L. 2009. Landscape and farm scale management to enhance biodiversity conservation in the cocoa producing region of southern Bahia, Brazil. Biodiversity and Conservation 18:577-603.

CBD. 2008. The Convention on Biological Diversity (2008). Year in review 2007. Secretariat of, Montreal, Canada.

CBD. 2010. Secretariat of the Convention on Biological Diversity (2010) Global Biodiversity Outlook 3. Available online www.cbd.int/GBO3, Montreal.

Chambers, R., 1989. Farmer-First: A Practical Paradigm for the Third Agriculture. In: Altieri M, Hecht S (eds) Agroecology and Small Farm Development. CRC Press, Florida.

Chaves, H.M.L., Braga, B., Domingues, A.F. and Santos, D.G. 2004. Quantificação dos Benefícios Ambientais e Compensações Financeiras do "Programa do Produtor de Água" (ANA): I. Teoria. Revista Brasileira de Recursos Hídricos 9 (3):5-14.

Cincotta, R.P., Wisnewski, J. and Engelman, R. 2000. Human population in the biodiversity hotspots. Nature 404:990-992.

Clergue, B., Amiaud, B. F., Pervanchon, Lasserre-Joulin, F., and Plantureux, S. 2005. Biodiversity: function and assessment in agricultural areas. A review. Agronomy for Sustainable Development 25:1-15.

CONAB, 2009. Acompanhamento da Safra Brasileira In: Abastecimento, C.N.d. (Ed.), Café. Ministry of Agriculture of Brazil, Brasília, DF, p. 18.

Conway, G.R. 1987. The properties of agroecosystems. Agricultural Systems 24 (2):95-117.

Costabeber, J.A., and Caporal, F.R. 2003. Possibilidades e Alternativas do Desenvolvimento Rural Sustentável, p. 157-194, *In* H. Vela, ed. Agricultura Familiar e Desenvolvimento Rural Sustentável no Mercosul. Editora da UFSM/Pallotti, Santa Maria.

Costanza, R. 2000. Social Goals and the Valuation of Ecosystem Services. Ecosystems 3 (1):4-10.

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., and Van Den Belt., M. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.

CTA-ZM, 2006. Monitoramento da sustentabilidade de Agroecossistemas - Construindo Indicadores. CTA/ZM - Centro de Tecnologias Alternativas da Zona da Mata Viçosa-MG, Brazil.

Cuenca, G., Aranguren, J., Herrera, R. 1983. Root growth and litter decomposition in a coffee plantation under shade trees. Plant and Soil 71:477-486.

Curl, E.A., Rodrigues-Kabana, R., 2001. Oxidizible organic carbon fractions and soil quality changes in a oxic paleustalf under different pasture leys. Soil Science 166, 61-67.

DaMatta, F.M., 2004. Ecophysiological constraints on the production of shaded and unshaded coffee: a review. Field Crops Research 86, 99-114.

DaMatta, F.M., Ramalho, J.D.C., 2006. Impacts of drought and temperature stress on cofeee physiology and production: a review Brazilian Journal of Plant Physiology 18, 55-81.

Daily, G.C., and Matson, P.A. 2008. Ecosystem services: From theory to implementation. Proceedings of the National Academy of Sciences 105:9455-9456.

Day, P.R. (Ed), 1965. Pipette method of particle size analysis. p. 552–562. Agron. Monogr. 9. ASA, Madison, WI.

Dean, W. 1995. With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest University of California Press, Berkeley.

De Marco, P. and Coelho, F. 2004. Services performed by the ecosystem: forest remnants influence agricultural cultures' pollination and production. Biodiversity and Conservation 13(7): 1245-1255.

Diez-Hurtado, A. 2001. Guía Metodologico para la Sistematización de Experiencias del Secretariado Rural. Secretariado Rural do Peru. Lima. Mimeo.

DIVERSITAS. 2002. DIVERSITAS Science Plan - Report No.1. ICSU, IUBS, IUMS, SCOPE, UNESCO, Paris.

Dominati, E., Patterson, M. and Mackay, A. 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics 69 (9):1858-1868.

Douthwaite, B., Kuby, T., van de Fliert, E. and Schulz, S. 2003. Impact pathway evaluation: an approach for achieving and attributing impact in complex systems. Agricultural Systems 78 (2):243-265.

Drummond, G.M., Martins, C.S., Machado, A.B.M., Sebaio, F.A., Yasmine, A. 2005. Biodiversidade em Minas Gerais: um atlas para sua conservação. 2nd edn. Fundação Biodiversitas, Belo Horizonte, Brazil.

Duarte, E.M.G. 2007. Ciclagem de nutrientes por árvores em sistemas agroflorestais na Mata Atlântica. MSc. Thesis, Federal University of Viçosa, Viçosa, Brazil.

Duarte, F., Mansinho, M.I., Barreira, M.M., Jones, N., Lúcio, C. and Nunes, A. (eds) 2004. Overview of Olive Production Cost Analysis for Trás-os-Montes SMOPS, vol Working Paper No. 3. Overview of production cost for Sloping and Mountaniouos Olive Plantation Systems (SMOPS) under different circumnstances, vol The Future of Olive Plantation Systems on Sloping and Mountainous Land, Scenarios for Production and Natural Resource Conservation, Lisboa.

Egoh, B., B. Reyers, M. Rouget, D.M. Richardson, D.C. Le Maitre, and A.S. van Jaarsveld. 2008. Mapping ecosystem services for planning and management. Agriculture, Ecosystems & Environment 127:135-140.

EMBRAPA, 1997. EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solo. Rio de Janeiro.

Erdmann, T.K. 2005. Agroforestry as a tool for restoring forest landscapes. In: Mansourian S, Vallauri D,Dudley N (eds) Forest restoration in landscapes: beyond planting trees. Springer, New York, pp 274-279

Evenson, R.E., and Gollin, D. 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. Science 300:758-762.

FAO, 1985. Digital Soil Map of the World and Derived Soil Properties. Rome, Italy.

Faria, S.M., Franco, A.A., Jesus, R.M., Menandro, M.S., Baitello, J.B., Mucci, E.S., Döbereiner, J., Sprent, J.I. 1984. New nodulating legume trees from South-East Brazil. New Phytol 98:317-328

Fernandes, J.M. 2007. Taxonomia e etnobotânica de Leguminosae Adans. em fragmentos florestais e sistemas agroflorestais na Zona da Mata Mineira. MSc. Thesis, Federal University of Viçosa, Viçosa, Brazil

Ferrari, E.A. 1996. Desenvolvimento da Agricultura Familiar: a experiência do CTA-ZM. Paper presented at the O Solo nos Grandes Domínios Morfoclimáticos do Brasil e o Desenvolvimento Sustentado. Sociedade Brasileira de Ciência do Solo, Viçosa,

Ferrari, L.T., Carneiro, J.J., Cardoso, I.M., Pontes, L.M., Mendonça, E.S. and Silva, A.L.M.S. 2010. O caso da água que sobe: monitoramento participativo das águas em sistemas agroecológicos. Agriculturas 3:30-34

Ferreira, A.S., Camargo, F.A.O., Vidor, C., 1999. Utilização de microondas na avaliação da biomasa microbiana do solo. Revista Brasileira de Ciência do Solo 23, 991-996.

Ferreira, F.M.C. 2008. A Polinização como um serviço do ecossistema: uma estratégia econômica para a conservação. Doutorado, Universidade Federal de Minas Gerais, Belo Horizonte.

Filius, A. 1982. Economic aspects of agroforestry. Agroforestry Systems 1:29-39.

Franchini, J.C., Crispino, C.C., Souza, R.A., Torres, E., Hungria, M., 2007. Microbiological parameters as indicators of soil quality under various soil management and crop rotation systems in southern Brazil. Soil and Tillage Research 92, 18-29.

Franco, A.A., Faria, S.M. 1997. The contribution of N_2-fixing tree legumes to land reclamation and sustainability in the tropics. Soil Biol Biochem 29:897-903.

Franco, F.S. 1995. Diagnóstico e desenho de Sistemas Agroflorestais em microbacias hidrográficas no município de Araponga, Zona da Mata de Minas Gerais. MSc. Thesis, Federal University of Viçosa, Viçosa, Brazil.

Franco, F.S. 2000. Sistemas Agroflorestais: uma contribuição para a conservação dos recursos naturais da zona da Mata de Minas Gerais. Ds. Thesis, Federal University of Viçosa, Viçosa, Brazil.

Franco, F.S., Couto, L., Carvalho, A.F., Jucksch, I., Fernandes Filho, E.I., Silva, E. and Meira Neto, J.A.A. 2002. Quantificação de erosão em sistemas agroflorestais e convencionais na Zona da Mata de Minas Gerais. Revista Árvore 26:751-760.

Freitas, H.R. 2000. Dinâmica da matéria orgânica em sistemas agroflorestais: caracterização da matéria orgânica do solo. Federal University of Viçosa, Viçosa.

Freitas, H.R., Cardoso, I.M., Jucksch, I. 2004. Legislação ambiental e uso da terra: o caso da Zona da Mata de Minas Gerais. Boletim Informativo, Rev Bras Ci Solo, 29:22-27.

Galindo-Leal, C., and Câmara, I.G. 2005. Mata Atlântica – Biodiversidade, ameaças e perspectivas Fundação SOS Mata Atlântica, São Paulo; Conservation International, Belo Horizonte, Belo Horizonte.

