ECOLOGICAL AGRICULTURE IN THE TORRES REGION OF RIO GRANDE DO SUL, BRAZIL: TRADEOFFS OR SYNERGIES?

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ECOLOGICAL AGRICULTURE IN THE TORRES REGION OF RIO GRANDE DO SUL, BRAZIL: TRADEOFFS OR SYNERGIES?

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This research examined the initiatives of sustainable agriculture that have been implemented in southern Brazil, and the main findings suggest that it is possible to promote a "positive-sum" relationship among agricultural production, livelihood enhancement, and environmental conservation. The impetus for this work was a major concern at the present time, usually framed as "sustainable development", i.e., the urgency to further economic goods and services for a growing population, and to concurrently preserve tropical ecosystems. The investigation compared two groups of banana producers who had adopted either conventional or agroecological methods (twenty-five each). The research site was the Torres region, northern coast of Rio Grande do Sul state, located within the Atlantic Forest Domain, one of the most threatened ecosystems in world. Data were collected from June 2005 to December 2006 using questionnaires, meetings, and direct measurements taken at the study sites. Farmers were asked about the size of their banana plots, the inputs utilized for production (fertilizers, pesticides, lime, manure, etc.), yields, labor, marketing prices, and management practices. A phytosociological inventory was carried out in a sub-group of eight agroforestry systems, within the group of agroecological farmers. Overall results indicated that agroecological banana production systems are slightly less productive in physical terms (kg ha^{-1}). However, these systems had better economic performances measured in terms of net income per hectare and labor productivity. In addition, they were contributing more effectively to a number of

environmental services: biodiversity conservation, carbon sequestration, reduction in pesticide use, and less consumption of petroleum-based inputs. These results provide a basis for designing planning strategies aimed at reducing the adverse effects of intensive agricultural activities and enhancing social, economic, and ecological sustainability of this region, and possibly elsewhere.

BIOGRAPHICAL SKETCH

André Luiz Rodrigues Gonçalves has over 20 years of experience working directly in rural development issues with small-scale farmers and grassroots organizations in Brazil. Prior to coming to Cornell, he was working with a local NGO in his country, Centro Ecológico, coordinating sustainable agricultural projects. One of his main accomplishments was the organization of several Ecological Farmers' Associations in southern Brazil, consolidating and increasing the number of organic farmers.

André is an agronomist from the Universidade Federal de Viçosa, Viçosa – MG; he has a M.Sc. in sustainable agriculture from the Imperial College at Wye, University of London, UK, and has participated in international courses at the United Nations University in Tokyo, Japan. He is member of an international network devoted to sustainable development issues called LEAD – Leadership for Environment and Development, based in London. Recently, he was one of the lead authors of the International Assessment of Agricultural Science and Technology for Development (IAASTD), Global Assessment Report.

Para Maria Tereza (Tetê)

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CHAPTER 1

INTRODUCTION

One of the main concerns at the present time, usually framed as "sustainable development", is the urgency to further economic goods and services for a growing population, and concurrently preserve the biosphere (Viglizzo et al. 1998; Uphoff 2001). In the agricultural sector, though, economic development and environment enhancement are frequently identified as two opposites rather than complementary objectives (Viglizzo et al. 1998; Lee et al. 2001). It is widely assumed that improvement of rural livelihoods, particularly in terms of food security and income generation, productive exploitation of natural resources, and promotion of environmental services such as biodiversity conservation, carbon sequestration, pesticide reduction, and soil and water conservation is much more a matter of tradeoffs than of synergies (Lee et al. 2001). This growing dilemma is extremely relevant for developing countries where rural development is needed to alleviate poverty, generate employment, and guarantee food security (Uphoff et al. 1998).

In Brazil, the incentives to promote agricultural intensification were historically oriented to the expansion of large-scale monocultures to produce exported commodities. This market-driven model is successful in increasing exports, but most of the time it generates a deceptive and unsustainable economic growth (Kimbrell 2002; Pádua 2002). Some evidence indicates that in most Latin American countries agricultural expansion, based on the exploitation of the abundant natural capital, i.e., land and natural resources, does not necessarily translate into sustained economic growth and regional development (Chonchol 1994; Barbier 2003). In addition, this development pattern has not been efficient in addressing the social and the environmental impasse which is characteristic of rural areas. Food sovereignty at risk, biodiversity loss, soil erosion, water contamination, continuing destruction of forest fragments, and the impoverishment of rural communities are some of the recurrent issues.

So far, the farm-household agricultural sector[1] which is fundamentally characterized by the social and productive relations among the dwellers rather than the size of the holding itself, plays an important role in the economic and social Brazilian context. In spite of the extreme land concentration, where approximately 85% of the agricultural properties occupy 20% of the total area farmed,[2] smallholder agriculture still contributes 10% of the total Gross Domestic Product (GDP). Moreover, some evidences show that the performance of this segment has been increasingly positive over the last few years, accomplishing better results than large-scale agriculture (Guilhoto et al. 2005). These figures are even more impressive if all the restrictions imposed on this sector such as difficulty to access credit lines, technological deficiency, shortage of land, and lack of technical assistance are taken into account (Guilhoto et al. 2005; DIEESE 2006).

In Rio Grande do Sul, the southernmost state of the country, the importance of smallholder agriculture in the economic, social, and environmental context is even more significant. In the period between 1995 and 2003, the production achieved by the farm-household segment had an increase of 52%, while the augmentation of the state GDP was 25%, and the national GDP increased by only 16%. In 2003, the sector was responsible for generating 27% of the total GDP of the state, producing 74% of the

[1] Farm-household or smallholder agriculture can be defined as a system where the production units operate under the following conditions: the farm is managed by the producer, and the labor is predominantly from the family. In addition, the criterion of maximum area in accordance to the local rural module, specified by the Brazilian federal legislation, is utilized.

[2] According to the Ministry of Agrarian Development, only 0.8 % of the properties in Brazil – 32,264 units – have more than 2,000 hectares and occupy 31.6 % of the farmed area (DIEESE 2006).

maize, 58% of the soybean, 71% of the swine, 74% of the poultry, and practically all the milk and dairy products (Guilhoto et al. 2005). Such numbers demonstrate the significance of the sector in sustaining food security and the influence that strategies oriented to promoting smallholder agriculture may have in rural development.

Farm-household systems also have a considerable stake in the preservation of the environment. The Atlantic Forest Domain, one of the most threatened ecosystems in world, originally occupied just in the southern region, an area of approximately 422,000 km^2, spreading along the states of Paraná, Santa Catarina, and Rio Grande do Sul. Similarly to other parts of the country, the region was successively cleared to make way for agriculture and urban expansion, and today the remaining forested area in these states corresponds to 9.26%, 18.06%, and 4.92% of the original area covered by the Atlantic Forest, respectively, in the three states (Ministério do Meio Ambiente 1998). According to INCRA (Instituto Nacional de Colonização e Reforma Agrária), about 900,000 small farmers operate in this region, which highlights the conservational role that this sector may play.

Ecoagriculture has been proposed as an integrative approach to overcome the apparent dichotomy between environmental conservation and agricultural development by focusing on rural livelihood, environmental services, and food production, (McNeely et al. 2003). Even though several efforts to further a more environmentally-friendly agriculture have been developed over the last few decades, the singularity of this new attempt arises from its explicit emphasis on possible synergies. Furthermore, the ecoagriculture concept suggests a merging of land-use systems and strategies to preserve ecosystem integrity, moving beyond the traditional tradeoff perspective.

Following from the theoretical approach proposed by ecoagriculture, the main thrust of this study is to identify where agricultural systems, particularly farm-household systems, and natural resources conservation have been enhanced. Proponents of an ecological perspective to agriculture[3] have accentuated the role of natural ecosystem processes to design sustainable land-use systems (Altieri 1987; Gliessman 1998; Jackson 2002; Buck et al. 2004). More specifically, biological diversity also has been highlighted as an imperative for devising sustainable agricultural systems and for promoting food security (Thrupp 1998; Cromwell 1999). The connections between rural livelihood and environmental degradation, with specific emphasis on poverty alleviation and food sovereignty, have also been proposed by researchers (Pretty et al. 2003). However, the combination of the multiple objectives of agricultural systems, i.e., food and fiber production, environmental services, and rural development, where all these aspects are scaled up, is still restricted to a few local examples (Buck et al. 2004).

1.1 Overall goal and objectives

The overall goal of the research was to assess through a systemic analysis whether the land-use systems that have been implemented by small farmers in the *Torres Region* of the state of Rio Grande do Sul, Brazil, are concurrently promoting environmental services, guaranteeing agricultural productivity, and supporting rural livelihoods. While the research focused on these aspects, it also sought to identify institutional arrangements that could facilitate the adoption of agroecologically-sound

[3] I am including generically in "ecological agriculture" all schools of thoughts that have proposed different management practices to land use systems in opposition to the Green Revolution technologies: chemical inputs, seed varieties with high response to external inputs, irrigation, and mechanization. I understand that such schools as, for instance, Biological Agriculture, Biodynamic Agriculture, Natural Agriculture, and Permaculture have demonstrably different perspectives, but they share a common and broad value of agriculture that relies on natural processes and renewable resources.

practices. In addition, it provided some information that could assist in the development of public policies more suited to the regional reality.

The potential positive correlation among these attributes (environmental services, rural livelihoods, and agricultural productivity) brought a secondary goal for the research, that is, the development of methodologies to measure, evaluate, and compare such aspects. Based on the agroecosystem perspective and agrarian system theory, a methodological framework for assessing the synergies and possible tradeoffs would allow strategies to be designed, implemented, and evaluated that would increase the chances for the adoption and the maintenance of the sustainable practices. Moreover, understanding that sustainability is neither an intrinsic characteristic of the land-use systems nor a steady value to be achieved, but may be the consequence of the permanent evolving relationship between farmers and their environment, the methodology should reflect this dynamism.

The first objective of the study was to analyze the relationship among the three aspects that characterize ecoagriculture, and to appraise the complementarities and tradeoffs. It was anticipated that by gathering empirical evidence at the local and regional levels that the three aspects proposed by ecoagriculture could be harmonized. From a sustainable rural development perspective, which encompasses the three attributes, if there is an insufficient achievement of one of the three, and/or if there is significant loss in one or two of the three attributes so as to diminish the third one, then it may suggested that the system is operating with tradeoffs rather than synergy.

The second objective was to contribute to the design and development of a monitoring and evaluation methodology that will support the assessment of ecoagriculture practices by local residents, researchers, practitioners, and development agents who can potentially contribute to sustainable rural development.

1.2 Chapter outline and methodological strategy

This document is based on work that has been carrying out with farmers in the *Torres Region* since 1991 by a local non governmental organization (NGO) called Centro Ecológico (CE), which I am one of the leaders. Most of the ecological production systems and smallholders' associations, which constitute the main source of research data, were implemented and organized through the collaboration of this NGO. Given my participation and protagonism, as well as my direct influence on the conversion of several farms into ecological production, I did not have the necessary distance to perform the investigation as an absolute external viewer. Nonetheless, since the advancements of quantum physics the idea of a distant detached observer, without direct interaction with the phenomena studied, needs to be understood differently than in classical scientific terms (Uphoff 1996).[4] The proximity allowed me to perform certain analyses and to gather types of information that is only accessible through a profound involvement with the local community. In fact, most of the findings confirmed what I already expected, and following the prescriptions of the scientific method was, somehow, a strategy to verify prior empirical evidence.

This paradoxical situation of an insider practitioner, who is to some extent also an outsider investigator, also permitted a few practical as well as reflective advantages. The usual introductory work as, for instance, contacting leaderships, connecting with key institutions such as universities, research units, rural extension service, syndicates, farmers' organizations, and visiting rural communities was not necessary. In addition, I had the chance to use the infrastructure provided by CE. Observing from an external situation, I also had the chance to explore the local context

[4] This comment is not to embark on an exegesis of research methods, but rather to posit a methodological position that the standard assumptions of independent observation contain their own distortions for understanding a reality.

through a virtual "macroscope" and to magnify the circumstances that I considered important for the investigation.

In spite of being written in the traditional format, this dissertation was formalized in a paper style not so much to facilitate the publication of future manuscripts, but for the sake of coherence to connect with the conceptual framework proposed by ecoagriculture. The first part is descriptive, composed of three chapters, where an overview of the topic is provided. Chapter Two is a review of relevant literature, and Chapter Three provides a characterization of the region under study. This first section situates the study within a broader perspective.

The first step to contextualize the investigation was a diagnosis of the regional agrarian system. Such diagnosis provides an outlook of the regional patterns and trends regarding the agricultural sector, in addition to pointing out some basic elements for the analysis. The methodological framework adopted is grounded in the agrarian systems theory (AST) proposed by two French investigators, Marcel Mazoyer and Laurence Roudart (1997), to study temporal and historical transformations of agriculture in a determined area. Based on such a concept, technical land-use systems developed in a particular region are considered time-determined by bioclimatic factors, in response to social, political, cultural, and economic circumstances (Mazoyer et al. 1997).

Coupled with AST, another standpoint for an initial diagnosis, as well as for the whole investigation, was the agroecosystem concept (Altieri 1987; Conway 1987; Gliessman 1998). Inherently complex, this approach is based on spatial and temporal features, while the interrelations among these aspects characterize and define the agroecosystem (Kropff et al. 2001). Moreover, as suggested by Schmitt (2001), production systems are not simple arrangements of technical elements, but they reflect culturally how humans, plants, and animals are associated. Any dichotomy between natural systems and managed systems is, therefore, arguable, and in some cases it is more proper to substitute by the impact gradient notion (Schmitt 2001).

The second part of the dissertation is constituted by two chapters, where each is an analytical attempt to study the specific dimensions framed by the ecoagriculture concept. This takes into consideration that knowledge presupposes analysis, and analysis implies division (Santos 1997). Tactically, the whole study object was decomposed into individual components. Despite the fact that these chapters can be considered independent segments in their essence, they constitute among themselves a larger whole, forming the core part of the investigation. The conjunction of these units compounding a single part is much more than the simple juxtaposition of the individual elements. However, all organizational associations necessarily impose restrictions or constraints on the compounding units (Morin 1993).

A comparative analysis of agricultural production between the ecological and the conventional systems is presented on Chapter Four. Instead of adopting the common, and often misleading, yield criterion, agricultural productivity is examined through the lens of the energetic approach, i.e., the balance between inputs utilized for agricultural production and the output harvested. In addition to the comparison of productivity in terms of kilograms per hectare and energy ratios, calorie and protein production also are evaluated. Such information, which essentially is derived from the total production, permits an assessment of the number of people that the system can potentially sustain. Food security and food sovereignty, imperative conditions for sustainable livelihoods, are some of the implications that can be appraised.

This chapter also analyses the potential of ecological systems for income generation. Based on the empirical information that has been produced in the last few years by conventional and ecological producers, the wealth generated by their holdings is compared. Two main indicators are used for assessing the systems' performance: income per unit of area (R$/ha)[5], and labor productivity. This chapter assesses one of the main components of smallholder agricultural systems, that is, their capacity for social reproduction. In addition, one particular conceptual standpoint oriented my approach: market as a social construction instead of as an abstract entity resulting from the interactions between supply and demand (Abramovay 2004).

Chapter Five is an assessment of the environmental services delivered by agroecological practices. Specifically, environmental integrity is evaluated through the capacity of ecological agricultural systems in promoting biological diversity, carbon sequestration, and reduction of pesticide use. A phytosociological inventory was performed for eight selected systems, and the results were compared with two forest fragments previously studied. Plant diversity, vegetation structure, similarity, and presence or absence of threatened species were the criteria used for this comparison. Also, the distribution of some key species, fundamental for ecosystem integrity, was assessed. Several allometric equations were used to calculate the amount of carbon sequestered. Even though the use of pesticides is an anachronistic technology, which will be eventually substituted by the advancements on genomics, its widespread utilization is still important to agriculture and impacts on the environment. Therefore, management systems that promote agrotoxic reductions are still important. The chapter concludes with some projections in terms of landscape, that is, inferring what would be the positive consequences for the whole area under banana cultivation in southern Brazil if farmers were to adopt some of the proposed technologies.

The third and final part of the dissertation is composed of Chapters Six and Seven. Building on the main findings of the previous section, Chapter Six is simultaneously a synthesis and an attempt to accomplish the original research goal, whether an assessment of ecoagriculture is a matter of tradeoffs or synergies.

[5] "Real" (R$) is the Brazilian currency. In September 4, 2007 US$ 1.00 was approximately R$ 2.00.

Strategically, it is assumed that it is possible to evaluate and quantify the sustainability of an agricultural system through its technical, spatial, economic, and social characteristics (Vilain 2003). Furthermore, the chapter discusses possible conditions for scaling up complementarities among food production, environmental services, and livelihood generation. This framework establishes positive-sum effects and rejects the pervasive grip of tradeoffs. Chapter Seven summarizes the dissertation, highlighting the main findings and pointing out the implications attainable with an ecoagriculture approach.

1.3 Methodological steps

Data collection was carried out through different actions, employing both quantitative and qualitative methods. In general, these actions were performed under the aegis of several development projects which have been implemented by the host organization in Brazil, Centro Ecológico. Accordingly, the information generated in this investigation is, to certain extent, part of the reporting obligations of CE to sponsoring partners. Specifically, data were gathered within the ambit of two major projects. The first one, "Farmers Managers Reference Network" [*Rede de Agricultores(as) Gestores(as) de Referências*], coordinated by a prominent NGO in Brazil called DESER (Department of Socio-Economic Rural Studies) and sponsored by the Agrarian Development Ministry, aims to foment through a network of several grassroots organizations, technical expertise to support public policies for the smallholder agricultural sector (Santos et al. 2004; Santos et al. 2006). The second one, Demonstration Projects A, sponsored by the Environment Ministry, under a broader program called International Pilot Program to Conserve the Brazilian Rain Forest (PPG7), supports initiatives of sustainable management of natural resources to generate information that will improve governmental policies (Carvalho 2003).

A group of 50 farmers were selected, 25 conventional and 25 adopting agroecological methods. The general criteria for selecting the ecological farmers were: a) integration in the organic agriculture movement which has been developing in the region; b) participation in any of the ecological farmers association; c) certification by the ECOVIDA network; and d) self-identification as following ecological practices. In general, as mentioned before, most of these organic farmers have been working with CE for several years. To allow a rigorous comparison between the two management systems and to minimize any bias, the best conventional farmers in their respective communities were selected. Following the snowball sampling technique (Patton 2002), the organic producers were asked to indicate some of their neighbors who were recognized for their excellence in conventional production. From this initial pool of 50 farmers a subset of 34 were selected for the specific studies, according to data quality and reliability.

The survey was carried on during the period of June 2005 to December 2006, through the application of questionnaires, meetings, and direct measurements at the properties. Information reliability was double checked with one research assistant from the local community, who is both an agricultural technician and a small farmer, and with local farmers. The information collected was submitted and discussed with different rural communities and groups, seeking to validate and gain feedback from farmers. A total of seven meetings were conducted with the general approach of focal groups (Krueger et al. 2000). Specific details about the methodological strategies are provided in the respective chapters.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

The debate on whether agricultural intensification, environmental protection, and livelihood enhancement is a matter of tradeoffs or synergies has been dividing the opinion of the academic and development community in the last few decades (Lee et al. 2001). Vosti et al. (1997), for instance, propose a "critical triangle" of three interconnected development goals: sustainability, growth, and poverty alleviation, because the achievement of one to the detriment of the others can lead to an overall collapse of the system.

Similarly, a positive correlation between food production and environmental needs has been systematically argued by several authors, particularly proponents of ecological approaches to agriculture. Pretty et al. (2003), in a survey of more than 200 projects from Latin America, Africa, and Asia, all of which addressed the issue of sustainable land use, found a general increase in food production and agricultural sustainability. In spite of asserting that tradeoffs are always inevitable among these choices, Conway (2001) considers that combined methods which take into account farmers' opinions and ecologically-based technologies can contribute to complementarities. Likewise, low external-input crop systems, when properly managed, have shown the potential to increase agricultural yield with less impact to the environment (Bunch 1999; Tiffen et al. 2002).