Geilfus, F. 2000. 80 Herramientas para el Desarrollo Participativo: Diagnóstico, Planificación, Monitoreo, Evaluación www.territoriosdacidadania.gov.br/o/890312. edn. GTZ - Deutsche Gesellschaft für Technische Zusammenarbeit / IICA - Instituto Interamericano de Cooperación para la Agricultura, San Salvador.

Giller, K.E., Rowe, E.C., de Ridder, N., and van Keulen, H. 2006. Resource use dynamics and interactions in the tropics: Scaling up in space and time. Agricultural Systems 88:8-27.

Gliessman, S.R. 2004. Integrating Agroecological Processes into Cropping Systems Research. Journal of Crop Improvement 11:61-80.

Goering, H.K., VanSoest, P.J., 1975. Forage fiber analyzes (Apparatus, reagents, procedures, and some applications). United States Department of Agriculture, Washington.

Golfari, L. 1975. Zoneamento Ecológico do Estado de Minas Gerais para reflorestamento - Série Técnica, 3. CPFRC, Belo Horizonte, MG, BR.

Gomes, S.T. 1986. Condicionantes da Modernização do Pequeno Agricultor. Universidade de São Paulo, São Paulo.

Guijt, I. Participatory Monitoring and Impact Assessment of Sustainable Agriculture Initiatives: an Introduction to the Key Elements. In: SARL Programme Discussion Paper No.1. International Institute for Environment and Development, London, UK, 1998.

Guijt, I. 1999. Monitoramento Participativo: conceitos e ferramentas práticas para a agricultura sustentável. 1a. Ed. ASPTA, Rio de Janeiro, Brazil.

Hairiah, K., Sulistyani, H., Suprayogo, D., Widianto, Purnomosidhi, P., Widodo, R.H., Van Noordwijk, M., 2006. Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung. Forest Ecology and Management 224, 45-57.

Harrop, S.R. 2007. Traditional agricultural landscapes as protected areas in international law and policy. Agriculture, Ecosystems & Environment 121:296-307.

Harvey, C.A., Komar, O., Chazdon, R., Ferguson, B.G., Finegan, B., Griffith, D.M., Martínez-Ramos, M., Morales, H., Nigh, R., Soto-Pinto, L., van Breugel, M., Wishnie, M. 2008. Integrating agricultural landscapes with biodiversity conservation in the Mesoamerican hotspot. Conserv. Biol. 22: 8-15.

Heal, G., and Simon, A.L. 2001. Biodiversity as a Commodity, p. 359-376 Encyclopedia of Biodiversity. Elsevier, New York.

Heller, N.E., and Zavaleta, E.S. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation 142:14-32.

Hernández-Martínez, G., Manson, R.H., and Hernández, A.C. 2009. Quantitative classification of coffee agroecosystems spanning a range of production intensities in central Veracruz, Mexico. Agriculture, Ecosystems & Environment 134:89-98.

Holliday, O.J. 2006. Sistematização das experiências: algumas apreciações. In: Brandão CR,Streck DR (eds) Pesquisa Participante, o Saber da Partilha. Idéias e Letras, Aparecida, pp 227-243.

Horn, P.M., Stür, H.H. 2003. Developing agricultural solutions with smallholders – how to get start with participatory approach. ACIAR monograph no. 99. CIAT, Vientianane, Laos (http://www.ciat.cgiar.org/asia/pdf/aciar_monograph99_contents.pdf). Accessed 12 Jun 2008

Horton, D. and Mackay, R. 2003. Using evaluation to enhance institutional learning and change: recent experiences with agricultural research and development. . Agricultural Systems (78):127-142.

IBGE 2000. Censo Demográfico (Minas Gerais) - Fundação Instituto Brasileiro de Geografia e Estatística. Rio de Janeiro/RJ, Brasil.

IBGE. 2005. Lavoura permanente (http://www.ibge.gov.br/cidadesat/default.php). Accessed 28 Jan 2009

IPCC. 1996. IPCC Technical Paper V - Technologies, policies and Measures for Mitigating Climate Change Climate Change and Biodiversity. Intergovernamental Panel on Climate Change, Geneva, Switzerland. (Eds) RT Watson, MC Zinyowera, RH Moss.

Jackson, L.E., Pascual, U., and Hodgkin, T. 2007a. Utilizing and conserving agrobiodiversity in agricultural landscapes. Agriculture, Ecosystems & Environment 121:196-210.

Jackson, L.E., Brussaard, L., de Ruiter, P.C., Pascual, U., Perrings, C., and Bawa, K. 2007b. Agrobiodiversity. Encyclopedia of Biodiversity:1-13.

Jaramillo-Botero, C. 2007. Resposta de cafeeiros ao sombreamento e à dinâmica de serrapilheira em condições de sistema agroflorestal. Ds. Thesis, Federal University of Viçosa, Viçosa, Brazil

Jaramillo-Botero, C., Martinez, H.E.P., Santos, R.H.S., 2007. Characteristics of shade-grown coffee (*Coffea arabica* L.) in North of Latin America and brazil: a comparative analysis. Coffee Science 1, 94-102.

Jiggins, J. 2001. Inter-active R, D&E. Livestock Production Science 72: 25-36.

Johnson, N.L., Lilja, N. and Ashby, J.A. 2003. Measuring the impact of user participation in agricultural and natural resource management research. Agricultural Systems 78 (2):287-306.

Jose, S. 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems 76 (1):1-10.

Junior, J.Z., Pinto, H.S., Assad, E.D., 2006. Impact assessment study of climate change on agricultural zoning. Meteorological Applications 13, 69-80.

Karlen, D.L., Ditzler, C.A., and Andrews, S.S. 2003. Soil quality: why and how? Georderma 114:145-156.

Kempers, A.J., Zweers, A., 1986. Ammonium determination in soil extracts by the salicylate methods. Communications in Soil Science and Plant Analysis 17, 715-723.

Kibblewhite, M.G., Ritz, K., and Swift, M.J. 2008. Soil health in agricultural systems. Philosophical Transactions of the Royal Society B: Biological Sciences 363:685-701.

Knoke, T., Calvas, B., Aguirre, N., Roman-Cuesta, R.M., Gunter, S., Stimm, B., Weber, M., Mosandl, R., 2009. Can tropical farmers reconcile subsistence needs with forest conservation? Frontiers in Ecology and the Environment 7, 548-554.

Kiptot, E., Franzel, S., Hebinck, P., and Richards, P. 2006. Sharing seed and knowledge: farmer to farmer dissemination of agroforestry technologies in western Kenya. Agroforestry Systems 68:167-179.

Klingen, K. 2009. Visions on Soils and Soil Management of Agroecological and Conventional Farmers in Minas Gerais, Brazil. Wageningen University, Wageningen.

Kremen, C., and Ostfeld, R.S. 2005. A call to ecologists: Measuring, analyzing, and managing ecosystem services. Frontiers in Ecology and the Environment 3:540-548.

Kuntashula, E. and Mafongoya, P.L. 2005. Farmer participatory evaluation of agroforestry trees in eastern Zambia. Agricultural Systems 84:39-53.

Lal, R. 2003. Global potential of soil carbon sequestration to mitigate the greenhouse effect. Critical Reviews in Plant Sciences 22:151-184.

Lewis, G.P., Owen, P.E. 1989. Legumes of the Ilha de Maracá. Royal Botanic Gardens, Kew, United Kingdom

Lewis, G.P., Schrine, B., Mackinder, B., Lock, M. 2005. Legumes of the world. Royal Botanic Gardens, Kew, United Kingdom

Lin, B.B. 2007. Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agricultural and Forest Meteorology 144:85-94.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., and Naylor, R.L. 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. Science 319:607-610.

Lundberg, J. and Moberg, F. 2008. Ecological in Ethiopia – Farming with nature increases profitability and reduces vulnerability. Swedish Society for Nature Conservation (SSNC), Stockholm.

Macedo, M.O., Resende, A.S., Garcia, P.C., Boddey, R.M., Jantalia, C.P., Urquiaga, S., Campello, E.F.C., Franco, A.A., 2008. Changes in soil C and N stocks and nutrient dynamics 13 years after recovery of degraded land using leguminous nitrogen-fixing trees. Forest Ecology and Management 255, 1516-1524.

Marangon, L.C., Soares, J.J., Feliciano, A.L.P., 2003. Florística arbórea da Mata da Pedreira, município de Viçosa, Minas Gerais. Revista Árvore 27, 207-215.

May, P.H., and Trovato, C.M.M. 2008. Manual Agroflorestal para a Mata Atlântica Ministério do Desenvolvimento Agrário, Brasília.

McGinty, M.M., Swisher, M.E., Alavalapati, J. 2008. Agroforestry adoption and maintenance: self-efficacy, attitudes and socio-economic factors. Agroforest Syst 73:99-108.

McIntyre, B.D., Herren, H.R., Wakhungu, J., and Watson, R.T. 2009. Agriculture at a Crossroads, Global Report. IAASTD - International Assessment of Agricultural Knowledge, Science and Technology for Development, Washington.

MEA. 2003. Millennium Ecosystem Assessment - Ecosystems and Human Well-being - a Framework for Assessment, Island Press, Washington.

MEA. 2005a. Millennium Ecosystem Assessment - Ecosystems and Human Well-being: Biodiversity Synthesis, World Resources Institute, Washington DC.

MEA. 2005b. Millennium Ecosystem Assessment - Ecosystems and Human Well-being: Desertification Synthesis, World Resources Institute, Washington DC.

Mekoya, A., Oosting, S.J., Fernandez-Rivera, S., Van der Zijpp, A.J. 2008. Farmers' perceptions about exotic multipurpose fodder trees and constraints to their adoption. Agroforest Syst 73:141–153.

Mejía, M.A and Croft, J. 2002. La Auto-investigación para la Gestión Municipal de Recursos. ASOPAL - Asociación de Patronatos de Las Lajas, Tegucigalpa

Méndez, E.V., Gliessman, S.R., Gilbert, G.S. 2007. Tree biodiversity in farmer cooperatives of a shade coffee landscape in western El Salvador. Agric. Ecosyst. Environ. 119:145–159

Mendonça, E.S., Stott, D.E., 2003. Characteristics and decomposition rates of pruning residues from a shaded coffee system in Southeastern Brazil. Agroforestry Systems 57, 117-125.

Mercer, D.E. 2004. Adoption of agroforestry innovations in the tropics: A review. Agroforestry Systems 61:311-328

Mertz, O., Ravnborg, H.M., Love, G.L., Nielsen, I., and Konijnendijk, C.C. 2007. Ecosystem services and biodiversity in developing countries, pp. 2729-2737 Biodiversity Conservation, Vol. 16.

Ministério do Meio Ambiente, 2006. Resolução do Conama, edição 61. http://www.mma.gov.br/port/conama/res/res06/res36906.xml. Accessed 17 Jan 2009.

Miranda, D., 2002. "Those folks with a lot of dirt in their coffee fields" - Agroecological innovations and peasants livelihood sustainability: the synergy of peasants, grassroot movements and an NGO in Araponga, Brazil. Management of Agricultural Knowledge Systems. Wageningen University and Research Center, Wageningen, p. 134

Moguel, P., Toledo, V.M., 1999. Biodiversity Conservation in Traditional Coffee Systems of Mexico. Conservation Biology 13, 11-21.

Molua, E.L. 2005. The economics of tropical agroforestry systems: the case of agroforestry farms in Cameroon. Forest Policy and Economics 7 (2):199-211.

Montes, C. and Sala, O. 2007. La Evaluación de los Ecosistemas del Milenio - las relaciones entre el funcionamiento de los ecosistemas y el bienestar humano. Ecosistemas 16:1-9.

Moonen, A.C., and Bàrberi, P. 2008. Functional biodiversity: An agroecosystem approach. Agriculture, Ecosystems & Environment 127:7-21.

Moors, E., A. Rip, and E. Wiskerke. 2004. Seeds of transition. Essays on novelty production, niches and regimes in agriculture p. 32-56, *In* W. J. a. v. d. P. JD, ed. The dynamics of innovation: a multilevel co-evolutionary perspective, Assen: Van gorcum.

Morais, H., Marur, C.J., Caramori, P.H., Ribeiro, A.N.A., Gomes, J.C. 2003. Características fisiológicas e de crescimento do cafeeiro sombreado com guandu e cultivado a pleno sol. Pesq Agrop Bras 38:1131–1137.

Miranda, D. 2002. "Those folks with a lot of dirt in their coffee fields" - Agroecological innovations and peasants livelihood sustainability: the synergy of peasants, grassroot movements and an NGO in Araponga, Brazil. Wageningen University and Research Center, Wageningen.

Montagnini, F. and Nair, P. K. R. 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. Agroforestry Systems 61-62(1): 281-295.

Moors, E., Rip, A. and Wiskerke, E. 2004. Seeds of transition. Essays on novelty production, niches and regimes in agriculture In: JD WJavdP (ed) The dynamics of innovation: a multilevel co-evolutionary perspective. Assen: Van gorcum., pp 32-56

Moreira, F.M.S., Siqueira, J.O., Brussaard, L., and Pereira, H.S. 2008. Organismos do Solo em Ecossistemas Tropicais: um Papel Chave para o Brasil na Demanda Global pela Conservação e Uso Sustentado da Biodiversidade, p. 13-42, *In* Moreira, F. M. S. et al., eds. Biodiversidade do Solo em Ecossistemas Brasileiros. Editora UFLA, Lavras, MG, Brasil.

Morton, J.F., 2007. The impact of climate change on smallholder and subsistence agriculture. Proceedings of the National Academy of Sciences 104, 19680-19685.

Muschler, R., 2001. Shade improves coffee quality in a sub-optimal coffee-zone of Costa Rica. Agroforestry Systems 51, 131-139.

MVSP, 2006. MVSP 3.13 m for Windows. Wales, UK.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B., and Kent, J. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.

Nair, P.K.R. 2007. Agroforestry for Sustainability of Lower-Input Land-Use Systems. Journal of Crop Improvement 19:25 - 47.

Nasi, R. (ed) 2010. Tropical forest management and sustainability issues, vol I. The role of forest biodiversity in the sustainable use of ecosystem goods and services in agro-forestry, fisheries, and forestry. Forestry and Forest Products Research Institute, Tokyo, Japan

Oliveira, R.D., Oliveira, M.D. 1982. Pesquisa social educativa: conhecer a realidade para poder transformá-la. In: Brandão, CR (ed) Pesquisa participante. 2nd edn. Ed. Brasiliense, São Paulo, pp17-33.

Onofri, A., Gresta, F., Tei, F., 2010. A new method for the analysis of germination and emergence data of weed species. Weed Research 50, 187-198.

Orr, A. and Ritchie, J.M. 2004. Learning from failure: smallholder farming systems and IPM in Malawi. Agricultural Systems 79:31-54.

Ouinsavi, C. and Sokpon, N. 2008. Traditional agroforestry systems as tools for conservation of genetic resources of Milicia excelsa Welw. C.C. Berg in Benin. Agroforestry Systems 74 (1):17-26.

Padua, J.A. 2002. Um sopro de destruição - pensamento político e crítica ambiental no Brasil escravista (1786-1888) Jorge Zahar Editora, Rio de Janeiro.

Pagiola, S., Agostini, P., Gobbi, J., de Haan, C., Ibrahim, M., Murgeitio, E., Ramírez, E., Rosales, M., Pablo Ruóz, J. 2004. Paying for Biodiversity Conservation Services in Agricultural Landscapes. Washington, The World Bank Enviroment Department: 1-37.

Pagiola, S., Ramírez, E., Gobbi, J., de Haan, C., Ibrahim, M., Murgueitio, E. and Ruíz, J.P. 2007. Paying for the environmental services of silvopastoral practices in Nicaragua. Ecological Economics 64 (2):374-385

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G., Giller, K.E., 2001. Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. Agriculture, Ecosystems & Environment 83, 27-42.

Parmesan, C., and Yohe, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42.

Parrotta, J.A. (ed) 2010. Restoring biodiversity and forest ecosystem services in degraded tropical landscapes. The Role of Forest Biodiversity in the Sustainable Use of Ecosystem Goods and Services in Agro-Forestry, Fisheries, and Forestry. Proceedings of International Symposium for the Convention on Biological Diversity, Japan.

PASW statistics 2009, PASW statistics version 17.0. Chicago, IL: SPSS, Inc.

Pascual, U. and Perrings, C. 2007. Developing incentives and economic mechanisms for in situ biodiversity conservation in agricultural landscapes. Agriculture, Ecosystems & Environment 121 (3):256-268.

Perfecto, I., and Vandermeer, J. 2008. Biodiversity conservation in tropical agroecosystems: A new conservation paradigm. Annals of the New York Academy of Sciences, Vol. 1134, pp. 173-200.

Perfecto, I., Vandermeer, J., Mas, A., Soto-Pinto, L. 2005. Biodiversity, yield, and shade coffee certification. Ecological Economics 54: 435-446.

Philpott, S.M., Lin, B.B., Jha, S., Brines, S.J., 2008. A multi-scale assessment of hurricane impacts on agricultural landscapes based on land use and topographic features. Agriculture, Ecosystems & Environment 128, 12-20.

Pollini, J. 2009. Agroforestry and the search for alternatives to slash-and-burn cultivation: From technological optimism to a political economy of deforestation. Agriculture, Ecosystems & Environment 133:48-60.

Posey, D.A. 1985. Indigenous management of tropical forest ecosystems: the case of the Kayapó indians of the Brazilian Amazon. Agroforestry Systems 3:139-158.

Reed, M.S. 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation 141 (10):2417-2431.

Ribas, R.F., Meira Neto, J.A.A., Silva, A.F., Souza, A.L., 2003. Composição florística de dois trechos em diferentes etapas serais de uma floresta estacional semidecidual em Viçosa, Minas Gerais. Revista Árvore 27, 821-830.

Ribeiro, C.A.N. 2003. Florística e fitossiologia de um trecho de Floresta Atlântica de Altitude na Fazenda da Neblina, Parque Estadual da Serra do Brigadeiro. MSc. Thesis, Federal University of Viçosa, Viçosa, Brazil

Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J. and Hirota, M.M. 2009 The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation 142 (6):1141-1153.