Following the notion of intensifying agricultural activities while enabling environmental enhancement, some authors argue that modernization, principally in areas well endowed with resources, is necessary to promote food security and alleviate the pressure on natural ecosystems and marginal lands. Generally, based on Green

Revolution technologies and more recently on the advance of genetic engineering, a technology-oriented intensification is advocated to increase food production. In this respect, Borlaug (2000) emphasizes the potential benefits of transgenic crops as an imperative to meeting the food needs of a growing world population. The argument of intensifying food production in specific areas, sparing land for conservation purposes, is also suggested by Waggoner (1997). Another advocate of this approach is Avery (1997), who argues for the use of chemical inputs and other modern farming practices to make best use of land and therefore protect wild refuges.

Some authors, however, argue that equating agricultural intensification with preventing deforestation is not necessarily straightforward. Barbier et al. (2001), studying the economics of tropical deforestation, have demonstrated that forest conversion to agricultural land depends, among other factors, on population growth, institutional aspects, land tenure systems, public policies, and market demand. Macro-structural adjustment policies can also have a negative impact on land use and deforestation, as suggested by Kaimowitz et al. (1999) in a study in Bolivia. Especially in Brazil, agricultural expansion is usually associated with environmental degradation. Currently, the intensification of two main Brazilian agricultural activities, soybean production and cattle ranching, is being undertaken through the opening of new agricultural land that have replaced natural forests (Fearnside 2001; Fearnside et al. 2001; Bickel et al. 2003; GTA et al. 2004).

Suggesting a relationship between per capita income and environmental quality, the environmental Kuznets curve (EKC) is another approach to the issue of tradeoffs and synergies (Lee et al. 2001; Yandle et al. 2004). According to this theory, initial economic growth is characterized by a direct relationship with environmental degradation, but after a certain threshold the tendency reverses, resulting in environmental improvement (Stern 2004). However, the evidence provided so far by many studies is controversial (Lee et al. 2001).

In a study to estimate EKC in 19 Latin American and Caribbean countries, over a period from 1975-1998, Martínez-Zarzoso et al. (2003) found mixed results, but a common trend of a continuous increase in gas emissions. Ehrhardt-Martinez et al. (2002) investigating the validity of EKC for deforestation have concluded that there is a positive correlation between economic development and forest protection, in particular related with urbanization, increase in the service segment, and democracy. Stern (2004), on the other hand, studying empirical evidences for the EKC, did not find a solid statistical basis to corroborate the theory.

EKC is not the sole theoretical framework that attempts to predict the correlation between economic growth and environmental protection, and other approaches have been designed to bridge these two goals. Integrated conservation and development projects (ICDP) have been proposed as a strategy to combine promotion of biodiversity conservation in protected areas with economic and social development initiatives in surrounding communities (Sanjayan et al. 1997). The principle behind ICDP is to improve the living conditions of local people, to alleviate the pressure on natural resources, with the support of nearby communities (Brandon 2001). However, three major concerns are noted by Brandon (2001) as potential obstacles to ICDP: the cost; the inherent difficulty of the approach, particularly to combine development and conservation objectives; and the need to address issues at both the policy and project levels.

Another contribution to the tradeoff versus synergy debate comes from the theoretical approach that Lee et al. (2001) term the “endogenous intensification and policy-led intensification strategy.” According to these authors, the first contribution to this line of investigation came from the work of Boserup in the book “The conditions of agricultural growth: the economics of agrarian change under population pressure" (1993), who proposed that population growth was the key reason for technological change and agricultural intensification. Aiming to anticipate possible environmental problems caused by a disordered agricultural expansion responding to population pressure, some authors advocate an intensification process driven by policies, particularly facilitating access to modern technologies and promoting institutional improvements (Lee et al. 2001). Following this perspective, Ruttan (1997; 1999) argues that a move to agricultural sustainability and economic growth should be related to technological and institutional advancement.

While various theoretical approaches point to different perspectives to combining agricultural expansion and development, the urgency to increase food production is unarguable. Basically, there are two rather distinct and broad perceptions of how agricultural production should be enhanced in order to meet the food needs of a growing population (Buck et al. 2004). The Green Revolution paradigm is advocated by those who understand that increased food production must be attained through the development of better genetic materials, particularly with the improvements promoted by biotechnology, and the use of external inputs (Buck et al. 2004). Diverging from this viewpoint, proponents of what is generically called "agroecology" claim that an agricultural system should resemble, as much as possible, a natural system, where dynamic and complex interactions among its components guarantee production and sustainability (Gliessman 1998). Nonetheless, other authors such as Fernandes et al. (2002) argue for a combined strategy to scale up agricultural outputs and environmental protection through the selection of best practices that already have shown to be efficient in food production, and the technological advancements promoted by modern science. In practical terms, though, any agricultural model should demonstrate the feasibility of combining higher productivity with a sustainable land-use system.

However, one of the main caveats for assessing the sustainability of farming systems, pointed out by Rigby et al. (2001), concerns the criteria generally chosen for the evaluation process, particularly when tradeoffs are considered. Different scales and units of measurement are commonly utilized to appraise agricultural aspects that, most of the time, are difficult to compare (Rigby et al. 2001). In addition, given the inherent complexity and multidimensional nature of agricultural systems, which involve social, political, economic, environmental, and cultural aspects, performance evaluations can be very complicated (Hurni 2000; Limburg et al. 2002).

To assess the environmental impact of land-use practices, Pervanchon et al. (2002) suggest using energy as an indicator, since energy efficiency is intrinsic to any definition of sustainable agriculture. Conforti et al. (1997) state that land productivity combined with energy ratio (output/input) can be used as an instrument to indicate environmental loading. Such an approach follows the studies of Bayliss-Smith (1982) who compared the energetic efficiency of several agricultural systems, and found a greater energy ratio for the less industrialized land-use systems. In a similar investigation, Pretty (1995) emphasizes that organic methods are, in general, less energy-demanding than modern agriculture technologies. In addition, he showed that certain high input systems in the USA can spend much more energy than low input systems, and achieve similar yields. Pimentel et al. (1996) analyzing the use of energy in different corn production methods found an energy ratio of 2.5 units of output per unit of input in mechanized systems in USA, and a 4:1 output/input ratio for traditional systems in Mexico.

The concept of energy efficiency is directly related to another important concern in designing sustainable agricultural systems, i.e., the distinction between the optimization paradigm underpinning agroecological approaches, and the idea of maximization which is characteristic of high input systems. Optimization can be defined as the highest possible yield of any given system without compromising its integrity (Gliessman 1998). Although this definition is rather ample, it opposes modern agriculture's striving for maximum yields at any cost (Gliessman 1998; Vivan 1998). Moreover, the strategies used for agricultural intensification have, so far, caused several adverse environmental impacts (Bennett 2000).

Despite the general negative consequences of agricultural intensification, some methods have demonstrated the potential to increase production with less external inputs. In the zero-tillage, or no-tillage system, mainly grain crops such as soybean and corn, are cultivated without plowing the soil (Landers 1999; 2001). The system uses green manure to cover the soil, and crop rotation (Landers 1999; 2001; Calegari 2002). Comparing crop yield and soil organic matter (OM) content in soybean systems cultivated under conventional and no-till methods, Calegari (2002) showed a substantial advantage for the latter method. Souza et al. (2003) also have demonstrated an increase in soil OM in corn fields cultivated using no-till practices.

In addition to promoting soil improvement and increasing yield, the no-till method also has been shown to prevent erosion, save energy (particularly fossil fuel), enhance biodiversity, and reduce weeds and diseases (Landers 2001; Calegari 2002). One explanation for the system's success is provided by Seguy et al. (2003) who propose that these systems "mimic the natural ecosystem." According to the authors, a key strategy is to imitate some functional and structural features of the original ecosystem, that is, soil protection by cover crops, optimization of climatic resources, nutrient recycling, and protection of the superficial soil layer (Séguy et al. 2003; Séguy et al. 2006).

Designing sustainable agriculture systems that imitate natural patterns also has been promoted by other authors. Jackson (2002), researching the potential of perennial grains for the American prairies as an alternative to annual crops, proposes natural systems agriculture (NSA), in which processes found in nature are the standards. Similarly, Soule et al. (1992) argue for the incorporation of ecological processes into agricultural systems. In tropical regions, particularly in areas where the original vegetation is forest, this notion tends to be more relevant. Comparing Indonesian complex agroforestry systems with conventional plantation of tropical trees such as rubber (*Hevea brasiliensis*), oil palm (*Elaeis guineensis* Jacq.), or coconut (*Cocos nucifera* L.), Michon et al. (1998) note that modern systems are comparatively simple, analogous to a grain field.

Another important point to the discussion of sustainable land-use systems and agricultural intensification is pest and disease control. Modern agriculture, up to now, has been based on a confrontational approach, where insects and pathogens must be controlled through the application of chemical inputs (Kroese 2002). However, pesticide use is one of the major causes of soil and water pollution and poisoning of farmers worldwide (Moore 2002). Some alternatives to pesticides, like integrated pest management (IPM) and systemic acquired resistance (SAR), have been developed in the last few decades (Heil 2001; Kuc 2001; Percival 2001; Jones 2002; Gozzo 2004). Also important is the theory of trophobiosis, in which the susceptibility of a plant to pest or diseases is directly associated with its biochemical state (Chaboussou 2004).

While the debate of tradeoffs and complementarities continues, the correlation between agricultural activities and environmental services cannot be ignored. Occupying an area equivalent to 12% of the total global area, agriculture and animal husbandry have been widely responsible for massive environmental impacts (McNeely et al. 2003). Particularly in the tropics, agricultural expansion has been posing drastic consequences for ecosystem integrity (McNeely et al. 2003). Pimm et al. (2000) estimate that two-thirds of biological diversity is concentrated in tropical areas, especially in tropical humid forests, which originally covered an area of about 16 million square kilometers, but today are reduced to half of this area. The biological richness of these habitats which are jeopardized by the current deforestation rate show the centrality of this issue (Myers 2003). Moreover, most of these tropical forests are located in developing countries, which have been putting continuous pressure on them to meet their development agendas.

Associated with the destruction of tropical forests, the process of ecosystem fragmentation is a major concern for biodiversity protection (Laurance et al. 2001; Myers 2003). According to Saunders et al. (1991), fragmented habitats are characterized by changes in microclimatic and biogeographic features, but the consequences of these changes will depend on the size, shape, and position of the remnants areas on the landscape. Particularly important is the proportion between the edge and the core area of the ecosystem fragment (Debinski et al. 2000). Areas with a greater perimeter are more likely to be more exposed to invasion by exotic species, and to abiotic effects such as wind and temperature (Saunders et al. 1991; Debinski et al. 2000). Schlaepfer et al. (2001), investigating the effects of forest-pasture edges on lizards and frogs in Costa Rica, found a significant variation in the number of species for core and edge plots. Differences in the wind-blown flux and accumulation of pollutants and nutrients from the canopy to the forest floor in edges and interiors were demonstrated in research conducted in deciduous-forest fragments in eastern United States (Weathers et al. 2001). In a study to assess the influence of patches size on the biota, under the Biological Dynamics of Forest Fragments Project (BDFFP) in the Amazonian region, Laurance et al. (2002) found significant differences in biophysical processes and species composition compared with intact forest. Understanding the biotic and physical patterns of forest remnants is critical to designing parks and biological reserves, however, since most impacts on fragments derive from adjacent areas, any management plan should embrace the whole landscape (Saunders et al. 1991).

One of the land-use systems that several authors recognize as potentially effective in mitigating abiotic impacts on forest remnants and promoting environmental services are agroforestry systems (AFS). Laurence et al. (2004) emphasize several benefits of AFS contiguous to forest fragments, such as prevention of drastic changes in the microclimate pattern and exposure to wind turbulence, connection between forest patches, eventually food and refuge provision for wild fauna, and most importantly, reducing the use of slash-and-burn practices by farmers, which obviously protects the forest against fire.

Furthermore, traditional systems where particular crops are established under the forest canopy in a multistrata type, e.g., rubber plantations in the Amazon, damar forests in Indonesia, and shaded coffee in several neotropical countries, have demonstrated an overall benefit for biodiversity (Michon et al. 1997; Schroth et al. 2003; Somarriba et al. 2004). In general, AFS, particularly the complex ones, resembles the structure and function of the original ecosystem (Schroth et al. 2004), and may play an important role as buffer zones for forest fragments (Noble et al. 1997; Laurence et al. 2004).

Even though the role of AFS in promoting environmental services is undeniable, it embodies a generalized perception of human-made spaces, in opposition of natural forests as pristine ecosystems. McNeely (2004), however, points out that humans have been interacting to varying degrees with what are called primary forests from time immemorial. The existence of a distinct division between nature and culture, where natural and human-made environments constitute independent realms, also has been questioned (Seeland 1997).

New approaches to ecology and the inherent complexity of biological and human systems, make the division between culture and nature virtually impossible (Ellen 1996). Thus, the concept of a landscape matrix composed of environmental patches with different gradients of human manipulation and distinct stages of ecological succession seems to be more appropriate. Thus, agroecosystems emerge as logical subunits of a multifaceted landscape, where natural processes such as energy flow, plant succession, soil transformation, and nutrient cycling are key to designing sustainable production systems (Lefroy et al. 1999). Biological diversity has, therefore, an operational importance for the integrity of the whole system. Pollination, nutrient cycling, control of pests and diseases, and detoxification of deleterious substances are some of the functional roles that biodiversity might have in agriculture (Altieri 1999). Pagiola et al. (1997) also describe the importance of biodiversity as an input to agriculture, highlighting the importance of genetic diversity for crops and livestock, insect and disease resistance, and soil health. Apart from this utilitarian principle underlying biodiversity conservation, there is also an ethical imperative from conservation biologists to preserve all species of organisms (Harmon 2003).

Agrobiodiversity, which is more specifically related to agricultural systems, has been defined through a multidimensional concept, encompassing genetic resources, plants and crops, livestock, soil biota, insects and fungi, wild species, and local knowledge (Thrupp 1998; Brookfield et al. 1999). It also has been described in terms of environmental, economic, and social dimensions (FAO 1999). Thus, the concept of agrobiodiversity associates its importance to food security and sustainable livelihoods. It serves as a direct basis for production, a contribution to nutrition, a source of raw material, and for ecosystem functioning (Thrupp 1998; Cromwell 1999; FAO 1999).

In spite of the present recognition of soil biological diversity as an essential support for agricultural production (Wardle et al. 2004), most of the research on soil science has, so far, concentrated on the physical and chemical aspects, neglecting the organic dimension (Sherwood et al. 2000). The "solid basis of life" (Eijsackers 2004), is in fact a living system in which the biological, chemical, and physical constituents interact dynamically (Primavesi 1980; Feiden 2001). More recently, two analogous terms that reflect this holistic perception have been proposed: "soil health" and "vital soil" (Sherwood et al. 2000; Eijsackers 2004). The notion embedded in the first term is self-explanatory and represents an integrative approach to soil management, and the latter "the long-term ability to maintain a proper functioning of the soil system through a diversity of processes and organisms that carry out these processes" (Eijsackers 2004). Vital soil is also a combination of four distinct attributes: robustness, resilience, recovery (structural and functional), and richness (Eijsackers 2004). Although a similar term, environmental health, was considered by Lancaster (2000) elusive and even non-scientifically grounded because it lacks objectivity, the concept of soil health is gaining momentum. Recent collaborative attempts, involving multiple organizations and a multidisciplinary team of farmers and scholars led by Cornell University, have been carrying out initiatives to further the notion of soil health (Sherwood et al. 2000; Uphoff 2006; Uphoff et al. 2006). Moreover, given the extensive problems with soil depletion, both concepts arise in a context where sustainable management of the soil is an imperative to guaranteeing an increase in food production. In this respect, soil biodiversity has an important role to play.

As Andren et al. (1999) have argued, there is a straight correlation between biodiversity and soil functioning. Neher (1999), studying the relationship between soil community composition and ecosystem processes, refers to five ecological functions in which soil biota are involved: plant growth, holding and releasing water, transfer of energy, environmental buffering, and recycling carbohydrates and nutrients. Directly associated with soil vitality, Verhoef (2004) points to three key biological soil processes: mineralization of organic matter, formation and maintenance of soil structure, and support of plant production. All these processes, which ultimately enable and maintain the different expressions of life, are directly affected by soil management (Doelman 2004).

Studying the population of earthworms in conventionally and organically managed soils in the UK, Scullion et al. (2002) measured a general higher earthworm biomass on the organic farms. In a investigation to determine soil mycorrhizal colonization under agroforestry and monocultural coffee systems at Zona da Mata, MG, Brazil, Cardoso et al. (2003) found significant differences according to the management system. For shaded coffee plantations, more mycorrhizal spores were found in the deeper soil layers, while in monocultural coffee greater colonization was found at the soil surface. Several direct benefits for the plant-soil system and for the environment are associated with mycorrhizal fungi: enhancement of nutrient uptake (particularly phosphorus), protection of the root system from pathogens, improvement in carbon sequestration, and soil aggregation (Bottomley 1999; Sylvia 1999; Wollum 1999).

Therefore, the results found might indicate that agricultural systems where the plants are able to explore a larger soil profile, have the potential to increase nutrient recycling (Cardoso et al. 2003). Cardelli et al. (2004) in analyzing the effect of management practices on the biochemical characteristics of soils in Italy found that soils under organic systems have higher organic matter content. Shannon et al. (2002)

suggest that differences in soil biota may occur where conventional and organic practices are adopted; however, the distinction might not be evident.

A positive correlation between sustainable land-use practices and environmental services has been claimed by several authors. The potential of AFS to sequester carbon was studied by Montagnini et al. (2004), who found that such systems can directly work as a carbon sink through perennial crops, and reduce the pressure on forest remnants.

The improvement of living conditions in rural areas, along with the promotion of environmental enhancement and increase in agricultural productivity, is an essential issue for rural development (Buck et al. 2004). According to Uphoff et al. (1998), most development policies promoted by governments and donor agencies over the last few years have explicitly favored urban areas. They note that such a development strategy, predominantly based on the neoclassical economic model, confers on the rural sector a secondary function, subsidiary to the industrial sector segment.

The State of Food and Agriculture report, prepared by The United Nations Food and Agriculture Organization (FAO), reports that approximately 800 million people in the world, most of them in rural areas of less developed countries, are undernourished or under severe food insecurity (FAO 2001). Nutrition has a direct impact on labor productivity, health, school performance, and ultimately, on economic growth (FAO 2001). Worldwide, there is a growing recognition that part of the cause for this situation of food shortage, and sometimes even famine outbreak, is the impoverishment of rural areas where farmers are deprived of basic production resources such as land, credit, equipment, inputs, and information (Mazoyer 2001).

Moreover, as millions of poor farmers are prevented from making a living in agriculture, they migrate to urban centers in search for better job opportunities (Mazoyer et al. 1997; Uphoff et al. 1998). As a consequence, there is an increase in overcrowding of urban centers, which are in general not properly equipped to absorb this population, and a growing impoverishment of rural areas, contributing to food insecurity (Uphoff et al. 1998). Thus, it can be argued that in spite of an urban bias pervading most development policies, and the industrial logic that characterizes modern agriculture, rural development still has a significant role to play, particularly for developing countries.

In an attempt to bring a holistic approach to rural development, taking into account the complexities and various dimensions of human life, the concept of sustainable rural livelihood (SRL) has become part of the lexicon in most development circles. According to Chambers and Conway (1991), one of the first definitions of SRL was proposed by the Advisory Panel of the World Commission on Environment and Development, in 1987, as an integrating concept combining three fundamental principles: capability, equity, and sustainability, three values that are simultaneously ends and means of sustainable livelihoods. These authors, however, suggested a different perspective where the improvement and exercise of capabilities is fundamentally a function of sustainable livelihoods (Chambers et al. 1991). They proposed the following working definition, which is very similar to the one adopted by the British Department for International Development (DFID 2001):

> "A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living: a livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in

> the short and long run. both now and in the future, while not undermining the natural resource base" (Chambers et al. 1991).

Even though the notion of sustainable rural livelihood has been widely used as a reference for promoting rural development, while encompassing a series of concerns related to poverty and environment, few studies address the issues of how to assess the tradeoffs (Scoones 1998). In the same way, the concept of ecoagriculture needs a better understanding of the relationship among the multiple dimensions of rural development, i.e., agricultural productivity, environmental services, and livelihood. Specifically, the following questions drawn from Buck et al. (2004) are still open for further elaboration:

1. How biodiversity-friendly agricultural practices are related to livelihood support?
2. How wild biodiversity can be protected without compromising agricultural productivity?
3. What is the relationship at the local, regional, and global levels between biodiversity and ecosystem functioning?
4. To what extent can the ecoagriculture approach be an alternative to conventional agriculture?
5. What are the scientific foundations underpinning ecoagriculture that show simultaneous improvement in agricultural productivity, livelihood, and environmental service?
6. How feasible is to achieve agricultural sustainability and food production relying predominantly on biological processes?
7. What institutional setting can help to scale up ecoagriculture?
8. What are the measures and indicators that can be used to assess ecoagriculture endeavors?

CHAPTER 3

RESEARCH SITE

3.1 Introduction

The agricultural model adopted in the study area or in any other region is, to some extent, the result of historical transformations and interactions between humans and the environment. In reality, any territorial (or geographic) configuration is determined by the natural systems and the material contributions superimposed by humans (Santos 1997). As has been extensively argued, the present does not arrive in a historical vacuum, but it is certainly the consequence of preceding facts. The main objective of this chapter is, therefore, to provide an overview of the chronological changes in the agricultural sector that have characterized the area where the current research was developed. For analytical purposes, the intention is to present environmental transformations in a historical perspective, and conversely to give an environmental foundation for historical transformations.

Throughout the interlude of almost 8,000 years that humans have been occupying the study region, four main periods can be broadly identified. The first one starts at the end of the Pleistocene period and lasts until the arrival of the first Europeans at the beginning of the 16th century. During this epoch, different groups of indigenous people were living in this territory. Hunting and gathering were the activities of the first humans, while agriculture was developed by subsequent settlers (Kern 1994). Despite considerable technological progress, some of their remarkable management practices are still evident, such as the ecological use of different production systems, the variety of items on which their diets were based, and the sustainable use of the tropical environment.

From the arrival of the first Portuguese settlers until the latter part of the 19th century, there was an agricultural system based on extensive farming with cattle production as the predominant activity. Such a system was primarily developed as a subsidiary sector for the main economic exploration taking in place in the country during the colonial time, i.e., sugar production for export and gold mining. The commercialization of agriculture and enslavement of millions of Africans contributed to a land structure that still persists in the country, as well as to many other social and economic characteristics of the sector that are descended from this period.

An agricultural system rooted in small properties, subsistence production, and local commerce was developed by the first German and Italian colonizers during the late 19th and early 20th centuries. Predominantly in Southern Brazil, the traditional peasantry created autonomous livelihoods where most of the food was produced and distributed locally, with some surpluses for marketing. A community-based life was typical of this period, and most of the country population lived, at that time, in rural areas.

From the 1960s onward, Brazil experienced profound transformations in its agricultural sector. Demographic expansion, urbanization, the development of sophisticated technologies, and new ways of producing and marketing are some of these changes. Environmental impacts also have arisen with this so called modernization. Some rural areas were systematically abandoned, and agriculture's share in the national economy receded to secondary place.

Suffice it to say that the division of a whole period of more than 8,000 years into four segments is only useful for reflective exercise. In reality, the episodes are articulated in a continuum, where facts and transformations superpose and overlap. Each contributes to the concrete manifestations of the next one. In addition, following the division proposed, it would be necessary to include a fifth period. The transformations which led to environmental depletion and social exclusion are, dialectically, provoking some positive reactions. In response to the social and environmental problems in the rural sector, a series of sustainable rural development initiatives have been organized which, to some extent, appear as a new stage in the rural sector's evolution in Brazil.

3.2 Land[1]

Aligned between the Atlantic Ocean to the east and the *Serra Geral* (Highland) to the west, along the northeast coast of Rio Grande do Sul, the southernmost Brazilian state, the meso-region named the Northern Littoral is composed of three successive environments (Figure 3.1). At the interface with the ocean, a Cenozoic sedimentary costal plain (*restinga*) is characterized by a shoreline with beaches, followed by sand dunes, some small hills, and a string of interconnected lagoons. Soils are sandy and nutrient-poor, with a predominance of grasslands, cactus bushes, freestanding bromeliads, and stunted trees. The incidence of salt marshes (*banhado*), with accumulation of littoral peat, is also common. The ecological characteristics of this environment allowed the first human settlement by indigenous people, as well as the initial colonization by Europeans. Historically, this zone was occupied for cattle

[1] The structure of these two subsequent sections, (3.2 and 3.3) follows the precedent of one of the most important books in the Brazilian literature, "Rebellion on the Backlands" (*Os Sertões*), by Euclides da Cunha (1923). In his classical book, da Cunha describes the massacre perpetrated by the republican army against the village of Canudos – a settlement largely composed of former slaves, mestizos, and landless people organized by a mystical leader, Antônio Conselheiro ("The Counselor"), during the late 19th century in the backlands of Bahia state. Some recent interpretations suggest that Canudos was an attempt of the oppressed people to have a decent life, instead of the common view which portrays them as a group of fanatics following a religious leader. Current social movements in Brazil such as the Landless Movement (*Movimento dos Sem Terra – MST*) were clearly inspired by Canudos. It is estimated that approximately 25,000 residents were killed by the federal army during the Canudos campaign. More than one hundred years after this civil war, some poor people are still assassinated in land conflicts.

ranching, and more recently for urban expansion (Rambo 1994; Ruschel 1995; Bernardes 1997).

Behind this area, in the direction of the *Serra Geral* and limited by the upland scarps, stand the inland hills with a network of rivers, valleys, and small lagoons which were eventually connected with the coastal lakes through marshes. Soils are clayey, from basaltic origin, with frequent outcrops of rock, and a vegetation pattern characterized by a typical humid subtropical forest, the Dense Ombrophilus Atlantic Forest (Rambo 1994). This zone is primarily devoted to smallholder agriculture. Paddy rice, tobacco, pasture, and some intensive horticulture are the main activities in the flat areas, along the river courses and margins of lagoons, while banana, cassava, and sugar cane are cultivated on the hills.

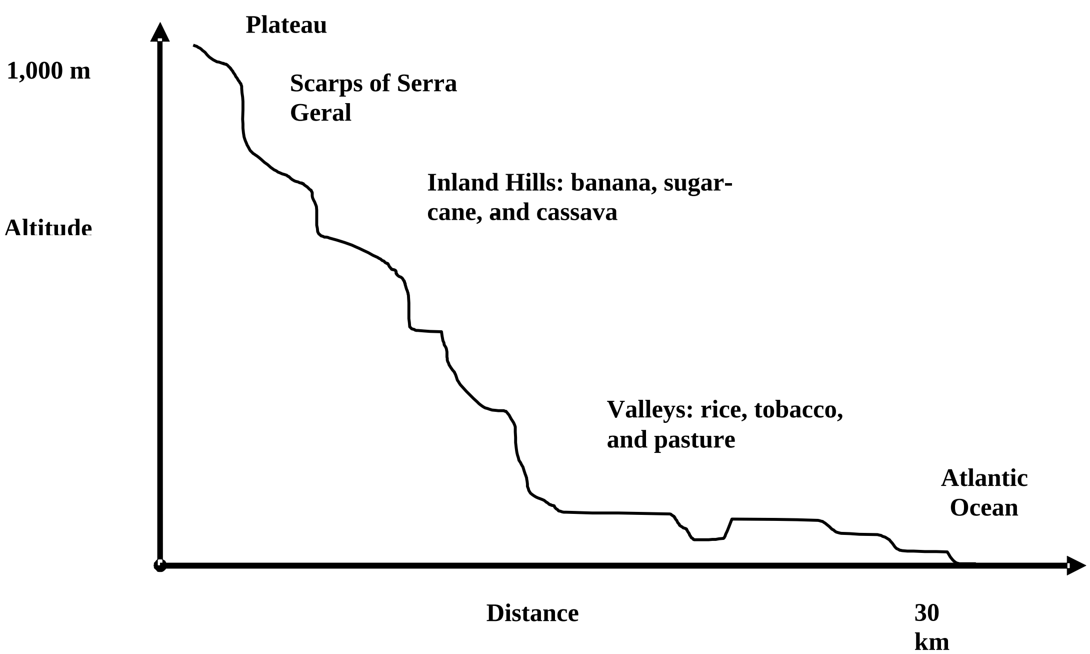

Figure 3.1: Topographic profile of the Torres region (adapted from Gerhardt 2002)

Finally, plateau-type topographical structure constitutes a third zone, covered with a mosaic of grassland and a pine forest, the Mixed Ombrophilus Atlantic Forest or Araucária Forest (*Mata de Araucárias*). This zone is actually the transition between the piedmont of *Serra Geral* and the highland plateau. Cattle ranching is the predominant activity, and given the difficulty of access this area is generally well protected (Gerhardt 2002).

The region's climate is generally classified as humid subtropical (Cfa), according to the Köppen classification system, which is based on annual and monthly averages of precipitation and temperature. Rainfall is relatively uniform throughout the year, with an average that oscillates between 1,300 and 1,500 mm. Winter is the dryer season, and most of the rains in this period are associated with polar frontal conditions. Average temperatures in the summer are about 22 °C, while in the winter they are about 12 °C. The area is exposed to cold winds from the south (*Minuano*), and affected by the Falklands Current that flows from the Antarctic during the whole year (Jarenkow 1994). Given the regulatory action of the Atlantic Ocean, frosts are relatively rare. During the summer, orographic precipitation is considerably frequent.

Within this meso-region, between the Mampituba and the Três Forquilhas rivers, lies the area generically called the *Torres Region* – an extension of land about 50 km long and 18 km wide. The Torres Region is composed of the municipalities of Torres, Três Cachoeiras, Dom Pedro de Alcântara, Mampituba, and Morrinhos do Sul (Figure 3.2). All these cities were originally part of the Torres municipality, and they have been emerging as independent administrative units since 1990, through a process of political subdivision. The rural areas of these localities constitute a single agroecosystem, sharing similar social, economic, cultural, and biophysical characteristics.

Distributed in the geomorphological provinces of *Planície Costeira* (Coastal Plain) and *Planalto Meridional* (Meridional Highland), this area is predominantly part of the Mampituba watershed, which spreads along Rio Grande do Sul and the neighboring state of Santa Catarina. Elevation varies abruptly from sea level to more than 1,000 m in the uplands, over a distance of approximately 20 km, forming a geographical corridor. Rambo (1994) called it "Torres' Door" (*Porta de Torres*) because it is the single forthright connection between the south of Santa Catarina and the northeast of Rio Grande do Sul, constituting an important corridor for tropical species migrating from other parts of the country. The *Porta de Torres* was also a natural access for the first European settlers coming down from northern Brazil.

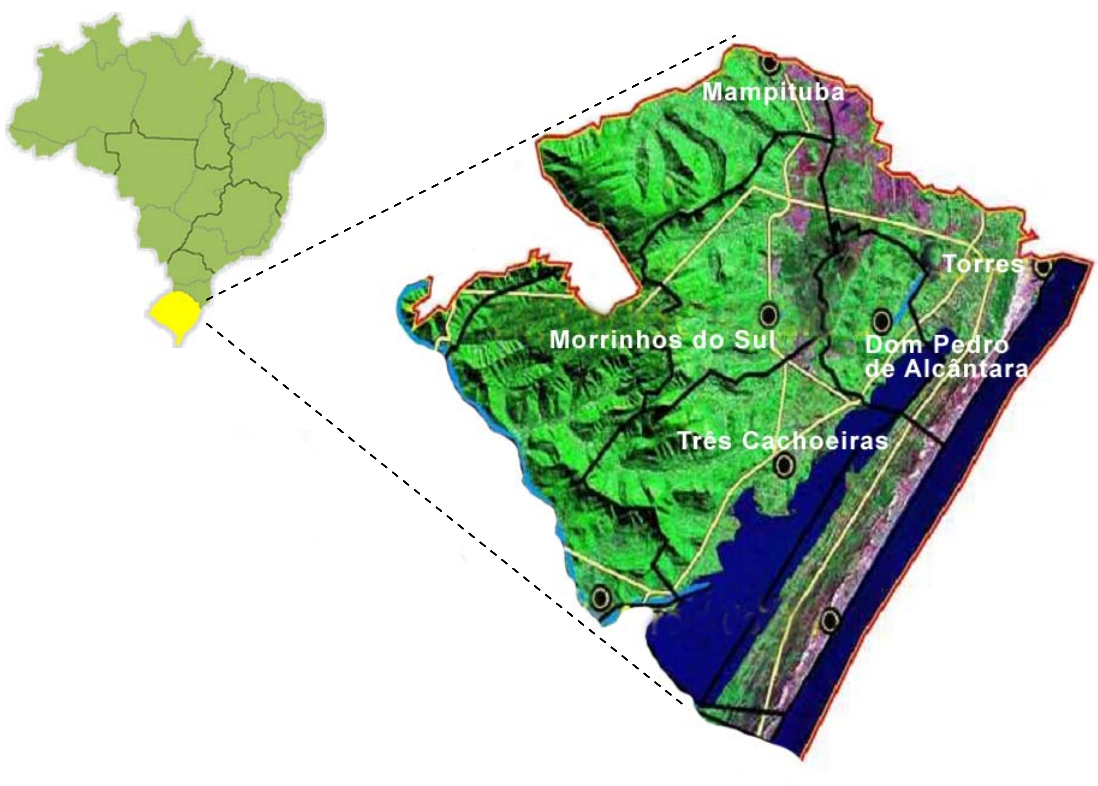

Figure 3.2: Brazil and the Torres region in detail (adapted from Biodiversidade 2007)

Torres is the main regional city and an important tourism destination in the regional context. During the summer, thousands of tourists from all parts of the state and the neighboring countries of Uruguay and Argentina spend their vacations here. In the other localities of the Torres region, agriculture is the main activity. In some of the cities, agriculture accounts for most of the GDP, and practically all the population is involved in this sector. However, the instability of agricultural prices associated with loss due to adverse climatic conditions (flood, frosts, and cold winds) cause several farmers to migrate to the littoral cities during the summer for a temporary job, particularly women. This cyclical movement provides significant income generation which is the main source of income for some rural households.

Regional land distribution is relatively homogeneous compared with the overall pattern for Brazil, with agricultural properties having an average area of 10 ha. The labor structure is predominantly based on the family. A considerable number of farmers own their own land. Based on the 1995-96 agricultural census, INCRA states that 77% of the farmers own land, 11% rent land, and 12% are sharecroppers.

Banana is the main cash crop in the Torres region, and the majority of families in the rural areas generate their subsistence from this crop. The main variety cultivated is *banana prata* (genomic group AAB) comprising approximately 90% of the production. The plantations occupy steep areas on the properties where there are appropriate microclimates for banana cultivation. Modern technologies such as the spraying of mineral oil associated with fungicides for disease control and heavy chemical fertilization are relatively recent innovations in the region. They are mainly promoted by the official rural extension service in order to increase production and improve fruit quality. Despite their consequences for the environment and human health, the adoption of such technologies has rapidly increased, due to the difficulties of selling the product if it does not meet certain quality standards.

Marketing is largely undertaken by intermediaries who determine the price and resell to wholesale businesses and/or directly to retailers. All the production is destined to supply the state and occasionally major markets such as Rio de Janeiro and São Paulo. When the market is saturated, the banana bunches are left in the fields or used to feed animals. With banana commerce controlled by a few intermediaries, the price received by the producers is low and the cost to the final consumers is high. In some cases, this difference reaches more than 300% between the two extremes in the commercialization chain.

Irrigated rice is the second most important cash crop in the region. It is also one that receives most of the financial resources from official credit lines. It is cultivated in the plains alongside rivers and lakes. The use of heavy machinery, chemical fertilizers, and pesticides is considerable, causing severe consequences such as chemical pollution of the watercourses.

Cassava cultivation has high importance, not only as a staple food but also as a cash crop. It is the main source of carbohydrate, and it is utilized for fresh consumption as well as to be transformed into flour and starch. Sugarcane is a traditional crop in the region and the production of brown sugar and brandy was one of the leading economic activities. It is still common to find sugar mills powered by animal traction. Despite its decrease now as a cash crop sugarcane constitutes a main source of income for some families. The importance of horticulture has been increasing substantially in recent years. Due to climatic conditions it is possible to cultivate vegetables in different periods across the main production regions of the state. This characteristic is allowing the activity to become increasingly important in the regional economy.

The Atlantic Forest

Tropical rain forests are, in terms of biodiversity, the richest ecosystems on the planet. Few places in the world possess so many types of life as the Brazilian Atlantic Forest. Thousands of plants, animals, and micro-organisms, most of them not even studied, live on the mountain scarps and in rivers, swamps, sandbanks, islands, caverns, upland prairies, and other habitats that compose the Atlantic Forest and its associated ecosystems. Given the role that such ecosystems should play in promoting the sustainable management of natural resources, the Atlantic Moist Forest was established as a Biosphere Reserve under the UNESCO's Man and Biosphere Programme, and was identified as an important part of the planetary patrimony (MMA et al. 2000; Morellato et al. 2000; Atlântica 2002).

Originally this exuberant tropical forest occupied an area of more than 1,000,000 km^2 – 12% of the Brazilian territory, stretching along the coast from the State of Rio Grande do Norte to Rio Grande do Sul and advancing in various degrees into the interior. It covered practically all of the states of Espírito Santo, Rio de Janeiro, Sao Paulo, Paraná, and Santa Catarina as well as significant parts of Minas Gerais, Rio Grande do Sul and Mato Grosso do Sul, reaching Argentina and Paraguay. Today it is reduced to just 5% of this area (Dean 1995; Morellato et al. 2000; Atlântica 2002; Tonhasca-Jr 2005).

In broad terms, the Atlantic Moist Forest constitutes a mosaic of ecosystems, with a variety of structures and floristic compositions, following the diversity of environments where it occurs. The common element in this context is exposure to the moist winds that blow in from the ocean. The interior-facing areas are characterized by upland forests, resulting from the existence of a humid climate but with a well-defined season. Several vegetal formations associated with recent sedimentation and the influence of ocean tides are found in the littoral zone (Morellato et al. 2000; Vivan 2000; Atlântica 2002; Tonhasca-Jr 2005; FEPAM 2006).

The Atlantic Moist Forest is considered one of the most threatened environments in the world (da Fonseca 1985; Atlântica 2002; Silva Matos et al. 2002; Câmara 2003; Tabarelli et al. 2005; Tonhasca-Jr 2005). Despite its huge devastation, the forest still has extremely important remnants. Among the palms, bromeliads, orchids and other epiphytes, more than 70% are endemic. In terms of mammals, 39% are endemic. The same pattern occurs among butterflies, reptiles, amphibian, and native birds. More than 20 species of primate live in the forest, and most of these also are endemic (Ministério do Meio Ambiente 1998; Vivan 2000; Atlântica 2002; Tonhasca-Jr 2005; FEPAM 2006).

3.3 Humans

Archeological evidence shows that territorial occupation of southern Brazil dates back about 10,000 years before present (BP), to the end of the Pleistocene period when the first pre-historic hunters arrived (Kern 1991). From the Patagonia region, at the extreme south of Argentina and Chile, to southern Brazil, vestiges suggest that these early humans based their lives hunting the characteristic megafauna of this period. During the transition from the Pleistocene to the Holocene, the cold and dry climatic conditions from the last glaciation started to change. The ancient fauna, predominantly composed by large herbivores, declined with climate changes, and early hunters gradually were replaced by a second wave of pre-historic settlers. During the early Holocene, about 9,000 years BP, new groups of hunters and gathers colonized the region. They occupied grasslands expanding toward the south and penetrating on the pampas region. A second group lived in the subtropical forests of the highlands, spreading along the river valleys. Finally, when the climate conditions reached the Warm Period, between 6,000 and 4,000 years BP, groups of hunters and gathers gradually started to colonize the coastal plain (Kern 1991).