Ricci, M.S.F. and Oliveira, N.G. 2007. Custos de Implantação e Manutenção e Receitas Brutas Obtidas com o Cultivo Orgânico de Café nos sistemas a Pleno Sol e Consorciado à Bananeira e Eritrina. Boletim de Pesquisa e Desenvolvimento 18:16.

Rice, R.A. 2008. Agricultural intensification within agroforestry: The case of coffee and wood products. Agriculture, Ecosystems and Environment 128:212-218.

Rocheleau, D.E. 1994. Participatory research and the race to save the planet: Questions, critique, and lessons from the field. Agriculture and Human Values 11 (2):4-25. doi:10.1007/bf01530443.

Rusten, E.P. and Gold, M.A. 1991. Understanding an indigenous knowledge system for tree fodder via a multi-method on-farm research approach. Agroforestry Systems 15:139-165.

Sala, O. and Montes, C. 2007. La Evaluación de los Ecosistemas del Milenio: las relaciones entre el funcionamiento de los ecosistemas y el bienestar humano. Asociacion Espanhola de Ecologia Terrestre, AEET.

Salgado, B.G., Macedo, R.L.G., Alvarenga, M.I.N., Venturin, N. 2006. Avaliação da fertilidade dos solos de sistemas agroflorestais com cafeeiro (*Coffea arabica* L.) em Lavras-MG. Árvore 30:343-349.

Sanchez, P. 1995. Science in agroforestry. Agroforestry Systems 30 (1):5-55

Sanginga, P., Kamugisha, R., and Martin, A. 2007. Conflicts management, social capital and adoption of agroforestry technologies: empirical findings from the highlands of southwestern Uganda. Agroforestry Systems 69:67-76.

Santos, S.R.M., Miranda, I.S., Tourinho, M.M. 2004. Análise florística e estrutural de sistemas agroflorestais das várzeas do rio Juba, Cametá, Pará. Acta Amazônica 34: 251–263.

Saporetti-Júnior, A.W. 2005. Composição florística e estrutura do componente árboreo em um remanescente de Floresta Atlântica Montana, Araponga, MG. MSc. Thesis, Federal University of Viçosa, Viçosa, Brazil.

Scales, B.R., Marsden, S.J., 2008. Biodiversity in small-scale tropical agroforests: a review of species richness and abundance shifts and the factores influencing them. Environmental conservation 35, 160-172.

Scherr, S.J. 1991. On-farm research: the challenges of agroforestry. Agroforest Syst 15:95-110.

Schroth, G., Fonseca, G.A.B., Gascon, C., Vasconcelos, H.L., Izac, A.-M.N. (Eds.), 2004. Agroforestry and Biodiversity Conservation in Tropical Landscapes. Washington, DC.

Schroth, G., Laderach, P., Dempewolf, J., Philpott, S., Haggar, J., Eakin, H., Castillejos, T., Garcia Moreno, J., Soto Pinto, L., Hernandez, R., Eitzinger, A. and Ramirez-Villegas, J. 2009. Towards a climate change adaptation strategy for coffee communities and ecosystems in the Sierra Madre de Chiapas, Mexico. Mitigation and Adaptation Strategies for Global Change 14 (7):605-625.

Schulze, C.H., Waltert, M., Kessler, P.J.A., Pitopang, R., Veddeler, D., Muhlenberg, M., Gradstein, S.R., Leuschner, C., Steffan-Dewenter, I., Tscharntke, T., 2004. Biodiveristy indicator groups of tropical land-use systems: comparing plants, birds and insects. Ecological Applications 14, 1321-1333.

Sena, M.M., Frighetto, R.T.S., Valarini, P.J., Tokeshi, H., Poppi, R.J., 2002. Discrimination of management effects on soil parameters by using principal component analysis: a multivariate analysis case study. Soil and Tillage Research 67, 171-181.

Siqueira, L.C. 2008. Levantamento Florístico e Etnobotânico do Estrato Arbóreo em Sistemas Naturais e Agroflorestais, Araponga, Minas Gerais. Mestrado, Federal University of Viçosa, Viçosa.

Soares, M.P., Saporetti-Júnior, A.W., Meira-Neto, J.A.A., Silva, F.A., Souza, A.L. 2006. Composição florística do estrato árboreo de floresta atlântica interiorana em Araponga, Minas Gerais. Árvore 30:859-870.

Somarriba, E. 1992. Revisiting the past: an essay on agroforestry definition. Agroforestry Systems 19:233-240.

Sommer, R. 2009. Dissemination in action research. Action Research 7 (2):227-236. doi:10.1177/1476750308097028.

Sorensen, T., 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. Vidensk Selk. Biol. Ski. (Copenhagem) 5(4) 1-34.

Soto-Pinto, L., Villalvazo-López, V., Jimenez-Ferrer, G., Ramirez-Marcial, N., Montoya, G., Sinclair, F.L. 2007. The role of local knowledge in determining shade composition of multistrata coffee systems in Chiapas, Mexico. Biodivers Conserv 16:419-436.

Souza, H.N. 2006. Sistematização da experiência participativa com sistemas agroflorestais: rumo à sustentabilidade da agricultura familiar na Zona da Mata Mineira. MSc. Thesis, Federal University of Viçosa, Viçosa.

Souza, H.N., Cardoso, I.M., Fernandes, J., Garcia, F.P., Bonfim, V., Santos, A., Carvalho, A.F. and Mendonça, E. S. 2010. Selection of native trees for intercropping with coffee in the Atlantic Rainforest biome. Agroforestry Systems 1:1-16. doi:10.1007/s10457-010-9340-9.

Sprent, J.I. 2001. Nodulation in legumes. Royal Botanic Gardens, Kew, United Kingdom.

SPSS, 2007. SPSS 15.0 for Windows. SPSS Inc., Chicago.

SSNC, 2008. Ecological in Ethiopia - Farming with Nature Increases Profitability and Reduces Vulnerability. Swedish Society for Nature Conservation (SSNC), Stockholm, Sweden.

Steyaert, P. and Jiggins, J. 2007. Governance of complex environmental situations through social learning: a synthesis of SLIM's lessons for research, policy and practice. Environmental Science Policy 10 (8):575-586.

Stotzky, G., 1965. Microbial respiration. Methods of soil analysis. American Society of Agronomy, Madison, pp. 1550-1572.

Tallis, H., P. Kareiva, M. Marvier, and A. Chang. 2008. An ecosystem services framework to support both practical conservation and economic development. Proceedings of the National Academy of Sciences of the United States of America 105:9457-9464.

Tedesco, M.J., Gianello, C., Bissanin, C.A., Bohnen, H., Volkweiss, S.J., 1995. Análises de solo, plantas e outros materiais. Departamento de Solos, UFRGS, Porto Alegre.

Teixeira, A.M.G., Soares-Filho, B.S., Freitas, S.R., Metzger, J.P., 2009. Modeling landscape dynamics in an Atlantic Rainforest region: Implications for conservation. Forest Ecology and Management 257, 1219-1230.

Ter Braak, C.J.F., 1986. Canonical Correspondence Analysis: A New Eigenvector Technique for Multivariate Direct Gradient Analysis. Ecology 67, 1167-1179.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A. Townsend Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Nature 427:145-148.

Thompson, .J and Guijt, I. (eds) 1999. Sustainability indicators for analyzing the impacts of participatory watershed management programs. Fertile Ground: The Impact of Participatory Watershed Management. IT Publications, London, UK.

Tian, G., Badejo, M., Okoh, A., Ishida, F., Kolawole, G., Hayashi, Y., Salako, F., 2007. Effects of residue quality and climate on plant residue decomposition and nutrient release along the transect from humid forest to Sahel of West Africa. Biogeochemistry 86, 217-229.

Tilman, D. 1996. Biodiversity: Population Versus Ecosystem Stability. Ecology 77:350-363.

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., and Siemann, E. 1997. The Influence of Functional Diversity and Composition on Ecosystem Processes. Science 277:1300-1302.

Tollefson, J. 2010. Food: the global farm. Nature 466:554-556.

UNCCD. 2008. The Global Mechanism of United Nations Convention to Combat Desertification Desertification, Migration & Local Development. International Fund for Agricultural Development, Rome, Italy.

Vaast, P., Bertrand, B., Perriot, J.J., Guyot, B., Génard, M. 2006. Fruit thinning and shade improve bean characteristics and beverage quality of coffee *Coffea arabica* L. under optimal conditions. Journal of the Science of Food and Agriculture 86, 197-204.

Valverde, O. 1958. Estudo Regional da Zona da Mata de Minas Gerais. Revista Brasileira de Geografia, 20:3-82.

Vandermeer, J., and Perfecto, I. 1995. Breakfast of biodiversity. The truth about rainforest destruction. The institute for Food and Development Policy, Oakland, California.

Vandermeer, J., and Perfecto, I. 2007. The agricultural matrix and a future paradigm for conservation. Conservation Biology 21:274-277.

Vandermeer, J., van Noordwijk, M., Anderson, J., Ong, C., and Perfecto, I. 1998. Global change and multi-species agroecosystems: Concepts and issues. Agriculture, Ecosystems and Environment 67:1-22.

van Schaik, C.P., and van Noordwijk, M. (eds.) 2002. Agroforestry and biodiversity: Are they compatible?, pp. 1-37-48. S. M. Sitompul and S. R. Utami (eds.) Akar Pertanian Sehat: Konsep dan Pemikiran. Biol. Manage. of Soil Fert. Brawijaya Univ., Malang, Indonesia.