3.3.1 First settlers – the *Sambaqui* period

The reason why indigenous groups colonized the subtropical coastal areas of the country is still controversial. The majority of paleoecologists accept an ecological explanation for this settlement. Some portions of the Brazilian coast, likewise most parts of Africa, peninsular India, and Western Australia, as a result of the dismemberment of the Gondwana continent, are marked by a series of small beaches delimited by mountains. In some parts, like in the Torres Region, the Holocene marine regression formed an extensive and narrow strip of sand, isolating small lakes. Rivers and streams flowing from the mountains, carrying down sediments, created nutrient-rich estuaries where a diverse fauna of mollusks, fishes, birds, reptiles and even small mammals found an ideal place to thrive (Fairbridge 1976; Neves et al. 1999; Neves et al. 2005).

Pre-ceramic Indian populations camped around these extremely propitious sites, where they could find a plentiful food source. Lagoons, sea, marshes, sheltered bay heads, and rivers provided an abundance of fish and shrimp. Clams, mussels, oysters, and shell fish could be easily collected on the beaches, mangroves and sea rocks. The mosaic of forests and shrubs on the adjacent mountains, and along the complex hydrographic network formed by rivers, lagoons, mangroves, marshes and beaches also offered a variety of plants and animals. Some evidence from sites located close to the shoreline indicates that these hunters and gathers explored a variety of ecological niches. However, they clearly suggest the predominance of fishing and the collection of mollusks (Fairbridge 1976).

The remains of these camp sites along the Brazilian coast, from the state of Espírito Santo in southeast Brazil to Rio Grande do Sul, are gigantic deposits of middens composed of a great variety of shells and bones. These mounds called *sambaqui* can reach up to 300 m long and up to 25 m high, accumulating thousands of cubic meters of shells. Estimations suggest these sites would have provided enough food for a considerable population during a period of 500 years. More likely, these sites were periodically occupied and abandoned, according to the availability and accessibility of food supplies (Fairbridge 1976; Dean 1995).

In spite of the predominance of hunting and gathering activities to acquire their food supply, recent anthropological research has found that pre-agricultural people accumulated a considerable knowledge about plants. A number of studies even suggest that some areas considered pristine landscapes have, in fact, been deliberately managed for millennia by aboriginal populations, challenging the concept of natural areas. That is the case, for instance, in the Amazon Basin where natives played a significant role in shaping the environment where they lived for several millennia (Moran et al. 2004; Rival 2006). Similarly, in the highlands of Rio Grande do Sul, the dispersion pattern of a tree called Pinheiro-do-Paraná (*Araucaria augustifolia*), which abundantly produces a high calorie-rich seed (*pinhão*), indicates the influence of humans in creating these environments. Probably, the early population in this part of the country followed a nomadic lifestyle, gathering *pinhão* on the highlands, and migrating to the littoral in search of other food resources. Evidence of such a migratory pattern is that communication between these two regions, the highlands and the coastal plain, is essentially the same today as in pre-colonial times (Rambo 1994).

3.3.2 The forest horticulturalists

The transition from hunting and gathering to an agricultural tradition is still a debatable subject. A possible explanation is that demographic changes have leaded to the development of agriculture (Boserup 1993). However, this view seems very utilitarian, implying that land is merely a production factor instead of a complex reality with biotic and abiotic components. Hence, it is plausible that early populations had to increase the intensity of managing the available resources (Dean 1995). What occurred, perhaps, was a gradual shift to agriculture while the ordinary food sources were becoming depleted. In fact, agricultural development has inexorably transformed the relationship of humans to the natural resources (Dean 1995).

When the first Europeans arrived, forest-fallow cultivation was already being practiced by natives. Remains of ceramic handcrafts, found in the upper part of the *sambaquis*, indicate that groups of proto-agriculturalists who had been living for millennia on coastal Brazil were replaced by other groups of indigenous people. Dispersed into southern Brazilian states, generally following the distribution of the subtropical forest, the Guaranis were widely established. In fact, the term Guarani was used by chroniclers in the 16th and 17th centuries to designate many groups sharing the same language from the Atlantic Coast to what is today Paraguay (Schmitz 1991; Monteiro 1992; Carle 2002).

Some linguistic studies have demonstrated that this group has its origin in the Amazon region, between the rivers Jiparaná and Aripuanã, tributaries on the right margin of the Madeira River. The reasons why they migrated to southern Brazil are not very clear, but it may be related to demographic growth and/or a long drought period, which forced them to search for new land that could supply their subsistence needs. Just within the territory that today corresponds to the state of Rio Grande do Sul it is estimated that about 200,000 people spoke Guarani at the beginning of European colonization (Schmitz 1991; Monteiro 1992; Kern 1994).

On the southern coast, occupying the strip of land between the *Serra Geral* and the Atlantic Ocean, two main groups of Guarani were living along the sea, lagoons, and river valleys, the Arachãs and Carijós. In reality these people were not two separated units, but were named differently based on the places where they lived for the convenience of the first Europeans colonizers (Schmitz 1991; Kern 1994). They were scattered into small settlements of approximately 300 individuals each, living in four to six communal houses (*choça* or *tapera*).

Similar to some groups in the Amazon region, their cultural and economic pattern is what some anthropologists call that of Forest Horticulturalists. Their subsistence was based on slash-and-burn agriculture, the *coivara* system, which still persists in different regions of the country. The *coivara* consists of clearing the underbrush of a patch on the forest, approximately one hectare, near the end of the dry season. Dried material was then burned just before the rainy period to make space for planting and to provide nutrients for the crops. After a period of three or four years, when yields had declined or the plot became infested with weeds, it was abandoned and the cycle started again in a new patch. The main foodstuffs planted were cassava, maize, beans, squash, and peanuts, which complemented protein from hunting, fishing, and collecting shellfish (Schmitz 1991; Monteiro 1992; Dean 1995).

Probably the cultivation system adopted by the Guarani, and the way they related to nature, was more than a simple slash-and-burn method. Some authors even regard as a myth that the area was abandoned after cultivating for a few years (Posey 1990). It is well recognized that many other indigenous groups in Brazil and elsewhere have much more sophisticated ways of managing the natural resources available. One typical example is the interaction of the Kayapó, a group of indigenous people from the Xingu valley in the Amazon Basin, with their environment. The areas that they clear for agriculture are, in fact, multipurpose. During several years, in a sequential manner, these plots produce different food stuffs such as cassava, sweet potato, yam, banana, and papaya, as well as medicinal plants and other useful materials. The abundance of food also attracts some game, which complements their diets with protein. Even after 40 years these areas still produce valuable food resources and what looks like an abandoned area is, in fact, a very productive system (Posey 1990; Moran et al. 2004). Likely, these groups do not have any sharp division between agricultural and natural areas.

Other cultural behavior patterns among the Guarani, shared by some other indigenous groups, reveal how they managed natural resources. All the settled areas kept a close interconnection among themselves through different events such as marriages, bartering, ceremonies, and other exchanging practices. In order to guarantee food resources for people traveling along the network of paths, linking the different settlements, they developed cultivated fields within the forest and also alongside the margins of these trails. A conservative estimation in one settlement among the Kayapó revealed a single path of such cultivation 500 km long by 2.5 m wide, which is indeed a considerable area (Posey 1990).

In spite of their acculturation, the remaining groups of Guarani living in Rio Grande do Sul and other regions of the country keep habits similar to their ancestors. These are reflected in their settlements with small numbers of people; their spatial mobility characterized by constant migration; a social organization based on the extended family – composed of the elderly couple, daughters, daughters' husbands, and grandchildren – which constitutes the basic unit of production and consumption; their agricultural practices; and by the political role played by their religious leaders. It is estimated that the Guarani population in Brazil is about 34,000 people subdivided into the Kaiowa (18,000 to 20,000), Ñandeva (8,000 to 10,000), and Mbya (5,000 to 6,000). In Paraguay, the Guarani population is estimated to be about 21,000, including the Pai Tavyterã / Kaiowa (9,000), Ñandeva (7,000) and Mbya (5,000). In Argentina, the Guarani population is about 4,000 people and almost exclusively Mbya concentrated in the province of Misiones. In the northern littoral of Rio Grande do Sul there are two groups of Guarani-Mbya, one in Maquiné and the other one close to the city of Torres.

3.3.3 Foreign settlers

An important element for understanding the occupation of the Brazilian territory is the role played by an institution called *bandeiras*.[2] The inland expansion of the Portuguese domain, even beyond the line established by the Tordesillas treaty, was initially carried out by expeditionary groups organized into military companies, the *bandeiras*, to hunt and enslave the natives. Most of these groups, called *bandeirantes*, were formed in their majority by *mamelucos* or *paulistas*, the offspring of white fathers, mainly the first Portuguese settlers, and Indian mothers (Ribeiro 1982; 2000). The driving forces that led these *bandeirantes* to organize such expeditions were the poverty of the Sao Paulo trading post, and primarily their lack of financial resources to acquire African slaves for the sugarcane plantations.

Different from the northeast region of the country, the areas suited for sugarcane plantations at the São Vicente captaincy, the present state of São Paulo, were distant from the coast, situated in the upland region. Transportation of products to the littoral, crossing the highland scarps, required much labor, and most of the time the value of the product would not compensate for the extra work. Essentially, free (unpaid) workers were needed for these enterprises. According to Sérgio Buarque de Holanda (1995), one of the main Brazilians historians, the expeditions to capture indigenous people had a very clear objective: basically to ensure the status quo and stability that the sugar barons had achieved in the northeast. In reality, the labor force represented by these captives was utilized for almost all daily tasks such as hunting,

[2] *Bandeira* means flag, a reference to the flags that the conquerors carried during the incursions into the territorry.

fishing, cooking, carrying the loads, and producing everything owners ate, used, or sold (Holanda 1995).

When the population of indigenous people started to diminish in the nearby region, groups of *bandeirantes* moved to other areas in search of the natives. They found new sources of slaves toward the southern territory, heading to the states of Paraná, Santa Catarina, and Rio Grande do Sul, and also advancing inland. The trafficking of Indian slaves on the southern coast, at the Port of Laguna, state of Santa Catarina, also had the collaboration of some indigenous leaders. Strategically distributed along the littoral of Santa Catarina and Rio Grande do Sul, a network of intermediaries, the *mus*, was responsible for capturing (*preamento*), concentrating the "pieces",[3] and then trading them. Eventually, the areas used to hold the stock of captives, which were equipped with strongholds (*feitorias*) and other structures, became the first European settlements (Ruschel 1995).

The trading intensification which occurred around the middle of the 17th century was associated with infectious diseases, smallpox, and measles brought by the white man, that helped to decimate the indigenous population. By the beginning of the 18th century, the southern Brazilian coast was practically empty, and the remaining Indians who escaped the genocide went to the backlands for refuge. Lasting into the early 20th century, when the country was already a republic[4], the Xokleng people in the states of Santa Catarina and Paraná, were systematically annihilated by professional hunters (the *bugreiros*) with official support of municipal and state administrations to make space for a new wave of European colonizers (Ribeiro 1982).

Specifically in the state of Rio Grande do Sul, a region under dispute between the Portuguese and Spanish crowns for several centuries, the economic basis for

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[3] Piece, or *peça* in Portuguese, was the standard measure for slaves.

[4] Republic proclamation was in November 15, 1889.

territorial colonization was the activities related with cattle ranching. The ecological characteristics of the Pampas – herbaceous vegetation forming extensive natural areas of grassland – provided the perfect conditions for the livestock brought into the region by the Jesuits. The abundance of palatable forage allowed livestock to reproduce rapidly, and soon there were immense herds of wild cattle ranging freely. In 1810, for instance, on the most productive cattle farms (*estâncias*), only a quarter of the whole herd was domesticated (Chonchol 1994).

The main economic activities in the center of the country, initially sugarcane production, and later gold and diamond mining in Minas Gerais, demanded great quantities of beef and leather products as well as animals for traction. In addition, to guarantee the permanence of military settlements placed in the region to strength their territorial claims, the Portuguese government reserved for that place a monopoly on mule and horse breeding. The activity of driving animals (*tropeirismo*) from southern Brazil to São Paulo and Minas Gerais soon became the main commercial connection between these regions. The exclusive link between the center of the country and the prairies of Rio Grande do Sul was the littoral corridor, and soon a series of *invernadas* – wintering grounds for fattening livestock – was established. In general, the *invernadas* were vast areas of land, separated by natural geographic features. In the littoral, the *invernadas* were placed in the ecological niche of the coastal area, were shrubs and grasses provided a suitable place for cattle ranching.

In an attempt to colonize the region, the Portuguese crown gave concessions of *sesmarias*[5] to militaries and other settlers to develop cattle farms. The *estâncias* were

[5] The *sesmaria* system was an institution created in Portugal during the 14th century to solve a problem of food supply. At that time the Portuguese land structure was still marked by a feudal system where, most of the time, the owners (lords) did not cultivate nor rent the land. The main objective of this law was to prevent idle land. Owners who have not cultivating their land would lose the right to keep hold of it, and the area would be distributed to favor collective interests. The system worked very well in Portugal, but when transplanted to Brazil, a country 76 times bigger than Portugal, the results were very different (Silva 1996).

generally immense areas of land, some of them reaching thousands of km^2, and until the beginning of the 20th century this was the hegemonic production mode in the state. For example, in the 1770s in the northern littoral of Rio Grande do Sul the entire coastal area, an extension of land spreading for more than 60 km, was owned by a single man (Ruschel 1995).

The work force in the *estâncias* was composed of some overseers, peons (usually Indians and mestizos), and sometimes African slaves. A few workers were able to take care of many animals, and extra labor was eventually hired for some specific tasks. Population sizes in these areas were, therefore, sparse. Food and other agricultural goods were supplied by some of the *estância d*wellers, authorized to cultivate in the humid parts of the farm, or by a few small holders living in the surroundings areas (Harnisch 1952; Barbosa 1983; Bernardes 1997).

Another effort of the Portuguese empire to occupy the land and to take control of the territory under dispute with Spain was the settlement of peasants from the Azoreans Islands. Initially, immigrants already established in Laguna, Santa Catarina, came to the state through Torres, the easiest access route from Rio Grande do Sul to the rest of the country. A second flux of Azoreans came directly to the region that is now Viamão, close to Porto Alegre, the capital of the state.

In contrast to the *sesmaria* system, these new settlements were based on small parcels of land, aiming at agricultural development in order to increase the number of residents and enhance territorial occupation. For each couple of settlers, the government provided basic means consisting of an allotment, two cows, the building of a church, and a priest. It is estimated that about 4,000 couples disembarked in Viamão, and most of the Azorean colonization was initially circumscribed to the littoral area (Barbosa 1983).

Little in known about the production systems adopted by the Azorean colonies, but some evidence suggests that they practiced subsistence agriculture, adopting some indigenous practices such as the *coivara* method for land preparation, and producing some surpluses for an incipient market (Barbosa 1983; Lessa 1984). Nevertheless, one important aspect that can be attributed to their settlement was the introduction of sugarcane for the production of liquor (*cachaça*) and sugar. Lasting until the middle of the last century, cachaça production was one of the main agricultural activities in the northern littoral of Rio Grande do Sul. In reality, sugarcane still plays an import economic role in some localities of this region.

3.4 Crisis and opportunity

3.4.1 Conservative modernization

From the beginning of the 1970s, profound structural changes occurred in the agrarian systems of most Latin American countries. Such transformations led to the establishment and expansion of immense agri-food complexes. Traditional agriculture, primarily based on smallholder production (*minifundio*) and on the plantation system (*latifundio*), was gradually substituted by modern capitalist enterprises, increasingly connected to a globalized market (Chonchol 1994). Nevertheless, these structural changes in the agricultural sector have mainly privileged dominant segments to the detriment of a great majority of peasants, and for that reason some authors call it a *conservative modernization* (Silva 1982; Chonchol 1994; Domingues 2002; Pádua 2002). According to Chonchol (1994), such modernization process was caused by the following factors.

a) Substantial increase in exports of agricultural commodities

Since the end of World War II the value of agricultural exports from Latin American countries has increased considerably. Commodities such as coffee, soybean, sugar, beef, and banana are primarily produced and exported by this region (FAO 2007). Presently, industrialization is confined to some specific areas, and therefore agricultural exportation is still an important source of income.

b) Expansion of internal market

Population increase and an escalating urbanization trend caused an expansion in internal markets for agricultural products. During the period between 1960 and 1990, the Latin American population expanded from 206 to 442 million habitants (Chonchol 1994). Improvement of living standards, substantial increase in the size of the middle class, and changes in food consumption habits are some of the aspects related with such expansion (Chonchol 1994).

c) Increase in agricultural commerce and changes in farming methods

The two factors mentioned above (increase in agricultural exports and expansion of internal markets) boosted agricultural commerce. As a result, a number of activities associated with the production and distribution of food and fiber had to be developed to meet market demands. Farming methods relying on the consumption of purchased external inputs became the prevailing model. Classification and standardization of agricultural products, new systems for storage and transportation, financing mechanisms and credit lines, technical assistance, and extension services are some of the activities developed to comply with expanding market exigencies. The agricultural sector was then completely transformed into a series of segmented (and connected) activities. Before production, stands a whole complex of automotive factories producing agricultural machinery (tractors, combines, trucks, implements, etc.) and the industry of chemical (fertilizers and pesticides) and biotechnological (seeds) inputs. After the farm gate, warehouses, food industries, transportation, distribution, wholesale, and supermarkets are some of the necessary links to reach the final consumer (Silva 1982; Chonchol 1994).

d) Public policies

Most governments in the region promoted a number of public policies to advance the agricultural sector. Such policies aimed to increase exports, foment food production, expand the agricultural frontier, and support food and fiber industrialization (Chonchol 1994). To support these policies, a multiplicity of programs had to be implemented as well. Investments in infrastructure (factories, roads, ports, irrigation schemes, etc.); development of extension, teaching, and research services; promotion of credit lines with low interest rates; subsidies for tractors, machines, and chemical inputs are some of the actions that were broadly taken during the 1960s and 1970s (Chonchol 1994).

e) Growing participation of the private sector in the generation and transfer of technology

During the 1950s and 1960s several public research and extension institutions were created in Latin America. Very often, such institutions counted on financial support from international organizations. During the last decades, however, private companies increased their role in technological production. Two main causes are related to this tendency. First, the expansion of the agricultural sector made it more profitable to invest in the development of chemical and biotechnological technologies. A legal framework protecting such technologies with patents was another important factor (Chonchol 1994).

f) Conversion of the agricultural sector into transnational endeavors

Another important aspect of modernization was the expansion of transnational corporations in controlling production and distribution of agricultural goods. Currently, most agricultural enterprise activities, from the production of seeds and fertilizers, to the distribution and marketing of food products, are controlled by a few transnational organizations (Chonchol 1994). In Brazil, a typical example is the industry of crushing and exporting soybeans. This sector, which is currently one of the most dynamic activities in agriculture, is controlled by a few transnational cereals companies such as Cargill, Bunge, and Anderson Clayton (Fearnside 2001; Bickel et al. 2003; Steward 2007).

g) New categories of agricultural entrepreneurs

Finally, another important factor that has favored the modernization process was related to new entrepreneurs leading the production process. Different from traditional producers, these new producers approach farming as a capitalistic enterprise where the main objective is profit. Accordingly, production is exclusively oriented to markets (Chonchol 1994).

3.4.2 Global problems and local solutions

In spite of the considerable increase in food and fiber production brought by agricultural modernization, the overall dynamics and trends are leading to a series of structural instabilities which, in turn, pose social and environmental costs. Some of the consequences can be reversed if appropriate actions are taken. However, a number of problems caused by the widespread agricultural model seem to be irreversible.

Besides the extensive conversion of forests and wetlands to agricultural lands, which inevitably causes biodiversity losses, a series of problems associated with soil erosion, contamination by pesticides, and water overuse are compromising the productive capacity of conventional farming systems. Such problems are particularly relevant in less developed countries where agricultural production should be enhanced to avert the problems associated with food insecurity (Thrupp 1998; Scherr 1999; Rasul et al. 2004; Zimmerer 2007).

Energy efficiency is another aspect that reveals structural problems associated with the current agricultural model (Pádua 2002; Rydberg et al. 2006; Kaltsas et al. 2007). Any definition of sustainable agriculture should encompass the concept of a positive energetic balance. Ultimately, agriculture is based on the capacity of plants to transform sunlight into harvestable useful products. Industrial farming methods rely predominantly on a non-renewable source of energy, which compromise their long term sustainability (Pimentel et al. 1983; Giampietro et al. 1992; Conforti et al. 1997; Gliessman 1998; Pervanchon et al. 2002). Also, energy costs are rising, changing the economics of modern agriculture (Uphoff 2003).