Veloso, H.P. 1991. Manual técnico da vegetação brasileira. Fundação Instituto Brasileiro de Geografia e Estatística, Departamento de Recursos Naturais e Estudos Ambientais, Rio de Janeiro, Brazil.

Verchot, L., van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., Mackensen, J., Bantilan, C., Anupama, K., and Palm, C. 2007. Climate change: linking adaptation and mitigation through agroforestry. Mitigation and Adaptation Strategies for Global Change 12:901-918.

Verchot, L.V., Mosier, A., Baggs, E.M., and Palm, C. 2004. Soil - Atsmosphere Gas Exchange in Tropical Agriculture: Contribuitions to Climate Change, p. 209-226, *In* M. v. Noordwijk, et al., eds. Below-ground Interactions in Tropical Agroecosystems. CAB International, London, UK.

Vieira, T.A., Rosa, L.S., Vasconcelos, P.C.S., Santos, M.M., Modesto, R.S., 2007. Agroforestry systems in areas of smallholder agriculture in Igarapé-Açu, Pará: floristic characterization, implantation and management. Acta Amazonica 37, 549-557.

Vivan, J.L. 2000. Saber ecológico e sistemas agroflorestais: um estudo de caso na Floresta Atlântica do Litoral Norte do RS, Brasil. MSc. Thesis, Federal University of Santa Catarina, Florianópolis, Brazil.

Walker, D.H., Sinclair, F.L. and Thapa, B. 1995. Incorporation of indigenous knowledge and perspectives in agroforestry development Part 1: Review of methods and their application. Agroforestry Systems 30 (2):235-248.

WinklerPrins, A.M.G.A., Sandor, J.A., 2003. Local soil knowledge: insights, applications, and challenges. Geoderma 111, 165-170.

Woodhill, J. 2002. Sustainability, social learning and the democratic imperative. Lessons from the Australian Landcare movement. Paper presented at the Wheelbarrows full of Frogs-Social Learning in Rural Resource Management, Koninklijke Va Gorcum, The Netherlands.

Yang, J.E., Slogley, E.O., Schaff, B.E., Kim, J.J., 1988. A simple spectrophotometric determination of nitrate in water, resin and soil extracts. Soil Sci Soc Am J 62, 1108-1115.

Yeomans, J.C., Bremmer, J.M., 1988. A rapid and precise method for routine determination of organic carbon in soil. Communications in Soil Science and Plant Analysis 19, 1467-1476.

Youkhana, A., Idol, T., 2009. Tree pruning mulch increases soil C and N in a shaded coffee agroecosystem in Hawaii. Soil Biology and Biochemistry 41, 2527-2534.

Young, A. 1997. Agroforestry for Soil Management. 2nd edn. ICRAF and CAB International, Wallingford, UK.

Young, I.M., and Crawford, J.W. 2004. Interactions and Self-Organization in the Soil-Microbe Complex. Science 304:1634-1637.

Zbinden, S. and Lee, D.R. 2005. Paying for Environmental Services: An Analysis of Participation in Costa Rica's PSA Program. World Development 33 (2):255-272.

Zheng, B., Duan, J., Jia, J., Liu, F., and Yan, Y. 2008. Assessment of ecosystem services of Lugu Lake watershed. The International Journal of Sustainable Development and World Ecology 15:62-70.

Summary

The general objective of this study is to generate knowledge and tools to optimize agroforestry systems towards sustainability at system and farm levels, by identifying environmental and soil management indicators for ecosystem services. To this end, I documented changes in agroforestry systems management since the beginning of 1993 in the Zona da Mata region of Minas Gerais State, Brazil. I describe and analyze the influence of agroforestry management on soil, biodiversity, microclimate, and family incomes. I also identify possibilities and constraints for integrating biodiversity conservation with production and other ecosystem services at farm and landscape level.

A better understanding of ecological and social processes related to the development of agroforestry systems was thought to contribute to the improvement of family farming systems with positive impacts on biodiversity and the delivery of ecosystem services. I hypothesized that biodiversity of agroforestry systems is intermediate between references for natural forest and conventional sun coffee, and that biodiversity is positively related to the delivery of multiple ecosystem services.

Structure of the thesis and findings of each chapter

In this thesis I first introduce the main societal issues related to biodiversity loss, food production and human well-being, as addressed in international agreements, and the potential to enhance ecological interactions in agroecosystems. To evaluate long- term experience with coffee agroforestry in the Zona da Mata of Minas Gerais, the second chapter presents a participatory approach to assess local knowledge on specific strategies used by farmers and their institutions. The third chapter focuses on the selection of tree species, as the main component of the structure and composition of agroforestry systems. In chapter 4 I assess the impact of coffee agroforestry, sun coffee and reference forest fragments on biodiversity, soil quality and microclimate at farm level and their effects at the landscape scale, such as connections between fragments and re-establishment of degraded areas. In chapter 5 I postulated that the analysis of profitability and productivity of coffee agroforestry compared to sun coffee would help to understand the relationships between ecological and economic benefits of ecosystem services. Finally, in chapter 6 a general discussion is presented on diversification of agricultural systems as an option to enhance benefits to people while contributing to food production, environmental protection and nature conservation at different levels.

The main findings of each chapter were as follows.

1. Introductory chapter

Currently, the main international development agendas discuss institutional efforts to establish practices and policies for the protection of ecosystems and the promotion of human wellbeing. The consensus is that sustainable agriculture can serve as a basis to cope with some of the most pressing concerns of society: hunger alleviation, nature conservation and land restoration. For this, the ecological connections among elements of agroecosystems must be understood as a prerequisite to enhance food production, to avoid soil degradation and to reduce biodiversity losses. Agroforestry systems have been suggested as a promising land use option to meet those concerns of society. Therefore, I reported ongoing experimentation with coffee agroforestry in the Zona da Mata region, located in the Brazilian Rainforest biome. I introduce the Brazilian context and emphasize the current constraints and potentials, proposing that the investigation of indicators of ecosystem services (provisioning, supporting, regulating and cultural services) could be helpful in understanding and monitoring the drivers that operate in favor or against the achievement of the above-mentioned benefits to society.

2. Learning by Doing: a Participatory Methodology for Systematization of Experiments with Agroforestry Systems, with an Example of its Application (Chapter 2)

Through a participatory methodology the central points of agroforestry were investigated in depth from a local historical perspective. Visits and interviews at farm level were conducted to get information concerning the structure and composition of the systems and the local resources used. Flow diagrams clarify existing and potential connections between sub-systems within the farm. Farmers' knowledge and objectives, local availability of tree species, and compatibility of trees with coffee production were identified as essential to improve agroforestry. The documentation of historical processes helped to evaluate causes and effects of technical interventions, financial support, labor requirements, fluctuations in production and overall farm strategies. Long-term experimentation by farmers elucidated the most important characteristics of agroforestry systems, which were: tree species composition, amount of trees intercropped, soil quality, production level and quality of coffee, and production costs/benefits ratio over time. Venn diagrams allowed the discussion of categories of institutional alliances and their performance, separating them into partners, allies and opponents of agroforestry in the region. Partners were local institutions such as the Centre of Technology of Zona da Mata, the Soil Science Department of the University of Viçosa, the grass roots organizations and the Family Farmer Unions. Allies in favor of the agroforestry systems but contributing sporadically to their development, were the Federal Program, the consultant for agroforestry system designs, the Regional Association of Farmers and the Ford Foundation. The State Institute for Forestry was considered to be opponent to the experimentation. On several occasions, the actors (farmers, technicians, researchers, stakeholders and institutional agencies) discussed the main issues related to the long-term coffee agroforestry experimentation with focus on sustainable agriculture. The systematization generated new knowledge, reinforced alliances, improved the methodology of design, implementation and management of on-farm participatory experimentation and created possibilities for the reflection and learning about agroforestry systems among farmers, extensionists and researchers. New actions were agreed upon and data enriched with local information were documented for further analysis and divulgation. The uniqueness of each farm's experience and institutional behavior were revealed. Thus, participatory systematization appeared to serve as a means to foster innovation.

3. Selection of native trees for intercropping with coffee in the Atlantic Coastal Rainforest biome (Chapter 3)

Due to the fact that agroforestry is not traditional in Brazil, choosing from the high diversity of tree species in the Atlantic Rainforest biome and assessing tree planting pattern and density in intercrop design with the main cash crop, coffee, as linked with individual farmer's goals, was imperative. It is well known that trees and crops compete for light, water, space and nutrients. Criteria of the farmers to select tree species were: compatibility with coffee, amount of biomass and harvestable products produced by the trees and labour needed for tree management. In total 85 tree species were identified. Most trees were either native to the biome, or imported fruit trees. From the total, 28 tree species were of the Leguminosae family. Leguminous tree species are important for agroforestry performance, because they fix nitrogen, contributing to increased soil fertility. Therefore, I made a specific inventory of trees of the Leguminosae family. I concluded that in order to design and manage complex agroforestry systems, family farmers need sufficient knowledge and autonomy, which they can acquire through a participatory learning process. In the case studied here, the farmers learned and shared knowledge on how to regenerate, conserve and manage their land. The diversification of production, especially with fruits, has contributed to income generation, and thus, to a low cost/benefit ratio of the agroforestry systems. The selection of trees already tested by other farmers may be considered as a shortcut to the composition of new agroecosystems. By doing that, risks of unexpected drops in production (e.g. coffee and other products) are reduced. Agroforestry systems showed potential to restore the degraded landscape of the Atlantic Rainforest biome and to enhance the autonomy of family agriculture.