Another acute setback related to the agricultural sector which reflects structural problems is the capacity to generate wealth and jobs, principally for poor people (Chambers et al. 1991; Uphoff 2002). Agricultural modernization, based on the adoption of machines and other external inputs, is displacing labor and is leading to a growing urbanization. Some can call it efficiency, but cities in developing countries are not well equipped to absorb this contingent of people and are demonstrating unequivocal signs of social disintegration (Pádua 2002; Uphoff 2002).

Solutions for some of the social and environmental impasses caused by agricultural modernization have been proposed and implemented by a number of what is generically called civil society organizations (CSO). Usually considered by mainstream development agencies as a minor sector, several NGOs and grassroots organizations (GRO), in many of the world, have increased their participation as a key actor in rural areas (Uphoff 1993). Some authors even claim that advancements in sustainable rural development, particularly based on agroecological practices, must rely on full participation of the communities and collective actions to succeed (Pretty 1995a; Pretty 1995b; Uphoff 1996; Uphoff et al. 1998; Uphoff 2001; Eshuis et al. 2005; Warner 2007).

In Brazil, specifically, the upsurge of CSO started in the early 1980s, as a consequence of the democratization process taking place in the country. In the rural areas, some of these organizations were established to promote alternative farming practices as well as to encourage associative and cooperative endeavors. In Rio Grande do Sul, such a mobilization process was even more intense. A number of environmental organizations, led by AGAPAN (*Associação Gaúcha de Proteção ao Ambiente Natural*), engaged in a campaign to pressure the state government to approve a law to regulate the use of pesticides.[6]

In this context, where modern agriculture and its negative results were increasingly questioned, a group of activists with financial support of a few Swedish NGOs decided to set up an organization to demonstrate the feasibility of alternative agriculture. Gradually, from its creation in 1985, Centro Ecológico (CE) began to work directly with farmers, and to establish partnerships with other organizations which shared similar principles. One of these organizations was the Pastoral Land Commission (*Comissão Pastoral da Terra* – CPT), which played a critical role in persuading farmers to adopt organic farming practices as well as in providing political and logistical support for the development of ecological agriculture (CPT 2007).[7]

Initially in the localities of Ipê and Antônio Prado, highlands of Rio Grande do Sul state (*Serra Gaúcha*), CE focused its activities on organizing groups of smallholders to produce and commercialize collectively. The first association established was AECIA (*Associação dos Agricultores Ecologistas de Ipê e Antonio Prado*), and later several groups of ecological farmers were organized as well.

[6] Rio Grande do Sul was the first state to formulate and approve a law to regulate the use of pesticides. Later, the State Law of Agrochemicals, as it is widely known, became the main legislative statement from the federal government on this matter.

[7] The CPT is a progressive organization created within the Catholic Church aiming to work for the poor rural people. According to their mission they were "convoked by the subversive memory of the evangel of life and hope, loyal to the God of poor people and to the land of God and to the poor people of the land, listening to the clamor that comes from the forests and the fields, following the practices of Jesus, CPT aims to be a solidarity presence, prophetic, ecumenical, fraternal, and affective, listening to the clamor of the poor people from the land and waters, to stimulate and reinforce their protagonism" (author's translation). One of their main accomplishments was to help create the Landless Movement (CPT 2007). During my first years working with farmers in the Torres region I was directly connected with CPT. In the jargon of the organization I was a *liberado* (freed) to promote organic agriculture.

Simultaneously, a number of direct selling initiatives were created making the first experiences in organic agriculture in southern Brazil economically viable. Such a strategy – organization of farmers and direct commercialization – demonstrated that CE could be very effective in promoting organic farming practices.

The positive results obtained by the ecological farmers from the *Serra Gaúcha* in farming organically and marketing their products directly, motivated some priests and other CPT members to promote similar experiences in the Torres region.[8] In 1991, ACERT (*Associação dos Colonos Ecologistas da Região de Torres*) was organized following the example of AECIA. A group of young Catholic leaders (*Pastoral da Juventude Rural* – PJR), concerned about the negative results of agricultural modernization, decided to experiment with new cultivation practices. Their first initiative was to sponsor an exchange with their peers in AECIA, and after that they decided to organize an association. This first encounter resulted in a request from these farmers for a course with technical staff from CE. This first course, which is considered the starting-point of the ecological agriculture work in the region, was held in April 1991.

Since the official rural extension service was not able to address their technical demands, ACERT started seeking a full time technician to work permanently in the region. With financial support from a Dutch NGO – BILANCE, the Pastoral Land Commission signed a technical cooperation agreement with CE in order to structure the work as well as to coordinate and facilitate the extension of sustainable agricultural production practices and commercialization. With the expansion of the work, other groups were organized and presently there are several smallholders' associations involving more than 300 families, spread among the five municipalities that compose the region. Empirical evidence suggests that the work established by CE and its

[8] At that time the Torres region belonged to the same diocese of Ipê and Antônio Prado.

partner organizations are: a) preserving/reconstituting the ecological basis for agroecosystems, b) making small scale farming socially and economically viable, and c) promoting transparent and direct relationships between farmers and consumers; and thereby demonstrate that it is possible to overcome the apparent impasse between environmental preservation and economic development.

CHAPTER 4[1]

PRODUCTION AND INCOME

4.1 Introduction

Since the advent of Green Revolution technologies some 40 years ago, the hegemonic model of food production has been based on intensification through the use of external inputs. The scientific community, particularly agronomic researchers, has been promoting a line of investigation grounded on simplistic and reductionist approaches to the detriment of systemic and complex views. Under this narrow perspective, plants, soils, and the environment are perceived as three different entities with only limited interfaces. In general, most technologies developed for agricultural production reflect this logic.[2]

Such a dominant perception is largely justified through the deceptive myth that world hunger is a consequence of limited food availability, that is, we need to adopt input-intensive technologies to guarantee sufficient food production for a growing population. Indeed, there is a need to increase production to alleviate food insecurity. However, several studies have clearly demonstrated that hunger is much more a matter of food distribution than of agricultural production (Lappé et al. 1998). The seminal work of the Nobel laureate economist Amartya Sen demonstrated that famine/starvation is largely a function of entitlement, i.e., purchasing power, which in

[1] The analytical part of this chapter had the fundamental collaboration of three colleagues. Professor Fernando Funes-Manzote from Universidad de Matanzas, Cuba, and Jonathan Castro from the NGO Corporación Educativa para el Desarrollo Costaricense (CEDECO), Costa Rica, contributed to the energy section; Alvori Cristo dos Santos from Departamento de Estudos Sócio-Econômicos Rurais – DESER, Curitiba – PR, Brazil, helped with the economic performance assessment.

[2] In spite of the widespread reductionist thinking in several scientific areas, this approach is particularly true for the agronomy field where the multiple disciplines that compose the curriculum are rarely integrated.

turn is related to multi-dimensional questions that comprehend economic, social, political, and legal issues (Dowlah 2006; Islam 2007; Sohlberg 2006). Moreover, there is no guarantee of a positive correlation between the use of chemical inputs, such as pesticides and chemical fertilizers and food production (Kimbrell 2002; Lappé et al. 1998).

In view of the social and environmental concerns regarding the role of agriculture, the employment of such modern technologies has been more and more questioned. The impacts caused by industrial agriculture, compromising the natural basis for food and fiber production, are leading to a growing interest in environmentally-friendly methods. Following the same narrow and reductionist perspective of Green Revolution technologies, advances in genomics are promising to produce enough food for a growing population without harming the environment, particularly in developing countries (McCouch 2001; McGloughlin 1999; Pinstrup-Andersen 2001). Engineered plants would be able to produce more and better outputs without the harmful effects of phased-out technologies. This attachment to modern technologies is espoused by most international research institutes, major universities, and big corporations (Meirelles 2006). Sometimes this approach is justified under the umbrella of the pervasive concept of “sustainable intensification.”

A different methodology is proposed by those who believe in systemic solutions. Agricultural systems are considered structurally and dynamically complex organisms, and this complexity arises primarily from the interaction between socio-economic and ecological processes (Altieri 1987; Carter 2001; Conway 1987; Gliessman 1998; Pretty 1995; Uphoff 2001; Vandermeer et al. 1997). Therefore, technologies should reflect this integral nature. Under this approach biological processes are emphasized, particularly soil biology, or more properly, soil health and strategies to build up soil fertility (Uphoff et al. 2006). Pests and diseases are considered expressions of an inadequate nutritional imbalance, rather than exclusively caused by external conditions (Chaboussou 1980; 2004). While conventional agricultural systems rely predominantly on exogenous production factors, organic systems tend to count on internal processes to guarantee production.

Some of the solutions proposed following this latter perspective are not necessarily innovations and many have been under study and development since the ending of the 19th century[3] (Davis 1880; Goodrich 1905; King 1904; Vivian 1909). Modern examples of this approach have been reported in different parts of the world. The zero-tillage method, which started a few years ago in Brazil, now accounts for millions of hectares in several countries where land is managed without plowing, thus accruing explicit environmental benefits such as energy saving, soil protection, and water conservation (Calegari 2002; Landers 1999; 2001). In spite of skeptical and conflicting views (Dobermann 2004; McDonald et al. 2006; Sheehy et al. 2004; Sinclair et al. 2004; Sinclair 2004), the System of Rice Intensification (SRI), which originally started in Madagascar and was further developed and adopted by several hundred thousands of farmers in different regions of the world, is a persuasive example that it is possible to farm efficiently using systemic principles (Uphoff 2007). Moreover, extensive studies recently released have demonstrated that it is possible to produce enough food for a growing population using ecological agriculture methods (Badgley et al. 2007; Pretty 1999; Pretty et al. 2003; Pretty et al. 2006; Scialabba 2007).

[3] There are innumerous ancient texts that have a holistic approach in terms of farming practices. Classical authors such as Zenophon, Cato, Pliny, and Virgil cited in their writings the use of green manure to improve soil fertility. Another good example is the Arabian text of Abú Zacarías Ahmed (Ibn al Awamm), *The Book of Agriculture* from circa 1200 and later translated into Spanish, where he encouraged the use of organic fertilizers for soil recuperation (Ahmed 1999). It is not my intention to call for a "return to the past," but rather reinforce the argument that modern agricultural research has privileged a narrow and limited line of investigation.

4.1.1 The energy approach

To a great extent the current food system is essentially dependent on fossil fuels. Farmers must rely upon the consumption of several external inputs to enable production. This reliance on commercial energy with substitution for labor brings several negative externalities such as emissions of greenhouse gases, and soil, water, and biological contamination (Pervanchon et al. 2002; Pimentel et al. 1989; Rydberg et al. 2006). The increasing distances to transport food from farms to consumers' plates in a globalized market also imposes environmental costs (Pretty et al. 2005). This escalating dependence on a non-renewable resource to produce and distribute food is, therefore, structurally unsustainable (Pádua 2002).

Conversely, traditional agricultural systems are much more efficient in energy use, as they rely predominantly on biological inputs and sunlight (Bayliss-Smith 1982; Pimentel et al. 1989; Pimentel et al. 1996; Ponting 1991). Nonetheless, such systems are generally less productive in terms of gross productivity per unit of labor and per unit of land (Rydberg et al. 2006). The challenge then is to design production systems less dependent on non-renewable energy sources which simultaneously can produce enough harvestable goods (Gliessman 1998).

Recently, many studies have been proposing an energy budget approach to assess the sustainability and efficiency of agricultural systems (Giampietro et al. 1992; Jianbo 2006; Kaltsas et al. 2007; Pervanchon et al. 2002; Pimentel 1980; Pimentel et al. 1983; Pimentel et al. 1989; Pimentel et al. 2005; Rydberg et al. 2006). The basic idea is to assess the difference between the energy embodied in production inputs – labor, pesticides, fertilizers, etc., and the output converted to energy equivalents. Such a method does not need to take into consideration the subsidy of solar energy, as it is virtually an interminable free resource. The first objective of this chapter thus, is to calculate and compare the productivity and energetic efficiency of the agricultural systems under investigation.

4.1.2 Income generation

Resisting the crescendo of urbanization, there are still innumerous examples of traditional populations all over the world showing that it is possible to harmonize agricultural production and environmental protection. Recent evidence even suggests that in spite of lacking support and appropriate policies, the smallholder agriculture sector has an important share in food production and rural development (Badgley et al. 2007; Guilhoto et al. 2005; Pretty 1999; Pretty et al. 2003; Pretty et al. 2006). Therefore, it is plausible to expect that this segment, if adequately stimulated and assisted, can play an important role in a transition toward sustainable rural development.

Another critical aspect rests on the ethical domain. More than one billion people live below the poverty line, surviving on less than U$ 1 per day. Most of them live in rural areas of developing countries, and their livelihoods depend directly on farming activities (Collier 2007; IFAD 2001). Improvement in agricultural production, particularly through the use of low-cost inputs and locally available technologies (Pretty et al. 2003), can have a series of desirable consequences such as food security, income generation, and overall better health. Yet, such a positive scenario is still under scrutiny since there are few illustrative examples worldwide. Therefore, a second objective of this chapter is to compare the economic performance of the two banana production systems (ecological and conventional) and to assess the impact of ecological farming practices on income generation.

4.2 Methodology

4.2.1 Data collection

From an initial pool of 50 households selected for the entire investigation, described on the first chapter, a sub-sample of 34 farmers (17 ecological and 17 conventional) was chosen for the economic performance analysis. Within this sub-sample, 16 ecological and 13 conventional cases were further selected for the energy study. The screening of farmers followed the general criterion of data consistency, including only cases where the data were complete and robust for critical analysis. This construction of samples was performed through discussions with key informants, such as community leaders, technicians from the local NGO, as well as being based on the author's experience. A research assistant from a local community was hired, and he also helped in selecting farmers. Data were collected through a questionnaire survey as part of a major project called "Farmers Managers Reference Network" [*Rede de Agricultores(as) Gestores(as) de Referências*], regionally implemented by the host organization, and supported by the Ministry of Agrarian Development. Altogether, the group of 34 households, was constituted by farmers from different localities, and was a significant representative sample of the two main banana production systems under analysis.

Farmers were asked about the size of the banana plots, the inputs utilized for production (fertilizers, pesticides, lime, manure, etc.), yield, labor, marketing price, and management practices. When farmers had an accurate system for recording their production, we asked to have access to their registers to validate numbers. Data collection was easier for the group of ecological farmers, as most of them market their products through their associations, keeping spreadsheets for accounting purposes. All the banana plots were measured using a Global Positioning System (GPS) device, model Garmin GPS map 76CSX.

4.2.2 Energy budget

Calculation of the energetic efficiency was based on an input-output analysis (Bayliss-Smith 1982; Bel et al. 1978; Fluck et al. 1980; Jianbo 2006; Kaltsas et al. 2007; Pimentel 1980; Pimentel et al. 1983), where each of the production factors and the total amount of banana harvested were transformed into their respective energy equivalents, according to the coefficients provided in Table 4.1. In addition to calorie production, the amount of protein harvested per hectare was calculated and the corresponding number of persons potentially fed was determined based on an average nutritional requirement per person. It was estimated that this amounted to 11.7 MJ (approximately 2,800 calories) and 0.042 kg of vegetable-origin protein per day (4,270 MJ and 15.3 kg per year respectively) for an adult person (FAO 2001; FAO/WHO 1971; FAO/WHO/UNU 1985). Banana has an average of 1.15% of protein content (Souci et al. 2000). When ripe, 20% of the total weigh is constituted by the peel (personal experience).

4.2.3 Economic performance

Economic performance of the systems was primarily assessed based on value addition per unit of land and by the labor productivity. These are the two criteria most used to assess economic performance of agricultural systems (Lima et al. 2005). The total revenue was computed by multiplying the amount of banana sold by the price actually accrued by farmers. Net income was calculated by subtracting the expenditures on intermediate inputs (production inputs) from the total revenue. To calculate the value added per unit of land, expenditures on intermediate inputs (chemical fertilizers, pesticides, manure, hired labor, diesel, etc.) were subtracted from the total revenue, and divided by the total area of the system. The productivity of labor was established by multiplying the value added per unit of land by the total area of banana that one labor unit can actually manage.

Table 4.1: Energy equivalents of agricultural inputs and outputs for banana production

Item	Unit	Energy Content (MJ unit^{-1})	References
General inputs			
Labor	hour	1.5	(Fluck et al. 1980)
Diesel	liter	38.67	(Cervinka 1980)
Gasoline	liter	34.24	(Cervinka 1980)
Polyethilene film for bunch cover	kg	108.9	(Liu 1980)
Chemical fertilizers and mineral amendments			
Nitrogen	kg	61.55	(Liu 1980)
Phosphorus	kg	5.44	(Liu 1980)
Potassium	kg	6.7	(Liu 1980)
Lime	kg	1.3	(Liu 1980)
Rock phosphate	kg	1.3	(Liu 1980)
Organic fertilizers			
Poultry manure[a]	kg	1.2	
Cattle manure	kg	0.3	(Funes-Manzote, in press)
Pesticides			
Fungicide	kg	92.11	(Pimentel 1980)
Herbicide	kg	238.6	(Pimentel 1980)
Oil for disease control	liter	47.79	(Liu 1980)
Output			
Banana (flesh)	kg	3.37	(Souci et al. 2000)

(a) A reliable energy equivalent for poultry manure was not found in the literature. For the proper calculations, the content in terms of nitrogen, phosphorous, and potassium was considered, and converted according to the energy equivalent found in chemical fertilizers.

In turn, one unit of labor was fixed as the equivalent of an eight-hour shift during 300 days per year,[4] or a total of 2,400 hours. For the ecological farmers, the financial costs and labor involved in marketing their products were also determined. Such expenses did not incur for the conventional farmers, since all of them market the banana bunches on the farm gate. Table 4.2 summarizes the performance criteria and the respective equations for calculating the results (Lima et al. 2005).

[4] This is an arbitrary value, adopted to allow the proper comparisons. However, it was based on the information provided by many local farmers on the number of days that they in fact work.

Table 4.2: Criteria for performance calculation and respective equations (adapted from Lima et al. 2005)

Performance Criteria	Equation
Total revenue (TR)	Amount of product sold (kg) X price (R$)[a]
Net income (NI)	TR – value of intermediate goods (R$)
Value addition per unit of land (VA)	NI / area of the system (R$/ha)
Labor productivity (LP)	VA X area in hectares that one unit of labor can manage (R$/unit of labor)

(a) One real (R$) is equivalent to approximately US$ 0.50 (September 15, 2007)

Another comparative analysis to assess the economic performance was carried out by summing the amount of all purchased inputs, including hired labor, and transforming it to the equivalent amount of banana according to prevailing market prices at the time that the investigation was carried out.[5] Similar studies suggest that this analytical procedure is more realistic, as it takes into consideration the genuine farmers' source of income (Kabir et al. in press). Such an analytical approach also permits the evaluation of changes in the production costs over time, and assess the amount of banana needed to purchase the intermediate inputs (Kabir et al. in press).

4.2.4 Data analysis

The differences between yields, conventional and ecological, and energy efficiencies were statistically determined using a student (t) test (Ott et al. 2001). For the comparison of the energy ratio between the two management systems, data were log-transformed, considering that the highest standard deviation corresponded to the ecological sample. A non-parametric test, using the Wilcoxon rank sum test technique, was also performed to calculate the mean difference in the energy ratios between the two groups. This method is commonly utilized when the differences are highly skewed or contain outliers (Ott et al. 2001).

[5] The price at the time of data collection and considered for the analysis was R$ 0.50 per kg of banana, which is approximately US$ 0.25 (on September 13, 2007).

4.3 Results and discussion

4.3.1 Energy budget

Energy inputs varied considerably according to the management system. While conventional banana production relies on the use of external inputs, mostly derived from fossil energy, fertilization is predominantly through the application of organic amendments in ecological systems (Table 4.3). In absolute terms, fertilization (NPK, organic amendments, and lime) accounted for 5,014.4 MJ energy equivalents in the conventional systems, and 3,578.7 MJ (organic + lime) in the ecological production systems. However, a comparison of the total use of fertilizers in terms of energy equivalents, relative to the total amount of energy utilized for banana production, shows a similar value for both systems. In the conventional system it accounts for nearly 57% and in the ecological, 61%. Such similar values suggest that both management farming methods are using the same production coefficients in terms of fertilizer application to sustain production.