4. Biodiversity and key ecosystem services in agroforestry coffee systems in the Atlantic Rainforest biome (Chapter 4)

In Chapter 4 I compared indicators of biodiversity (e.g. species richness, indices of similarity) in coffee agroforestry and reference forest to investigate effects of microclimate and soil quality. I analyzed soil biological, chemical and physical parameters to address changes in supporting (soil fertility) and regulating (temperature) services. I showed that 13 years after the adoption of agroforestry the growth of tree species made previously tree-less areas within farms more productive. In general, agroforestry systems and sun coffee had similar soil chemical and biological characteristics, but different from reference forest; however, there was a trend to improved soil quality in agroforestry in comparison to sun coffee. Beyond that, the agroforestry systems mitigated temperature extremes more than sun coffee, providing more suitable microclimate conditions and likely higher resistance to expected climate change. In terms of management, leaf litter quality was likely associated with protection of the soil surface against erosion. Tree composition in agroforestry reflected very different farmers' preferences and local resources availability. Hence, these diversified systems contributed to a higher β-diversity than α-diversity. By enhancing regional habitat diversity for plants and other organisms, agroforestry systems match with recent environmental policies for rehabilitation of forests and riparian areas in the Brazilian Atlantic Rainforest area.

5. Strategies and economics of farming systems with coffee in the Atlantic Rainforest Biome (Chapter 5)

A group of about 600 families were involved in a transition from agriculture on degraded pasture land to agroforestry.. The transitional phase turned out to be an uncertain phase in the adoption of agroforestry. Farmers maintained multiple coffee systems (e.g. conventional, organic, agro-ecological and agroforestry coffee systems) to cope with oscillations of prices and total production per farm. Productivity depended on arrangement and composition of systems and the response time of the crop, while the transitional phase increased labour efforts with temporary low economic return. Profitability depended on the selection of marketable products according to local conditions and regional infrastructure. To have both coffee systems side by side, at least during the transitional/learning phase, seemed to be a good option for risk reduction. The total production value for agroforestry systems was on average 43% higher than for sun coffee systems. The diversification of production rendered additional income and risk mitigation. The agroforestry systems provided various ecosystem services, but future research is needed on the quantification and valuation of these benefits. Agricultural production systems that strengthen the delivery of multiple ecosystem services have the potential to reduce the need for external inputs and contribute to reaching major local, regional and global aims.

6. General discussion and conclusions (Chapter 6)

Low-input systems are both a reality and an alternative to high-input systems for family agriculture in the Zona da Mata region and should be better investigated for impact on different scales. However, the benefits may not accrue in the short term and for this reason long-term monitoring of changes in indicators of ecosystem services is advisable. The comparison between reference forest, coffee agroforestry and sun coffee revealed the potential of agroforestry systems to conserve local tree biodiversity and to increase total productivity per area. The used tree species are important in family agriculture for the provision of multiple ecosystem services and potentially can connect remains of the Atlantic Rainforest. Selection of appropriate tree species is essential to the success and upscaling of agroforests. Studies on tree species will further highlight the delivery of supporting services through soil quality, while generating understanding on provisioning and regulating services. Studies on local social organization and landscape changes probably will identify more cultural services (e.g. sense of place, knowledge, and aesthetics) in the near future.

Agroforestry systems can be made to work for crop production and conservation of biodiversity in the context of family agriculture and the threatened status of the Brazilian Atlantic Rainforest. Continued participative work among scientists and stakeholders may help to increase the delivery of ecosystem services provided by agroforestry systems, next to just crop production, with potential to reduce the need for external inputs and to contribute to reaching major local, regional and global objectives on sustainability and human well-being.

Samenvatting

De algemene doelstelling van dit onderzoek is om kennis en gereedschappen te genereren voor de optimalisatie van boslandbouwsystemen in de richting van duurzaamheid op systeem- en boerderijniveau, door het identificeren van indicatoren voor milieu- en bodembeheer voor ecosysteemdiensten. Hiertoe heb ik veranderingen in het management van boslandbouw sinds het begin van 1993 in de regio Zona da Mata van de staat Minas Gerais in Brazilië gedocumenteerd. Ik beschrijf en analyzeer de invloed van boslandbouwmanagement op bodem, biodiversiteit, microklimaat en gezinsinkomens. Ik identificeer ook mogelijkheden en beperkingen voor de integratie van behoud van biodiversiteit met productie en andere ecosysteemdiensten op boerderij- en landschapsniveau.

Ik heb aangenomen dat een beter begrip van ecologische en sociale processen, die verband houden met de ontwikkeling van boslandbouwsystemen, zouden bijdragen aan de verbetering van gezinslandbouwsystemen, met positieve effecten op de biodiversiteit en de levering van ecosysteemdiensten. Ik veronderstelde dat de biodiversiteit van boslandbouwsystemen intermediair is tussen referenties voor natuurlijk bos en conventionele koffiemonocultuur in de volle zon, en dat de biodiversiteit positief is gerelateerd aan de levering van meerdere ecosysteemdiensten.

1. Structuur van het proefschrift en de bevindingen van elk hoofdstuk

In dit proefschrift introduceer ik eerst de belangrijkste maatschappelijke vraagstukken die gerelateerd zijn aan biodiversiteitsverlies, voedselproductie en het menselijk welzijn, zoals genoemd in internationale overeenkomsten, en het potentieel om de ecologische interacties in agro-ecosystemen te versterken. Voor het evalueren van ervaringen op de lange termijn met boslandbouw in de Zona da Mata van Minas Gerais, presenteer ik in het tweede hoofdstuk een participatieve benadering om de lokale kennis te beoordelen op specifieke strategieën die worden gebruikt door boeren en hun instellingen. Het derde hoofdstuk richt zich op de selectie van boomsoorten, als de belangrijkste component van de structuur en samenstelling van boslandbouwsystemen. In hoofdstuk 4 onderzoek ik de impact van boslandbouw, koffiemonocultuur en referentiebos op biodiversiteit, bodemkwaliteit en microklimaat op bedrijfsniveau en hun effecten op landschapsschaal, zoals de verbindingen tussen bosfragmenten en het herstel van gedegradeerde gebieden. In hoofdstuk 5 veronderstel ik dat de analyze van de winstgevendheid en de productiviteit van boslandbouw in vergelijking met koffiemonocultuur zal helpen om de relaties tussen ecologische en economische voordelen van ecosysteemdiensten te begrijpen. Ten slotte bespreek ik in algemene zin in hoofdstuk 6 de diversifiëring van landbouwsystemen als een optie om de revenuen voor de mens te vergroten en tegelijkertijd bij te dragen aan de voedselproductie, bescherming van het milieu en natuurbehoud op verschillende niveau’s. .

De belangrijkste bevindingen van elk hoofdstuk waren als volgt.

1.1. Inleidend hoofdstuk

Momenteel gaan de belangrijkste internationale ontwikkelingsagenda’s over institutionele inspanningen om de praktijken en het beleid vast te stellen voor de bescherming van ecosystemen en de bevordering van het menselijk welzijn. De consensus is dat duurzame landbouw als basis kan dienen om in te spelen op een aantal van de meest dringende problemen van de samenleving: voedselzekerheid, natuurbehoud en landherstel. Hiervoor moeten de ecologische verbindingen tussen elementen van agro-ecosystemen worden opgevat als een voorwaarde om de voedselproductie te verbeteren, bodemaantasting te voorkomen en de verliezen van biodiversiteit te beperken. Boslandbouwsystemen zijn voorgesteld als een veelbelovende landgebruiksoptie om aan die zorgen van de samenleving tegemoet te komen. Daartoe heb ik lopende experimenten met boslandbouw in de regio Zona da Mata gerapporteerd die gelegen zijn in het Braziliaanse regenwoudbioom. Ik introduceer de Braziliaanse context en benadruk de huidige beperkingen en mogelijkheden, suggererend dat het onderzoek naar indicatoren voor ecosysteemdiensten (voorzienende, ondersteunende, regulerende en culturele diensten) nuttig zou kunnen zijn bij het begrijpen en monitoren van de krachten die werken in het voor- of nadeel van de hierboven genoemde revenuen voor de maatschappij.