Table 4.3: Summary of the energy coefficients for conventional and ecological systems (Standard Error of the Mean – S.E.M. in parenthesis, n = 16 for the ecological and n = 13 for the conventional)

Item	**Ecological**		**Conventional**	
	Quantity (MJ/ha)	%	Quantity (MJ/ha)	%
Labor	521.2 (55.5)	9.2	442.8 (41.4)	5.0
Fertilizer (NPK)	0.0	0.0	3,642.9 (333.9)	41.1
Organic + Lime	3,588.7 (1,102.4)	61.0	1,371.5 (725.0)	15.5
Pesticide	1,492.9 (387.3)	25.4	2,882.0 (337.3)	32.5
Other	262.4	4.5	513.7	5.8
Total	5,882.6	100.0	8,853.5	100.0

A diminution in the use of external inputs, particularly those potentially harmful to the environment, is one of the conditions for sustainable agriculture. However, an agricultural production system based on the use of organic fertilizers does not necessarily indicate that the system is expected to be more sustainable, compared with a conventional system. The prevalent use of poultry manure by most ecological farmers in the region reveals a management strategy based on input substitution, rather than on internal processes such as nutrient cycling from trees and/or legume cover crops.

Organic fertilizer derived from intensive poultry production brings a multiplicity of indirect costs such as transportation, potential of nitrogen leaching, and contamination with growth hormones and antibiotics (Costanza et al. 1997; Gary et al. 2006; Israel et al. 2007). In addition, there is a considerable environmental cost in producing grain-fed birds, as a large amount of the feed comes from conventional farming practices. In fact, a similar study comparing environmental, energetic, and economic performance of organic and conventional farming systems showed that one of the main challenges for organic production is nitrogen deficiency (Pimentel et al. 2005), which partially explains the widespread use of manure.

It must be noted that eight ecological farmers did not use any amendments – organic fertilizer, rock phosphate, and/or lime, during the agricultural period in which the investigation was conducted (the year 2005). One possible explanation is associated with commercialization strategies. The market of organic products is more flexible in terms of the visual aspect of products, allowing farmers to alternate the use of such inputs without compromising their incomes. In reality, a number of conventional producers reported that they are compelled to use a series of chemical inputs to meet quality standards, otherwise the intermediaries do not accept the bananas.[6]

No significant statistical difference was found comparing the physical production (Mg of banana)[7] in the ecological systems accrued by the group of farmers who utilized fertilizers with those who did not (Figure 4.1). Possibly, to reach the same productivity levels, the systems are still benefiting from the residual effects of fertilizers applied over previous years. Such a trend indicates that it is possible to rationalize the use of external inputs without jeopardizing production and income. In addition, is suggests that in a long time-span these systems employ less exogenous energy, which is an indicator of sustainability.

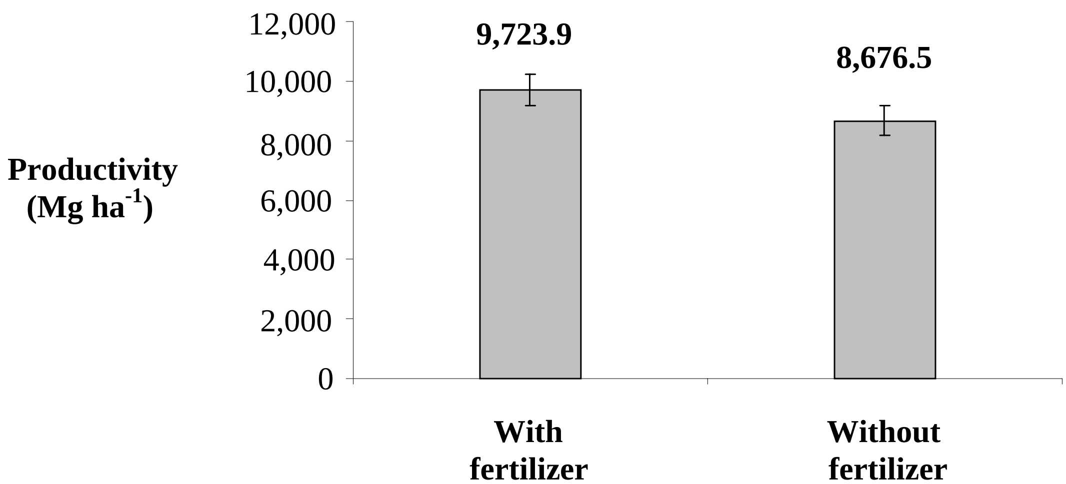

Figure 4.1: Productivity mean of the two ecological subgroups (n = 8 for the two subgroups)

[6] One common practice among conventional farmers in the region is to spray the banana bunches with the herbicide 2-4-D in low concentrations. Small doses of this herbicide have an effect similar to auxin, a plant growth hormone.

[7] One megagram (or metric ton) is equivalent to 1,000 kg.

In absolute terms, total pesticide use was much higher in the conventional management systems (2,882 MJ against 1,492 MJ in the ecological systems), as it is common to use herbicides to control weeds, and fungicides associated with mineral oil to prevent sigatoka disease. In turn, ecological farmers use some organic components such as biofertilizers[8] mixed with mineral oil.[9] This practice has a growing acceptance, even among conventional farmers, as it has been effective in controlling disease and improving plant health (Shah et al. 2006; Stamford et al. 2007). Overall, farmers spray their plantations three to six times per year, concentrating the applications during the summer. Banana production in the region is not highly intensive in terms of pesticide application and fertilizer use, compared to traditional production areas of South and Central America (Liu 1980).

The total amount of oil pesticide sprayed per hectare was statistically equal for those using this practice in the two groups, conventional and ecological (Figure 4.2). The total equivalent in terms of energy accounted 2,311.5 MJ and 2,171.5 MJ, respectively. In fact, all conventional farmers sprayed their banana plantations, while five ecological producers did not use this input. Hence, if the average of mineral oil utilized is computed the whole group of ecological farmers, the value is substantially lower (1,492.9 MJ).

Mean energy input in the form of labor varied between the two systems. For ecological production it accounted for 9.2% of the total energy input, whereas for the conventional it represented 5.0% (Table 4.3). In three ecological systems, however, labor was the single source of energy input, revealing a quasi-extractive form of managing these banana plantations. In spite of the apparent disparity, a statistical test

[8] Biofertilizer is a general term describing a liquid fertilizer prepared by local farmers and extensively adopted. The substance is prepared by fermenting water, manure, milk, and sugar, enriched with some micronutrients such as zinc, copper, molybdenum, and boron.

[9] Organic farmers use only non-synthetic chemical products in their production systems. However, the application of mineral oil for disease control is allowed in organic banana production.

showed that the means were not significantly different. Such findings are essentially consistent with the general notion that ecological agriculture is more labor-intensive.

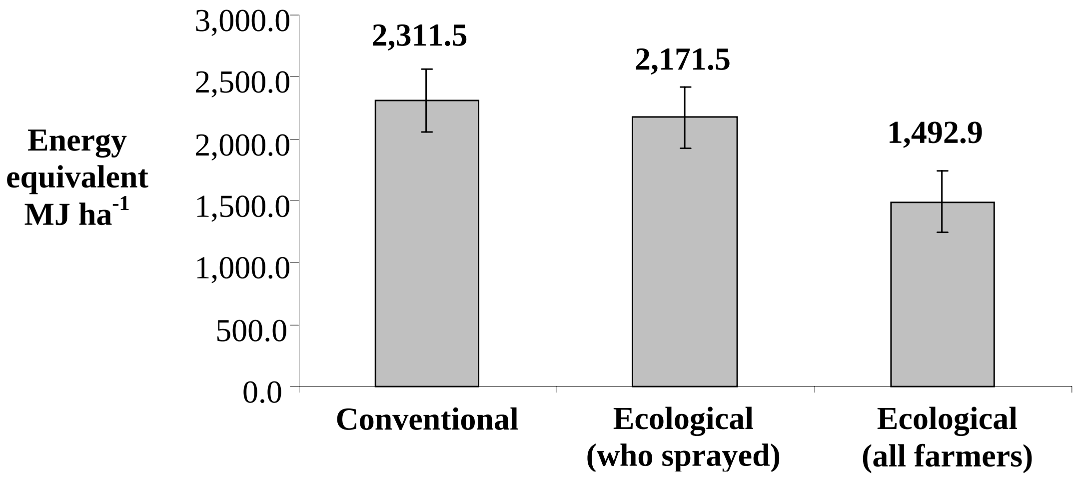

Figure 4.2: Energy equivalent for oil pesticide sprayed (conventional, n = 13; ecological who sprayed, n = 11; and all ecological, n = 16)

Surprisingly, efficiency measured in terms of labor energy to produce one kilogram of banana was not statistically different between the two groups. Ecological farmers use, on average, 58.3 kJ of energy for each kilogram produced, and the conventional 44.0 kJ. Increase in the use of commercial energy in agricultural production in general leads to a decrease in labor requirements, and principally in the productivity per unit of labor (Odum 1980; Rydberg et al. 2006). A possible explanation for the similarity found among farmers is that both banana production systems are very similar in terms of management practices, and to some extent this is consistent with the input substitution strategy adopted by many ecological producers.

On average, conventional systems utilized 815.6 kJ of energy from external sources (exogenous energy), and the ecological 534.0 kJ, to produce one kilogram of banana. In spite of the apparent difference, these means are not statistically different

(Figure 4.3). Probably, the high variation in the consumption of external inputs among the ecological systems is preventing a significant difference when compared with the conventional banana production systems.

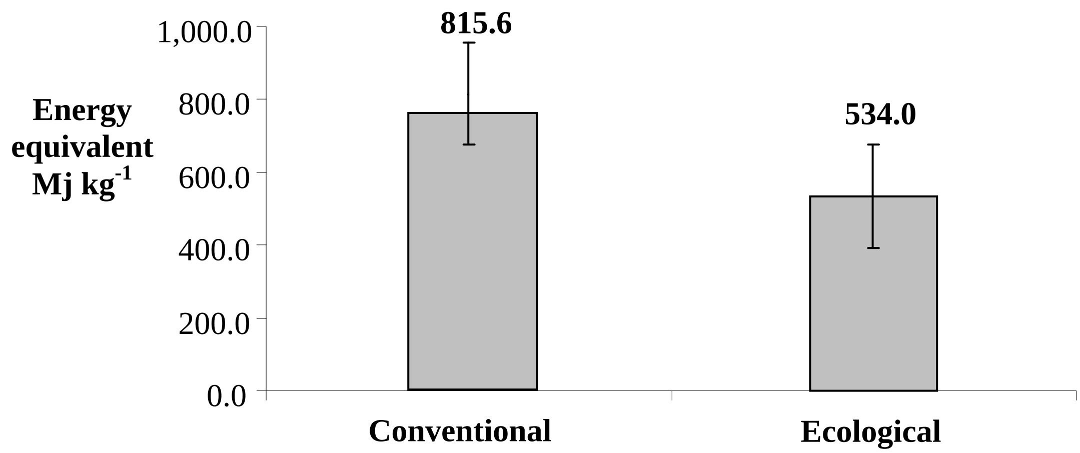

Figure 4.3: Average in energy equivalents of external inputs utilized to produce 1 kg of banana in all conventional and all ecological systems (conventional, n = 13; ecological, n = 16)

On the other hand, if only the exogenous energy equivalents of synthetic fertilizers and agrochemicals employed for each kilogram of banana produced are considered, the averages are different (Figure 4.4). Such a comparison is essential to assess the sustainability of agricultural systems, as the use of external energy for agricultural production, principally petroleum-based inputs, is a critical indicator of sustainability. Moreover, the negative effects of a continued use of chemical fertilizers and pesticides, such as soil salinization, outbreak of pests and diseases, etc., reported by many scientific studies as well as by local farmers, compromise long-term agricultural sustainability (Altieri 2000; Amin 1992; Andreoli et al. 2000; Bunch 1999; Chaboussou 2004; Costabeber 1998; Daly et al. 2007; Descalzo et al. 1998; Donald et al. 2006; Gliessman 1998; Guzmán-Casado et al. 1999; Hillel 1991;

Kimbrell 2002; Maron et al. 2007; Matson et al. 1997; Meriles et al. 2006; Pádua 2002; Pimentel et al. 2005; Pretty 2002; Pretty 1995).

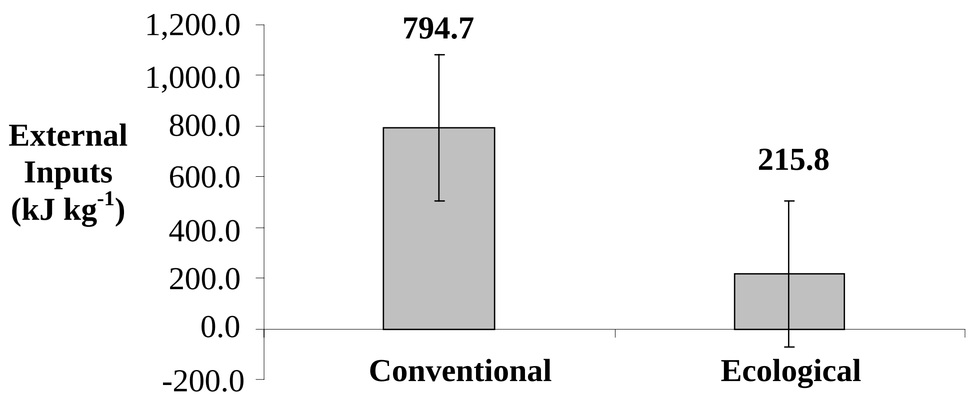

Figure 4.4: External inputs utilized to produce 1 kg of conventional and ecological banana considering synthetic fertilizers and agrochemicals (conventional, n = 13; ecological, n = 16)

In general, total energy efficiency varied between the systems. Means of the output/input ratio were significantly higher in the ecological than in the conventional production systems (Figure 4.5). In addition, ecological production had a greater ratio variation, ranging between 110.0 MJ/ha and 2.2 MJ/ha. Such a result is because three ecological banana systems used labor energy as the exclusive input source and therefore had high energy ratios. In these three systems, the energy output/input ratio reached the impressive average value of 67.0 (110.0, 53.1, and 37.9). When analyzed without these three outliers, the mean decreases to 7.6 MJ/ha.

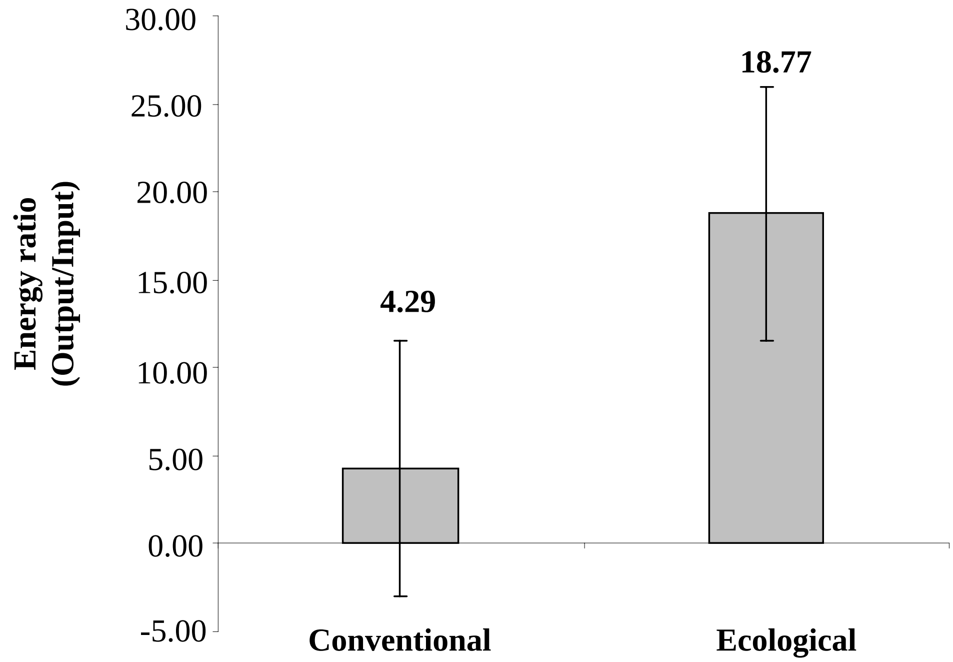

Figure 4.5: General energy ratio (output/input) of conventional and ecological systems (Conventional: n = 13 and S.E.M. = 0.56; Ecological: n = 16 and S.E.M. = 7.04)

The statistical tests performed to compare the ratios mean between the two samples showed similar results. The 't' test, with the data log-transformed, revealed a significant difference between the means. The non-parametric test also pointed out the salient difference between the two sample means. However, when a 't' test was run without the means from the three ecological systems that predominantly used labor energy (outliers), no statistical difference was found. Such results are also in accordance with the findings previously reported, suggesting an input substitution management strategy.

4.3.2 Calorie and protein production

The total amounts of calorie and protein harvested per hectare were higher in the conventional management systems, as shown in Figures 4.6 and 4.7. Statistical comparison of the two management systems showed significant difference between the means. Conventional systems produced 35,505.5 MJ/ha of calorie and 108.3 kg/ha of protein, which correspond to a productivity of 11,079.8 kg/ha of banana. On average, ecological systems harvested 28,762.7 MJ/ha of calorie and 87.4 kg/ha of protein, equivalent to a banana productivity of 8,975.7 kg/ha.

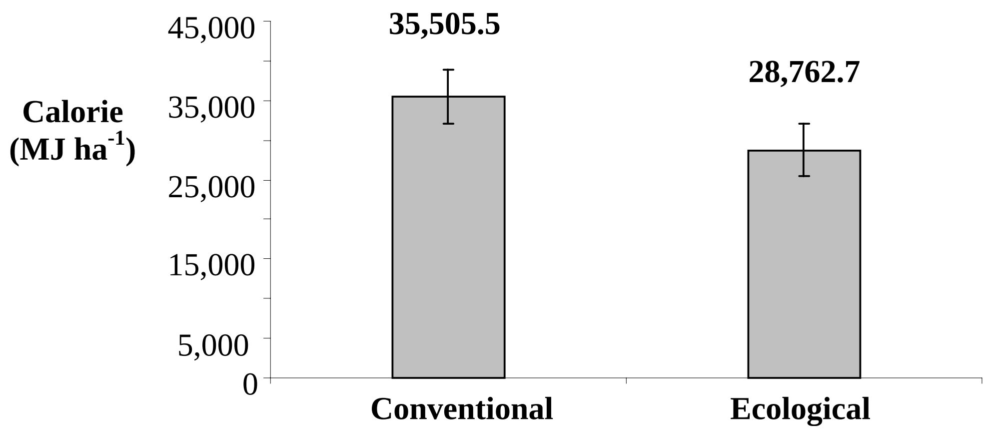

Figure 4.6: Average of calorie production in MJ/ha in conventional and ecological systems (n = 17 for both management systems)

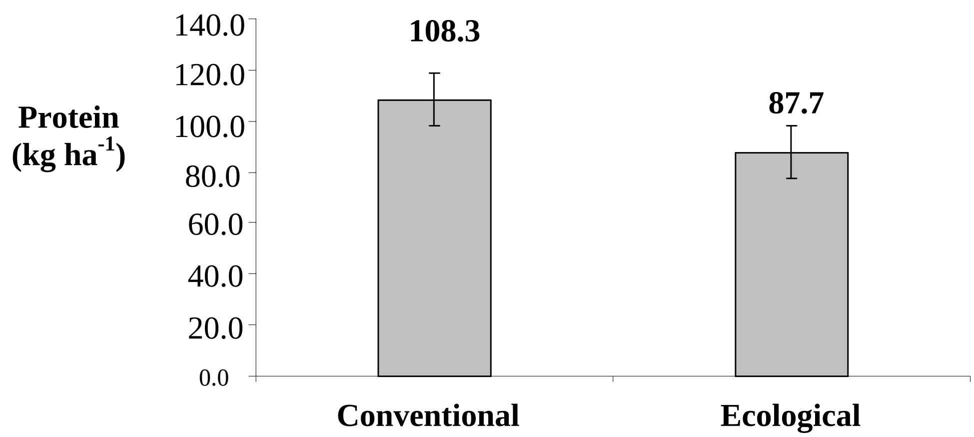

Figure 4.7: Average of protein production in kg/ha in conventional and ecological systems (n = 17 for both management systems)

Despite the better performance of conventional systems in calorie and protein production per unit of area, such values are not conclusive evidence that these systems are more productive. Some other production factors such as labor, cash, and energy should also be taken into consideration. As previously reported, some ecological farmers have been adopting agroforestry practices, that is, intercropping banana with other tree species. One of the species that has been increasingly adopted by farmers is *palmito* (*Euterpe edulis* Martius) or palm heart. Apart from the conservational role that this species might have in helping to preserve the Atlantic Forest (Fantini et al. 2007; Galetti et al. 1998; Silva Matos et al. 2002), it is also an alternative for income generation and food security improvement. Similarly to the *Euterpe oleracea*, extensively produced and consumed in the Amazon region, the extraction of the pulp of palm hearts generates a highly caloric and fatty substance, the *açaí*, which is a functional food product with potential to enhance the diet of local people, especially the poor (Clare 2002).

Differently from conventional producers, ecological farmers have been mixing other plants such as cassava, papaya, guava, avocado, citrus, and innumerous native fruits with bananas. These additional products were not measured in the total amount of food produced in those systems, since most of the farmers do not consider them as "economic production." Nonetheless, several studies have demonstrated that the cultivation of different plants is important to sustaining household food supply, particularly for marginal populations (Fernandes et al. 1985; Kumar et al. 2004; Miller et al. 2006; Nair 2007; Shrestha et al. 2006; Wezel et al. 2003).

Another aspect that should be taken into consideration is the biological quality of the food. Organic products are in general more nutritious than food conventionally produced, containing higher levels of micronutrients, antioxidants, vitamins, pigments, and other important substances (Asami et al. 2003; Mitchell et al. 2007; Worthington 2001). Therefore, an exclusive comparison of calorie and protein production can mask some relevant outcomes in terms of food security from ecologically managed systems. It was interesting to observe though, that most conventional farmers do not eat the banana that they produce. In general, for home consumption, they prefer to grow some plants in their backyards without using pesticides and synthetic fertilizers.

Maximization is the general approach implicit in agricultural research and rural extension services. However, to match the present environmental agenda it would be more adequate to design agricultural systems based on the optimization of available resources. Under this premise, one question that should be investigated is the length of time that farming systems based on the maximization logic would continue to be productive. In the long-term, it seems that high-input systems have their production capacities compromised. Accordingly, several farmers in the region mentioned that their banana plantations became more vulnerable to pests and diseases, particularly to panama and sigatoka, when production was intensified.[10]

4.3.3 Economic performance

The average value added per unit of land (R$/ha) varied between the two management systems (Figure 4.8). While the ecological production systems averaged R$ 5,418.4/ha (n = 17; S.E.M. = R$ 643.5/ha), the mean for conventional systems was R$ 4,031.6 (n = 17; S.E.M. = R$ 453.0/ha). However, no significant difference was found through a statistical test. A possible explanation is that the ecological systems had a higher S.E.M., compared with the conventional ones.

However, when the net income per unit of production (R$/kg), or the value aggregated for each kilogram of banana produced is considered, the figures are different (Figure 4.9). On average ecological systems have a return of R$ 0.61/kg (n = 17; S.E.M. = R$ 0.20/kg), and conventional production R$ 0.35/kg (n = 17; S.E.M. = R$ 0.02/kg). Statistically, there is a significant difference between the two means.

[10] In fact, some farmers tell that when the plantation is infested with the panama disease they have to stop using chemical fertilizers and pesticides in the area. After a certain period without applying the chemical inputs the plot restores its production capacity.

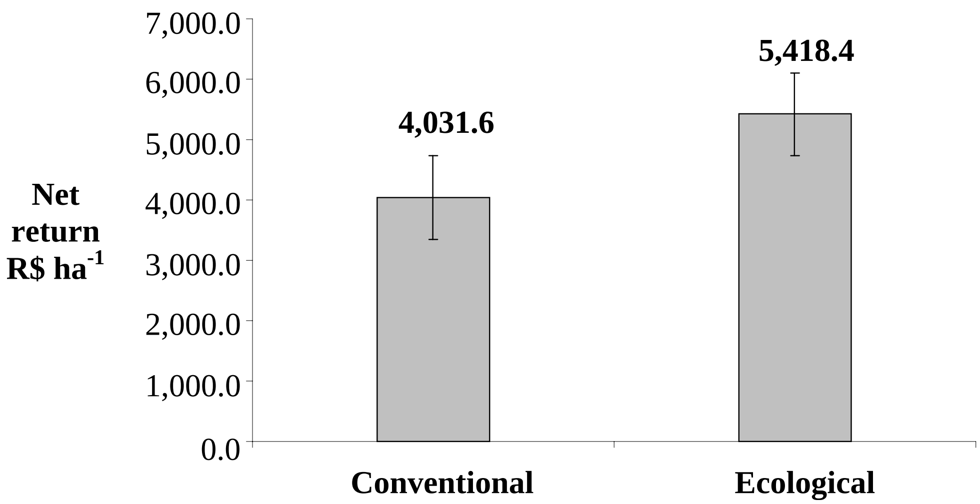

Figure 4.8: Averages of net income per hectare in conventional and ecological systems (R$/ha)

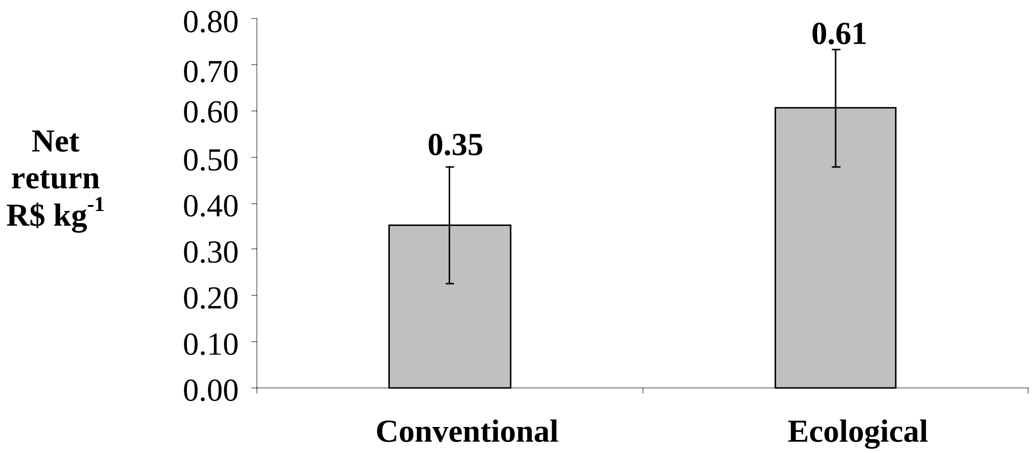

Figure 4.9: Net return per Kg in conventional and ecological systems (R$/kg)

Access to better markets is the main reason why the ecological management systems had a superior performance compared with the conventional ones, when net return for each kilogram was considered. While conventional producers market their products at the farm gate, predominantly via intermediaries, most ecological farmers sell their products directly. It must be noted, though, that in spite of a better remuneration for the products, in most instances where the ecological farmers participate in direct commercialization, customers pay a fair price. Contrary to the common paradigm that ecological products are more expensive and oriented to economic and intellectual elites (Conner 2004), the prices for such products in these direct commercialization endeavors are similar to those paid for conventional products in the marketplace, and sometimes are even below.

In addition to better prices for farmers, and very frequently for consumers, commercialization channels that connect more effectively producers and urban costumers have been praised as a way to promote sustainable agriculture and rural community development (Lyson et al. 1995; Lyson et al. 1999; Lyson et al. 2001). In effect, local food systems based on face-to-face links are central to scaling up social and environmental benefits. Direct agricultural markets, where food locally produced is commercialized, can facilitate a series of horizontal interactions, contributing to creating social capital (Lyson et al. 1999; Uphoff 2000; Uphoff et al. 2000).[11] On the other hand, hierarchic commercialization structures are impersonal, exclusively designed to maximize profits and comparative advantages (Brown et al. 2007; Enshayan 2007; Hinrichs 2000; Lyson et al. 1995; Lyson et al. 1999; Meirelles 2007).

Therefore, these results suggest that an important condition to expanding sustainable agriculture is a redesign of the commercialization structure. Marketing channels where farmers and their organizations are directly linked to consumers, preferably at the local level, seem to be an adequate promising (Brodt et al. 2006). Moreover, empirical evidence points out that such endeavors can help to promote

[11] In spite of the controversy, in the last few years the concept of social capital has been widely used by academics and practitioners as one of the fundamental conditions to explain the development of any region. There is a vast literature on this topic, but this work utilizes the concept proposed by Uphoff (2000) and Uphoff et al. (2000) in which social capital is a set of values, norms, attitudes, beliefs, social networks, etc. that facilitate *mutually beneficial collective action* (MBCA).

connections between producers and consumers based on cooperation, transparency, and solidarity, moving the conception of marketplace beyond a mere institution for commercial transactions (Brown et al. 2007; Lyson et al. 1995).

Imperative to the promotion of such commercialization strategies is the participation of governments in designing and implementing public policies. In Brazil, one specific initiative which has a great acceptance among farmers is the *Programa de Aquisição de Alimentos da Agricultura Familiar* (PAA) (foodstuff acquisition program of family agriculture). Under such an initiative, which is within the sphere of a broader policy called Zero Hunger (*Fome Zero*), the federal government through different mechanisms acquires food directly from organized farmers, and distributes it to local organizations, such as daycare centers and schools. Several farmers reported that this policy was a stimulus to adopting ecological practices, as the program pays a higher price for organic products in addition to assuring the purchase of them. Other reported benefits of the program are the recuperation of fair prices and incomes for farmers, improvement of the diet of children and elderly, and a general increase in food security.

Labor productivity (LP) did not vary significantly according to the management system (Figure 4.10). When compared to the total amount of work devoted exclusively for banana production, the average was R$ 34,150.2/unit for the conventional (LPc) and R$ 42,551.2/unit for the ecological (LPe). Notwithstanding the higher value for the ecological management systems, a ‘t’ test shows that the pair of means was not statistically different. When the time expended on the commercialization activities was taken into consideration,[12] the productivity of labor

[12] As noticed before, conventional farmers sell their products to intermediaries, at the farm gate. Therefore, they do not have labor and financial costs associated with marketing activities.

for the ecological farmers (LPt) and for the conventional producers had similar values, which were not statistically different.

Contrary to the general assumption that ecological agriculture is more labor-intensive, means for the difference in total units of labor dedicated to production were not statistically significant (Figure 4.11). On average, ecological producers allocated 0.15 units of labor to manage one hectare of banana in one year, approximately 43 days, while conventional farmers spent 0.13 units, roughly 38 days. Such a finding is consistent with the empirical evidence that both systems require about the same amount of work.

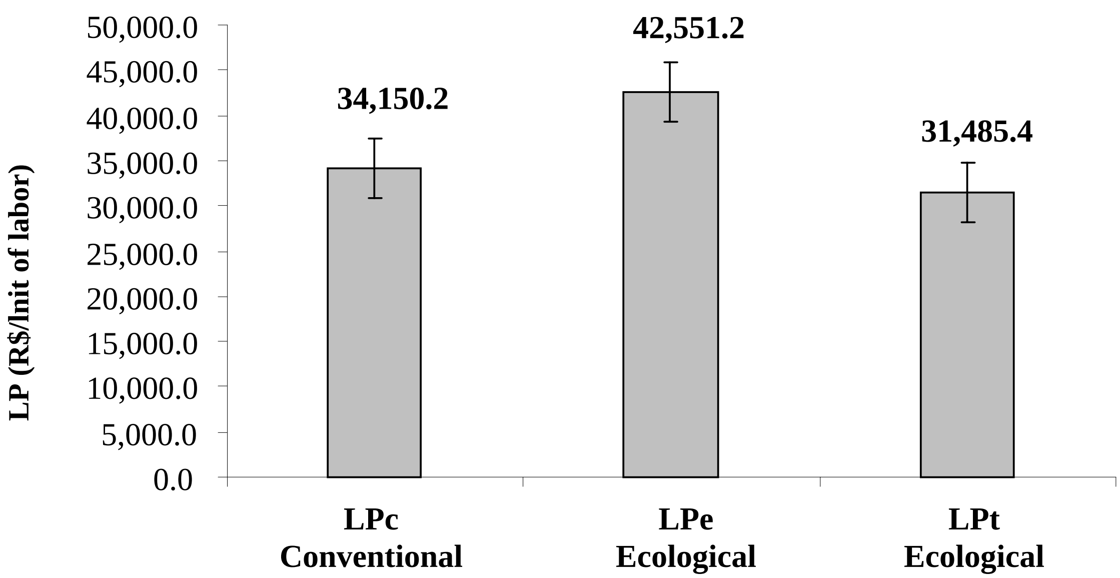

Figure 4.10: Labor productivity (LP) between the two groups of banana production systems (conventional, n = 17, S.E.M. = R$ 3,722.3/unit; ecological only production, n = 17, S.E.M. = R$ 5,838.1/unit; ecological total, n = 17, S.E.M. = R$ 2,236.0/unit; R$ 1.00 = US$ 0.50 approximately)

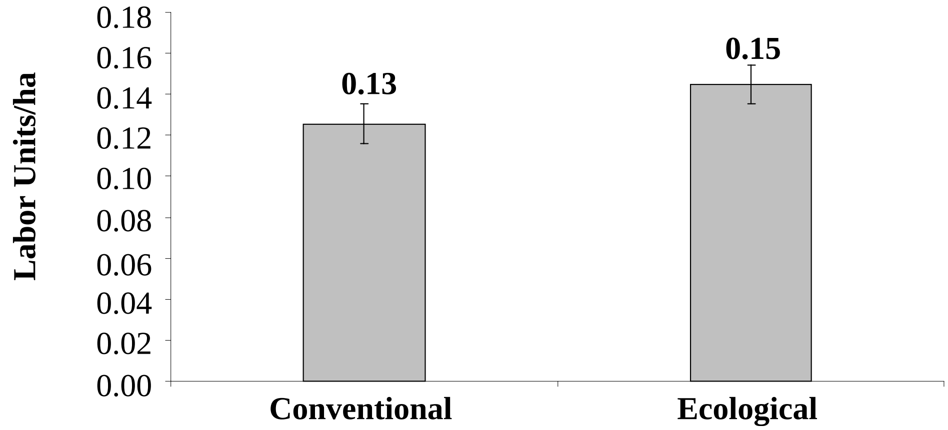

Figure 4.11: Units of labor devoted for the management of one hectare of conventional and ecological banana systems (conventional n = 17, S.E.M. = 0.009; ecological n = 17, S.E.M. = 0.015)

In spite of not finding a significant statistical difference between the averages of labor productivity when only the work related to banana production was considered, the values suggest that conventional farmers have to manage a larger area to achieve the same labor productivity as ecological farmers. In fact, the average area cultivated varied according to the management system being used. In the ecological systems area averaged 2.58 ha (n = 17; S.E.M. = 0.36), and conventional systems had an average area of 4.03 ha (n = 17; S.E.M. = 0.34).

The nature of the tasks associated with the production and marketing of products also should be considered. Some conventional farmers have experienced health problems associated with the use of pesticides, precluding them from working fully in their plantations. Hence, there are costs involved in going to the hospital, buying medicines, etc. A precise comparison of the economic performance between the two management systems should take such costs into consideration. On the other hand, the activities associated with marketing the products directly are considered by some conventional farmers somewhat troublesome. A number of farmers even argued that they do not convert their systems into ecological production for the reason of the extra labor involved. To market directly farmers are required to prepare the banana bunches, to ripen, cut, box, and transport to the market, and finally sell it. In addition, there is always the risk of not selling everything. For that reason, some conventional farmers consider that the better prices received by the ecological producers for selling bananas directly do not pay for the extra work involved.

An analysis of the production costs in terms of banana equivalents, i.e., transforming the expenditures of purchased inputs (labor, chemical fertilizers, lime, and agrochemicals) according to the most common banana price in the marketplace (R$ 0.50/kg = U$ 0.25/kg on September 13, 2007) shows that in average conventional farmers spent 2,416.5 kg of banana ha^{-1}, and the ecological producers 1,043.6 kg ha^{-1} (Table 4.4). The net income, however, was slightly higher for the conventional producers, but there were no significant statistical difference between the two means. In a context of increasing costs of petroleum-based inputs and diminishing values of agricultural products, such numbers tend to be different, favoring farmers who avoid purchasing external production inputs.

Table 4.4: Costs of banana production and net returns in real terms (kg ha^{-1})

System	Production cost kg ha^{-1}			Net income kg ha^{-1}
	Input	Labor	Total	
Conventional (n = 17)	1,776.2	640.3	2,416.5	8,663.4
Ecological (n = 17)	607.2	436.4	1,043.6	7,932.1

The overall findings indicate that basically two different strategies should be considered for improving the economic performance of agricultural systems. Within the production unit, or more specifically, considering the aspects related to the production process, farmers should attempt to reduce the use of external inputs, particularly those derived from fossil fuel. Agricultural production systems that are designed to maximize, directly and indirectly, the use of sunlight are more efficient energetically, and therefore tend to be more efficient economically as well.

Outside the farm gate, or considering commercialization strategies, initiatives that favor the direct contact between producers and consumers seem to be more appropriate. In general, by selling their products directly, thereby reducing the links in the commercialization chain, farmers get better prices. Ultimately, successful farmers (conventional or ecological) are those who optimize the use of free energy available within the production unit, reduce the use of external purchased inputs, and simultaneously have access to better markets.

4.4 Conclusion

This chapter investigated the energetic balance, productivity, and economic performance of banana production under two different management systems. Comparisons between the two showed that ecological banana production is more efficient in terms of energy use, i.e., the ratio of calories harvested for each unit invested is generally higher in these systems. Such findings show promise for enhancing social and environmental benefits if some of the practices adopted by some local farmers could be expanded to other production areas.

Banana is one of the main crops in the world. In 2005, according to the FAO, the area cultivated represented more than four million hectares, mostly in developing countries (FAO 2007). Commercial production of the fruit at present is highly dependent on fossil energy, predominantly agrotoxics and nitrogen inputs (Liu 1980). Reduction in the use of pesticides and/or substitution by environmentally-benign compounds such as biofertilizers and manure would improve the energy efficiency, as well as enhance overall ecosystem health. This can be particularly important as banana production is concentrated in tropical regions.

A better performance or efficiency in terms of energy use does not necessarily imply that the system as a whole is more efficient. Economic and social circumstances also need to be taken into account. Banana is a major export commodity for several countries in Latin America, constituting the living for millions of workers. Apart from the environmental benefits that ecological systems can represent, better marketing strategies can also signify an improvement in livelihoods. The relatively better economic performance of ecological farmers compared with conventional ones can be partially explained by access to improved markets. Also illustrative is the federal policy in the ambit of the "Zero Hunger" Program (*Fome Zero*), where organized farmers can sell their products for a better price, with a premium for ecological products. Such a program has been very important to motivating changes, demonstrating the role that public policies might have in promoting sustainable agriculture.

CHAPTER 5[1]

FARMING PRACTICES AND THE PROMOTION OF ENVIRONMENTAL SERVICES

5.1 Introduction

Differently from other Latin American countries colonized by the Spaniards, where first economic activities were based on gold and silver mining, the incorporation of Brazilian territory was promoted through agricultural activities. Coming from a modest country in terms of natural resources, the first Portuguese conquerors found, as they thought, an endless land (Caminha 1500, 1963).[2] Under the doctrine of mercantilism, the primary motivation was to develop an extractive industry in the new colony to allow the production of economic assets through a positive balance of trade. This initial impetus, coupled with a context of extreme ecological abundance, generated a predatory agricultural model (MacDonald 1996; Pádua 2002a; 2002b).