1.2. Leren door te doen: een participatieve methodologie voor het systematiseren van experimenten met boslandbouwsystemen, met een voorbeeld van de toepassing ervan (hoofdstuk 2)

Door middel van een participatieve methodologie werden de centrale punten van boslandbouw onderzocht vanuit lokaal historisch perspectief. Bezoeken en interviews op bedrijfsniveau werden uitgevoerd om informatie over de structuur en samenstelling van de systemen en de lokaal gebruikte hulpbronnen te verkrijgen. Stroomschema's verduidelijkten bestaande en potentiële verbindingen tussen sub-systemen binnen de boerderij. Boerenkennis en -doelstellingen, lokale beschikbaarheid van boomsoorten, en de verenigbaarheid van bomen met de productie van koffie werden geïdentificeerd als essentieel om boslandbouw te verbeteren. De documentatie van historische processen hielp om oorzaken en gevolgen van technische ingrepen, financiële ondersteuning, beschikbaarheid van noodzakelijke arbeid, schommelingen in de productie en de algehele boerderijstrategieën te evalueren. Lange termijnexperimenten door boeren helderden de belangrijkste kenmerken van boslandbouwsystemen op. Dit waren: de samenstelling van boomsoorten, de hoeveelheid bomen tussen het gewas, de bodemkwaliteit, het productieniveau en de kwaliteit van koffie, en de kosten/batenverhouding van de productie in de tijd. Venn-diagrammen stelden categorieën van institutionele samenwerkingen en hun prestaties open voor discussie, zodat ze konden worden gescheiden in partners, bondgenoten en tegenstanders van boslandbouw in de regio. Partners waren lokale instellingen, zoals het Centrum voor Technologie van Zona da Mata, de bodemkunde-afdeling van de Universiteit van Viçosa, de *grass root* organisaties en de unie van gezinslandbouwers. Bondgenoten vóór boslandbouwsystemen, maar die sporadisch bijdragen aan hun ontwikkeling, waren het Federale Programma, de adviseur voor het ontwerpen van boslandbouwsysteem, de Regionale Boerenbond en de Ford Foundation. Het Rijksinstituut voor Bosbouw werd beschouwd als tegenstander van de experimenten. Bij verschillende gelegenheden spraken de actoren (boeren, technici, onderzoekers, belanghebbenden en institutionele bureaus) over de belangrijkste kwesties in verband met de lange termijn van experimenteren binnen boslandbouw met focus op duurzame landbouw. De systematisering genereerde nieuwe kennis, versterkte allianties, verbeterde de methodologie, de implementatie en het beheer van participatieve experimenten op de boerderij en creëerde mogelijkheden voor reflectie en leren over boslandbouwsystemen onder boeren, voorlichters en onderzoekers. Nieuwe acties werden overeengekomen en data verrijkt met lokale informatie werden gedocumenteerd voor verdere analyze en verspreiding. Elke unieke bedrijfservaring en institutioneel gedrag werd inzichtelijk. Op deze manier bleek participatieve systematisering te dienen als een middel om innovatie te bevorderen.

1.3. Selectie van inheemse bomen voor combinatielandbouw met koffie in het Atlantische kust-regenwoudbioom (hoofdstuk 3)

Gezien het feit dat de boslandbouw traditioneel niet wordt toegepast in Brazilië, was het absoluut noodzakelijk om te kiezen uit de grote diversiteit van boomsoorten in het Atlantische regenwoudbioom en het vaststellen van patroon en dichtheid van bomen in het ontwerp van de combinatie met het belangrijkste handelsgewas, koffie, in connectie met de doelstellingen van de individuele boer. Het is algemeen bekend dat bomen en gewassen concurreren om licht, water, ruimte en voedingsstoffen. Criteria van boeren om boomsoorten te kiezen waren: verenigbaarheid met koffie, hoeveelheid biomassa en oogstbare producten van de bomen en de arbeid die nodig is voor onderhoud van de bomen. In totaal werden 85 boomsoorten geïdentificeerd. De meeste bomen waren ofwel afkomstig uit het bioom of geïmporteerde fruitbomen. Van het totaal behoorden 28 boomsoorten tot de familie Leguminosae. Stikstofbindende boomsoorten zijn belangrijk voor de werking van boslandbouw, omdat ze bijdragen tot een grotere vruchtbaarheid van de bodem. Daarom heb ik een specifieke inventaris van de vlinderbloemige bomen gemaakt. Ik kwam tot de conclusie dat, om complexe boslandbouwsystemen te ontwerpen en beheren, boeren voldoende kennis en autonomie nodig hebben, die zij kunnen verwerven door middel van een participatief leerproces. In het bestudeerde geval hebben de boeren kennis gedeeld en geleerd hoe om te gaan met het regenereren, behouden en beheren van hun land. De diversificatie van de productie, vooral met fruit, heeft bijgedragen aan het genereren van inkomsten en dus aan een lage kosten/baten-verhouding van de boslandbouwsystemen. De selectie van bomen die reeds getest waren door andere landbouwers, kan worden beschouwd als een snelkoppeling naar de samenstelling van nieuwe agro-ecosystemen. Door dat te doen worden de risico's van onverwachte productiedalingen (bijvoorbeeld van koffie en andere producten) verminderd. Boslandbouwsystemen toonden potentie om het gedegradeerde landschap van het Atlantisch regenwoudbiooom te herstellen en de autonomie van gezinslandbouwers te verbeteren.

1.4. Biodiversiteit en de belangrijke ecosysteemdiensten in boslandbouw met koffie in het Atlantisch regenwoudbioom (hoofdstuk 4)

In hoofdstuk 4 heb ik de indicatoren voor biodiversiteit in boslandbouw (bijvoorbeeld soortenrijkdom, similariteitsindices) vergeleken met referentiebos om de effecten van microklimaat en de kwaliteit van de bodem te onderzoeken. Ik heb bodembiologische, -chemische en -fysische parameters geanalyzeerd om zicht te krijgen op veranderingen in ondersteunende (bodemvruchtbaarheid) en regulerende (temperatuur) diensten. Ik heb aangetoond dat 13 jaar na het in praktijk brengen van boslandbouw de voorheen boomloze gebieden op boerderijen door de groei van boomsoorten productiever werden. In het algemeen hadden boslandbouwsystemen en koffiemonocultuur vergelijkbare chemische en biologische bodemeigenschappen, maar verschillend van die van referentiebos; wel was er een trend naar verbeterde bodemkwaliteit in boslandbouw vergeleken met koffiemonocultuur. Bovendien dempten de boslandbouwsystemen extreme temperaturen meer dan koffiemonocultuur, waardoor er een meer geschikt microklimaat ontstond waarin waarschijnlijk een hogere weerstand tegen de verwachte klimaatverandering optreedt. In termen van beheer stond de kwaliteit van bladresten waarschijnlijk in verband met de bescherming van het bodemoppervlak tegen erosie. De bomensamenstelling in de boslandbouw weerspiegelde heel verschillende boerenvoorkeuren en lokale beschikbaarheid van hulpbronnen. Vandaar dat deze gediversifieerde systemen hebben bijgedragen aan een hogere β-diversiteit dan α-diversiteit. Door het versterken van de regionale habitatdiversiteit voor planten en andere organismen passen boslandbouwsystemen in recent milieubeleid gericht op het herstel van (oever)bossen in het Braziliaanse Atlantisch regenwoudgebied.

1.5. Strategieën en economie van landbouwsystemen met koffie in het Atlantisch regenwoudbioom (hoofdstuk 5)

Een groep van ongeveer 600 gezinnen was betrokken bij de overgang van landbouw op gedegradeerde graslanden naar boslandbouw. De overgangsfase bleek een onzekere fase in de adoptie van boslandbouw te zijn. Boeren handhaafden meerdere koffiesystemen (bijvoorbeeld conventionele, biologische, agro-ecologische en boslandbouw koffiesystemen) zodat zij konden inspelen op prijsschommelingen en de totale bedrijfsproductie. De productiviteit was afhankelijk van indeling en samenstelling van de systemen en de reactietijd van het gewas, terwijl in de overgangsfase de arbeidsinspanningen verhoogd waren met een tijdelijk laag economisch rendement. De rentabiliteit was afhankelijk van de keuze van vermarktbare producten op basis van lokale omstandigheden en regionale infrastructuur. Door beide koffiesystemen naast elkaar te laten plaatsvinden, leek risicospreiding, in ieder geval gedurende de overgangsfase, een goede optie. De totale productiewaarde voor boslandbouwsystemen was gemiddeld 43% hoger dan voor systemen met koffie in monocultuur. De diversificatie van de productie leverde extra inkomsten en risicobeperking. De boslandbouwsystemen leverden verschillende ecosysteemdiensten, maar onderzoek is nodig naar de kwantificering en waardebepaling van deze voordelen. Landbouwproductiesystemen die de levering van meerdere ecosysteemdiensten versterken hebben de potentie om de behoefte aan externe inputs te verminderen en dragen bij aan het bereiken van lokale, regionale en mondiale doelstellingen van groot belang.

1.6. Algemene discussie en conclusies (hoofdstuk 6)

Lage-input systemen zijn zowel een realiteit als een alternatief voor de hoge-output systemen voor gezinslandbouw in de Zona da Mata regio en moeten beter worden onderzocht op impact op verschillende schalen. De voordelen op de korte termijn zijn echter mogelijk niet zichtbaar en om deze reden is lange termijnmonitoring van veranderingen in de indicatoren voor ecosysteemdiensten aan te raden. De vergelijking tussen referentiebos, boslandbouwkoffie en monocultuurkoffie heeft het potentieel van boslandbouw blootgelegd om de lokale bomenbiodiversiteit te behouden en de totale productiviteit per oppervlakte te verhogen. De gebruikte boomsoorten zijn belangrijk in gezinslandbouw voor de levering van meerdere ecosysteemdiensten en kunnen in potentie overblijfselen van het Atlantisch regenwoud verbinden. Selectie van geschikte boomsoorten is essentieel voor het succes en de opschaling van boslandbouw. Studies over boomsoorten zullen de levering van ondersteunende diensten door middel van bodemkwaliteit verder aan het licht brengen, terwijl die ook inzicht in voorzienende en regulerende diensten genereren. Studies over lokale sociale organisatie en landschap zullen in de nabije toekomst waarschijnlijk nog meer culturele diensten identificeren (bijvoorbeeld gevoel van verbondenheid met het woongebied, kennis en esthetiek).

Boslandbouwsystemen kunnen worden gebruikt voor gewasproductie en het behoud van biodiversiteit in de context van gezinslandbouw en de bedreigde status van het Braziliaanse Atlantische regenwoud. Voortgezet participatief werk onder wetenschappers en belanghebbenden kan helpen om de levering van ecosysteemdiensten waarin wordt voorzien door boslandbouwsystemen, naast alleen maar productie van gewassen, te vergroten met de potentie om de behoefte aan externe inputs te reduceren en om bij te dragen aan het bereiken van belangrijke lokale, regionale en mondiale doelstellingen over duurzaamheid en het menselijk welzijn.

Acknowledgements

I am extremely happy because I have many people I wish to thank. Firstly, I thank God for keeping by my side at all moments in life. Thanks to my family for the unconditional support always given to my crazy ideas. To all my sisters Aparecida, Cleide, Luzia, Fátima, Ana Lúcia, and my sister-in-law Márcia I express my profound gratitude, which I extend to your beautiful families.

And many others:

- To CAPES for the full PhD fellowship in the second part of my studies abroad, and to CNPq for the time spent in Brazil (2006/2007).
- To the Soil Quality group from Wageningen University for the intellectual support and administrative help, and mainly for creating a favourable atmosphere to make my journey abroad even more enjoyable. The breaks, coffees, chats, seminars, trips, birthdays, biweekly meetings, "soil quality drinks"...
- To the staff and colleagues I met at Soil and Plant Nutrition of Federal University of Viçosa during the first phase of my PhD study for all facilities during the lab and field work and lectures.
- To the permanent and temporary people I met in Wageningen, for all short or long moments together: Flora, Steve, Tamas, Roland, Mari Luz, David, Gerard, Eva(s), Loes Mertens, Daniel(a), Laura, Chrissi, Lucas, Giorgios, Hanneke, Hella, Mette, Stefan, Irene Visser, Fredrick, Julia, Ingrid, Ben, Ruut, Willen, Klarien, Leonardo, Paul, Francisca, Dorien, Debby, Karst, Andreas, Stevam, Mette and Juanita. You all showed me different types, styles, behaviours, thoughts, that I loved to get to know about and will forever keep in my mind, as a special piece of each one of you.
- To my friends from Brazil. Thanks for the visits, messages, calls, help, receptions, drinks, emotional, spiritual, technical, intellectual and financial support, and the welcome back to Brazil. I'll save you all in my heart: Flávio, Iranise, Edivânia, Léo, Iara, Carol, Marcelo(s), Alysson, Lucas, Frederico, João Marcos, Cláudio, Juliana, Flávia, Guta, Andreza, Celice, Valéria, Guilherme, Beth, Ju/Flávia, Cerila, Neusa, Mirinho, Bárbara, Dona Ana, Anaíde, Leon, Marlos/Érica, Gisele (TimTim), Janela/Leila, Marina, Hermes/Leda, Humberto e Harlei.
- To the farmers who gave me motivation and inspiration. They were definitively the real "professors" I've ever had in the art of agroecology. Initially, to all farmers without distinction between gender and generation, from Simonésia/MG who opened a new windows in my life. Special thanks to the three selected famers and their families for being so kind with us – Alexandre, Ângelo and Romualdo. The most valuable thing I learned from you was that simplicity is everything. I pray to God to reach the same level as you.
- To CTA-ZM - permanent staff, members and followers – for the opportunity of growing up among similarities and differences.
- Some special persons I met in Europe: Henny, my English teacher and friend, Helleke my acupuncturist, Ir. Goretti my spiritual guide, the Mannigel and Plesch families (from Nienstaedt and Hamburg).
- To all my temporary "lovers" from Spain, Germany, Italy, France, The Netherlands, Tunisia and of course Brazil: in many occasions you helped me not to get crazy, neither climbing the walls!
- Special gratitude goes to Elke, Marcelo and Flávio: life without you three would be extremely boring...
- A very special thanks to Lijbert, my promoter, to Mirjam, Ron and Jan, my supervisors, for making me understand that science is a privileged place for those who have ability to be the best, being simple.

All you made me a better man of me and made me feel the real sense of happiness. Now I know that this really exists!

Biography

Helton Nonato de Souza, one of eight children of Maria das Graças Fonseca e Souza and Francisco Ramos de Souza, was born on February 10, 1970 in the city of Itaúna, state of Minas Gerais in Brazil, where he finished the primary and secondary teachings in public schools. For many years he pretended to become a father of Catholic Church, but he is glad today that someone else strongly advised him not to follow that choice. To compensate that he became an activist of Christianity taking the front line of different movements such as Young Ministry, Confirmation Ministry, and Prison Ministry. He graduated in Sanitation Technology from the Technological Center of Environmental Sanitation of Parana in Curitiba in 1991. In the same year he was admitted through a public exam to work as responsible technician for the actions of rural sanitation of SAAE - Autonomous Service of Water and Wastewater of Itaúna, Minas Gerais. He studied two and half years of mechanical engineering and gave up in order to begin with a new career. He joined in 1994 a course on forestry, where he worked with watershed management, graduating as forest engineer from the Federal University of Viçosa in March 1999. He was invited to assume the position of Coordinator of Environmental Licensing for agro-silvopasture activities at the State Forestry Institute of Minas Gerais, where we worked until 2001. Then, he became manager of a protected area called Sossego (meaning a quiet place) in Simonésia and led the implementation of sustainable environmental practices in the neighboring communities by the year 2003. That was the phase from which the most conflicting research questions came across… After that, he worked as a consultant of the GTZ - Deutsche Gesellschaft für Technische Zusammenarbeit in communitarian projects aiming for the sustainable use and management of natural resources in the Amazon (National Forest of Tapajós) and the CTA / ZM - Centre for Alternative Technologies in the Zona da Mata of Minas Gerais. In March 2004 he began a post-graduate course in soil and plant nutrition, at the Federal University of Viçosa and concluded it in February 2006. Immediately afterwards, he started a PhD course at the Federal University of Viçosa and moved to Wageningen University to get his diploma under the supervision of the Soil Quality Group. Nowadays (2011), he works at the United Nations Development Programme office, in Brasília, Brazil, for the Environment Unit. At the stage of finishing his PhD studies he has chosen the four most inspiring words of life: fraternity, equality, freedom and diversity (for all, always).

PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (5.6 ECTS)
- Agroforestry as a means to benefit the environment and human well-being

Writing of project proposal (4.5 ECTS)
- Agroforestry as a key to biodiversity and (soil) ecosystem services in sustainable landscapes

Post-graduate courses (7.5 ECTS)
- The use of Generalized Linear Models (GLM) and Generalized Additive Models (GAM) in ecology; IMAR, University de Coimbra (2009)
- Multivariate statistical tools in ecology and ecotoxicology; IMAR, University de Coimbra (2009)
- The art of modelling; PE&RC (2009)
- Agroecology; UFV, Brazil (2006)
- Soil management and conservation; UFV, Brazil (2006)

Laboratory training and working visits (2 ECTS)
- Soil analysis – PhD course; 7-8 moths full time; Federal University of Vicosa (2006/2007)

Deficiency, refresh, brush-up courses (3 ECTS)
- Soil chemistry (2006)
- Environmental impacts (2006)
- Brazilian phytogeography (2007)

Competence strengthening / skills courses (1.5 ECTS)
- PhD Competence assessment; WGS (2009)
- English: academic reading/writing; WGS (2008)
- EndNote; Library, WUR (2009)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.3 ECTS)
- PE&RC Weekend (2009)
- Netherlands Annual Ecology Meeting (2009)

Discussion groups / local seminars / other scientific meetings (2 ECTS)
- Biweekly PhD/MSc students seminars of 2 hrs. (2006-2011)

International symposia, workshops and conferences (3.4 ECTS)
- Workshop on Conservation Agriculture; Brazil (2007)
- 2nd World Agroforestry Congress; Nairobi, Kenya (2009)

Supervision of one MSc student; 6 months (3 ECTS)
- Loes Mertens: the role of *mycorrhiza*l trees in family farming systems

Ei, dor!
Eu não te escuto mais
Você não me leva a nada
Ei, medo!
Eu não te escuto mais
Você não me leva a nada...
E se quiser saber
Pra onde eu vou
Pra onde tenha Sol
É pra lá que eu vou...

O Sol
Jota Quest (Brazilian rock band)

Hey, pain!
I won't hear you anymore
You do not get me anywhere
Hey, fear!
I won't hear you anymore
You do not get me anywhere...
If you want to know
Where I am going
To where the sun is shining
That's where I'm going to ...

This work was financied by

CAPES – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

Cover designed by

Cássio Ribeiro from Federal University of Minas Gerais, Brazil, with pictures taken by the author during the field work. Some pictures belong to CTA-ZM's archive.

Financial support for printing this thesis was obtained partially from

The LEB Foundation,Wageningen, The Netherlands.