The plantation system introduced by the Portuguese was based on extensive monocultures of sugarcane. For the production of an export commodity (sugar),

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[1] Research for this chapter was carried out with support of the Brazilian Environmental Ministry in the ambit of the subprogram of the Pilot Program to Conserve the Brazilian Rain Forest (PP-G7), an international initiative approved and supported by the Group of Seven (G7) countries. The group of local farmers composed of Antonio Model, Rudimar Bilibio, Adroaldo Cardoso, Malquias Klein, Valdecir Steffen, Sérgio Weber, Mauri Martins and the brothers Paulo and Tobias Fernandes was critical to the investigation. Apart from kindly allowing information gathering on their properties and helping with the vegetation inventory, their intellectual participation was indispensable. The contribution of Martin Grings, at the time of the field work a biology student at Universidade Federal do Rio Grande do Sul (UFRGS), was also crucial to the investigation.

[2] Pero Vaz de Caminha, the chronicler on Cabral's fleet, wrote in his first letter to the King Dom Manuel after the "discovery" of Brazil: "Watching from the sea the land looks very extensive – we cannot see anything but land and trees. Until this moment we do not know if there is gold or silver, or any other thing of metal, or iron. However, the land itself has very fresh air, as the ones from Entre-Douro-e-Minho. Water is bounty and infinite…" (Author's translation). In spite of the Eurocentric perspective, the letter is considered the Brazilian "birth certificate" [Caminha 1500 (1963)].

immense properties of land were donated to nobles by the Portuguese crown through the *sesmaria* system (Silva 1996), and a labor force was created primarily composed of African slaves. According to Pádua (2002a), three main environmental aspects are associated with this model: a) a sense that natural resources available in the new colony were unlimited and ready to be explored; b) a destructive and exploitative attitude, justifying land-extensive and inappropriate technologies; and c) negligence with biological specificities and ecological imperatives. This model still has relevant influence on practices and mentalities related to Brazilian agriculture (Pádua 2002a).

An immediate outcome of this agricultural model was the destruction of tropical forests causing a considerable loss of biodiversity and drastic changes in ecosystem services. Territorial occupation led to significant habitat devastation and a complete modification of the landscape. Even today, with a growing concern worldwide about environmental impacts and their negative consequences, expansion of the agricultural frontier through a production model based on the triad *timber-cattle-monoculture* still persists, posing definitive threats to the integrity of Brazilian ecosystems (Fearnside 2001; Fearnside et al. 2004; Greenpeace 2006).

Yet, the majority of attempts to protect the last remnants of the Atlantic Forest domain, and eventually recover part of this ecosystem, seem to not be sufficient (Rylands et al. 2005; Tabarelli et al. 2005b). The solutions proposed by the government, and espoused by several environmental NGOs, are primarily based on the establishment of protected areas such as parks, ecological stations, and private reserves. Actually, the Brazilian Atlantic Forest is one of the regions in South America with the greatest number of strictly protected areas, and a considerable amount of resources are allocated for its conservation (Tabarelli et al. 2005b). However, a significant portion of the ecosystem is still not protected. Apart from the costs involved in setting up protected areas, and the legal struggle to satisfy different interests, such a conservational strategy holds an explicit secondary function to agriculture, at most, as buffer zones for core conservation areas.

The efficiency of protected areas in meeting a conservation agenda has been systematically questioned by several authors (Brandon 2001; Diegues 2004). One of the main arguments, advocated by those who are against such a strategy, is based on the equivocal concept of wilderness or untamed nature, where humans have no place (Gomez-Pompa et al. 1992; Sarkar 1999). Another caveat is the process where parks and reserves are established. In most of the cases, it is through top-down approaches where local populations are not consulted about the compulsory precincts on their territories. Apart from the political and social costs, this conservation model is always very expensive. Most of the time, it is only feasible with financial support from northern nations, multilateral institutions, and mega-NGOs (Diegues 2004).

Restrictions imposed by the Brazilian legislation on farming activities are another attempt to protect Atlantic Forest remnants. Through several juridical instruments such as the Forest Code from 1965, the Federal Decree number 750 from 1993, and the recently sanctioned law number 11,428, rural properties are required to set aside at least 20% of their total area as a forest reserve (*reserva legal*); steep slopes cannot be used for agricultural purposes; and river margins must be covered by gallery forests (Câmara 2003). However, given the fragility of governmental institutions and their difficulties enforcing these obligations, compliance with the law rarely happens. In reality, development plans proposed by the government very often clash with its own environmental legislation.

5.1.1 Environmental services

Notwithstanding the apparent conflict between farming activities and environmental protection, it is undeniable that agriculture should play a fundamental role in meeting conservation challenges (Power 1999; McNeely et al. 2003;

Vandermeer et al. 2007). Increasingly, there is a worldwide concern about the conservation aspects of farming activities and a shift to more public investments in agriculture that focus on the supplying environment services (Antle et al. 2006). Water quality enhancement, biodiversity and wildlife habitat protection, greenhouse gas mitigation, visual amenities and landscape preservation, pesticide reduction, and soil conservation are some of the positive externalities and public goods expected to be provided by agriculture.

Biodiversity

Specifically, several direct and indirect benefits derive from biodiversity and wildlife conservation. Within farming systems, agrobiodiversity is related to genetic diversity for crops and livestock, insect and disease resistance, soil health, and pollination, and it is an imperative for food security. Habitat for economically important species, improvement in the availability of water, recreation, and temperature regulation are aspects connected with ecosystem preservation. In general, ecosystem integrity has a cause-and-effect relationship with biodiversity (Pagiola et al. 1997; Thrupp 1998; Naeem et al. 1999).

Carbon sequestration

One mechanism to compensate for the emissions of greenhouse gases is the removal and storage of atmospheric carbon in the terrestrial biosphere. Hence, carbon uptake by agricultural systems, particularly by farming practices that incorporate the arboreal component, is relevant in a scenario to constrain global warming. A critical issue in this respect is to accurately measure the potential of those systems to sequester carbon, especially for nations committed to international agreements to reduce greenhouse gases (Fearnside et al. 1996; Brown 2002a; Albrecht et al. 2003; Graham 2003; Zhang et al. 2007).

Pesticide

A number of recent studies have demonstrated the deleterious effects of pesticides on the environment and human health (Meeker et al. 2004; Sattler et al. 2007). The continuous use of these substances can cause biodiversity loss, deterioration of natural habitats, pollution of ground and surface waters, and soil contamination (Descalzo et al. 1998; Meriles et al. 2006; Taylor et al. 2006). Farming systems that reduce or eliminate the use of agrotoxics can certainly play a major role in preventing adverse environmental impacts.

Historically, in Brazil, several traditional populations[3] composed of indigenous people, rubber tappers, *quilombolas*, *geraiseiros*, *caatingueiros*, *barranqueiros*, *caboclos*, *ribeirinhos*, *caiçaras*, and many others have been using the immeasurable agrobiodiversity and the natural resources in a sustainable manner (Arruda 1999; Begossi 1999; Begossi et al. 2000; Diegues 2004). More recently, some development projects with the explicit objective of promoting sustainable agricultural practices have been implemented in different regions of Brazil. Casting the original research question, the objective of this chapter is to analyze the farming practices that have been adopted by small farmers in the Torres Region, and to appraise the potential to promote the environmental services described above, specifically: a) biodiversity conservation, b) carbon sequestration, and c) pesticide reduction. Particularly, this chapter assesses the role of alternative agricultural production methods in the preservation of the Atlantic Forest.

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[3] The generic term "traditional population" adopted in this study aims to characterize segments of the Brazilian population that historically lived on the margins of economically dynamic centers. These populations adopted and developed a "rustic" culture, very much influenced by indigenous people, and escaped into places where land and natural resources were somewhat abundant, allowing the reproduction of their *modus vivendi* (Arruda 1999).

5.2 Methodology

Three major indicators were selected to assess the potential of ecological systems in provide environmental services. The first one, biodiversity, or more specifically, vegetal diversity, is directly related to the conceptual framework adopted in this investigation. Floristic composition and vegetational structure were the parameters utilized to assess the role played by the alternative systems in preserving the Atlantic Forest. Basically, the objective in adopting such parameters is to measure how similar in terms of plant composition – form and structure – are the alternative agricultural systems compared with two regional forest fragments previously investigated in the localities of Morrinhos do Sul (Jarenkow 1994) and Dom Pedro de Alcântara (Nunes 2001), thereafter Morrinhos and Dom Pedro, respectively. Carbon sequestration was the second indicator, given the increasing concern about global warming and the potential for such systems to deliver this service. Ten allometric equations were employed to calculate the potential for carbon fixation. Finally, the amount of chemical amendments (pesticides and synthetic fertilizers) utilized for conventional banana production in Southern Brazil was estimated, based on the recommendations of official research and extension services, and the potential benefit to the environment from production systems adopting alternative farming methods was evaluated.

5.2.1 Sampling procedures

Eight ecological banana plantations managed under agroforestry practices were chosen for the comparison, summing to 21.06 hectares of ecological systems in four different localities of the Torres region (Table 5.1). Based upon the experience of the author, who has been working in the region with small producers for more than ten years, the general criterion used to select the farmers was their potential to contribute to the objectives of the study. Specifically, the banana production systems selected were those where farmers had been managing under the general approach of agroforestry for at least five consecutive years, and where a substantial population of endemic vegetation (trees and shrubs) still existed.

The first step after selecting the systems and setting the days with the farmers for collecting the data, the first step was a floristic appraisal to determine plant species (trees, shrubs, and herbs) occurring on the plot. The survey was based on the walking (*caminhamento*) method described by Filgueiras et al. (1994). As the name suggests, the method consists of walking thorough the area to assess the occurrence of plant species, and when the inclusion of a new additional species becomes rare it means that sufficient sampling has been achieved (Filgueiras et al. 1994).

Table 5.1: Systems selected for the study, locality, area, and geographic information

System	Locality	Area (ha)	Geographic information		
			Latitude (S)	Longitude (W)	Altitude range (m)
Agricultural systems					
A	Três Cachoeiras	1.96	29º 25`	49º 53`	85.0 – 147.7
B	Dom Pedro	3.90	29º 25`	49º 53`	37.4 – 153.5
C	Mampituba	6.00	29º 15`	50º 00`	128.0 – 334.2
D	Morrinhos	2.00	29º 19`	49º 58`	80.9 – 181.3
E	Três Cachoeiras	0.76	29º 25`	49º 55`	58.8 – 120.8
F	Dom Pedro	3.74	29º 22`	49º 51`	142.9 – 60.7
G	Morrinhos	1.16	29º 20`	49º.57`	81.9 – 195.8
H	Morrinhos	1.54	29º 17`	49º 57`	88.6 – 129.4
Total area		21.06			
Forest fragments					
Nunes (2001)	Dom Pedro	2.5	29º 38`	49º 50`	30.0 (estimate)
Jarenkow (1994)	Morrinhos	1.0	29º 35`	49º 58`	440.0 – 480.0

Species identification was performed by combining farmer's knowledge with that of an expert, in this case a botanist with extensive experience in classifying

Atlantic Forest plants. For species not promptly identified by the specialist in the field, vegetative material was collected and sent to the botany laboratory at the Universidade Federal do Rio Grande do Sul (UFRGS) in Porto Alegre. Species classification was validated according to (Cronquist 1992), and further rectified following the rules of the Angiosperm Phylogeny Group – APG II (APG-II 2003).

A phytosociological inventory using the point-quarter sampling method was carried out to appraise plant community characteristics (Cottam et al. 1956; Smith 1990; Kent et al. 1992). Instead of demarcating fixed sampling units to collect the information, this method is based on establishing transects across the research area, and fixing randomly equidistant points along a selected line. For each point marked along a transect, four quadrants are drawn by visualizing a perpendicular grid line. In each quadrant, the tree that is closest to the center point and more than three meters height is selected, and the distance from the point is recorded (Figure 5.1). After that, the diameter at breast height (DBH) is measured and the species is identified (Cottam et al. 1956; Mueller-Dombois et al. 1974; Smith 1990; Kent et al. 1992). Also, the height is estimated through comparison using a three-meter bamboo stick placed beside the tree stem. These measurements were utilized to calculate the phytosociological parameters, as well as to estimate the potential of the system for carbon sequestration.

The point-quarter method was selected for this study given its simplicity and also because it is considered one of the most reliable procedures for sampling communities where individuals are widely distributed (Mueller-Dombois et al. 1974; Smith 1990). Another evident advantage, compared with standard plot sampling techniques, is its efficiency in terms of results obtained per time expended (Cottam et al. 1956; Bryant et al. 2005). One potential limitation of the method is the bias when plant distributions are aggregated or individuals are clumping (Mueller-Dombois et al.

1974; Bryant et al. 2005). However, considering the fact that the trees and shrubs in all the agroforestry systems selected for the study were randomly distributed, the analysis was not jeopardized.

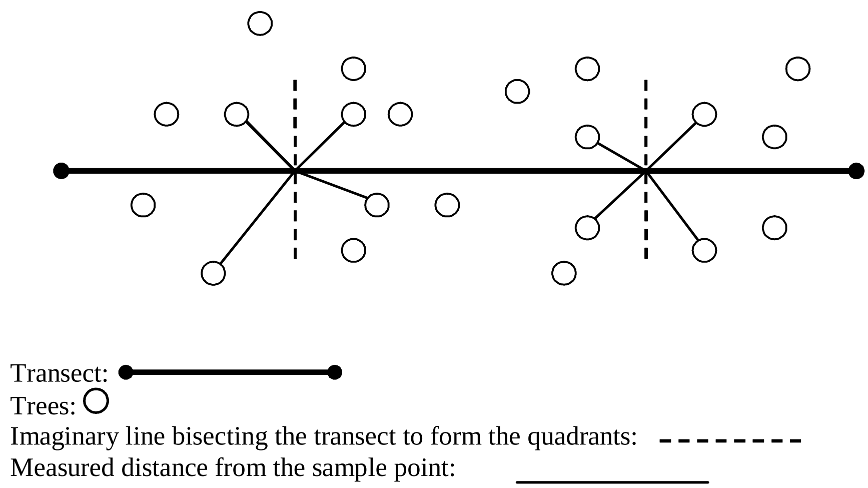

Figure 5.1: Diagram of the point-quarter sampling method (adapted from Smith 1990)

Taking into account that some of the banana production systems have a sparse population of native species, and/or the trees were not high enough to measure DBH, some adaptations to the method had to be made. In those cases young individuals (seedlings) were sampled and the DBH measurement was simply ignored. In a few situations it was not possible to find a tree or a seedling in the quadrant. Since the occurrence of such episodes was relatively rare, considering the number of sampled units, the overall quality of the data and the conclusions derived from this information remained rather robust.

The minimum DBH to include sampling species was determined as 5 centimeters. Such a procedure allowed the inclusion of plants that otherwise would not have been sampled. In addition, it permitted accurate inferences related to the dynamic aspects of plant population through the analysis of height and diameter distributions (Jarenkow 1994). The incorporation of such species also is justified for the purpose of a continuing evaluation process and future monitoring activities.

Sampling sufficiency was evaluated through the curve given by the cumulative number of collected species by sampled units (Mueller-Dombois et al. 1974). The curves were adjusted using the general regression equation $Y = a + b\log X$. Where:

Y = number of species;

a = coefficient;

b = coefficient;

X = number of sample units

5.2.2 Analytical procedures

5.2.2.1 Biodiversity

The information collected on the farmers' systems was compiled and compared with two phytosociological academic studies carried out in forest fragments located in the region a few years before this investigation. The first study, conducted by Jarenkow (1994), was part of his Ph.D. research where he investigated the structure and diversity of a plant community at Morrinhos (Table 5.1). Similarly, Nunes (2001) researched an Atlantic Forest remnant at Dom Pedro for a Master's degree program. The areas where both studies were conducted and the locations of the farmers' plots share the same physiographic characteristics.[4] Since the Atlantic Forest is recognizably a very fragmented ecosystem, the studies selected for the comparison purpose seem quite representative.

[4] Table 5.1 shows the geographic position (latitude, longitude, and altitude) of each of the systems. Considering that in tropical ecosystems there is a great variation according to altitudinal gradients, in which different species occupy particular ecological niches, information to determine precisely the geographic position is critical in studies of this nature.

Another source of secondary information utilized for comparative purposes was the Continuous Forest Inventory of Rio Grande do Sul (Inventário Florestal Contínuo do Rio Grande do Sul), an initiative coordinated by the University of Santa Maria, RS, and the Department of Forests and Protected Areas, State Secretary of Environment, Government of Rio Grande do Sul. The inventory is the result of a joint effort of several institutions to create an instrument for the qualitative and quantitative assessment of the state's forest resources. The inventory database has updated information about the main vegetal formations in Rio Grande do Sul (UFSM/SEMA-RS 2007).

In general, the study followed two basic analytical strategies to compare and evaluate the results. Initially, each of the farmers' systems was considered independently, that is, the role of the single production unit in promoting biodiversity conservation. A second comparison was performed considering the systems collectively, i.e., each of the single systems as a component of the whole unit. This second approach was an attempt to evaluate the production strategies in their role to preserve the landscape.

a) Floristic

All species collected in each of the banana production systems were listed for floristic composition analysis. Fundamentally, qualitative and quantitative aspects were inferred based on the incidence of species. Also, the occurrence of threatened species was appraised. The similarity of plant communities among the systems, and between each single system and the forest fragments, was assessed using the Jaccard and the Sørensen indexes. These indexes measure the similarity (or dissimilarity) through mathematical expressions based on the presence-absence relationship (Mueller-Dombois et al. 1974).

SIj = a / (a + b + c)

SIs = 2a / (2a + b + c)

Where:

SIj = Jaccard similarity index

SIs = Sørensen similarity index

a = number of common species

b = number of species on sample 1

c = number of species of sample 2

b) Phytosociological parameters

The study of plant communities, recognizing their patterns and compositions, is the aim of phytosociological analysis (Mueller-Dombois et al. 1974; Kent et al. 1992). Based on measurements of the sampled areas, the following phytosociological parameters were determined: Total Frequency (Ft), Relative Frequency (Fr), Total Density (Dr), Relative Density (Dr), Total Dominance (Do), Relative Dominance (Dt), Importance Value (IVI), and Relative Importance Value (IVIr).

Where:

Total Frequency (Ft) = % of sampled units on which species i occurs;

Relative Frequency (Fr) = (frequency of species i/Σ frequency for all species) * 100;

Total Density (Dt) = number of species i per hectare (#i/ha);

Relative Density (Dr) = (density of species i/Σ density for all species) ∗ 100;

Total Dominance (Do) = Density * Species Basal Area;

Relative Dominance (Dm) = (species basal area/Σ basal area of all species) * 100;

Importance Value (IVI) = Fr + Dr + Dm;

Relative Importance Value (IVIr) = (IVI / Σ IVI) * 100 ;

Species Basal Area (m^2/ha) = $p^2 * 4\pi$, (p = perimeter).

c) Specific Diversity

The alpha diversity, that is, the biodiversity found in a circumscribed area, was determined through the Shannon index. This index reflects the diversity of a particular plant community based on the number and frequency of species. The specific diversity estimations for plant communities in the banana systems were performed using a computer program called SPADE (Species Prediction And Diversity Estimation), developed by (Chao et al. 2003). The formula for the index (H) calculation is:

$H = -\Sigma(n_i/N)\log(n_i/N)$. Where:

n_i is the number of individuals of species I;

N is the total number of individuals of all species.

d) Dynamic Features

Some considerations about dynamic aspects of the plant communities in the banana production systems were drawn through the interpretation of height and diameter distribution histograms. These graphs also allowed comparisons with the forest fragments regarding vegetative structure.

5.2.2.2 Carbon sequestration

Tree biomass for each of the agroforestry banana production systems was calculated using ten different allometric equations, following methodological procedures adopted in similar studies (Brown et al. 1989; King 1996; Brown 1997; MacDicken 1997; Nelson et al. 1999; West et al. 1999; Chave et al. 2001; Ketterings et al. 2001; Brown 2002a; 2002b; Malhi 2002; Albrecht et al. 2003; Masera et al. 2003; Oelbermann et al. 2004; Zianis et al. 2004; Martins 2005). These different equations permitted some estimation of the potential of those systems to absorb and trap carbon. As long as the objective of this study was to analyze the incremental benefit of agroforestry systems in carbon sequestration, compared with conventional banana productions that are typically managed under monocropping style, just aboveground biomass was estimated. Precisely, this was the carbon trapped in the biomass of the trees that the ecological farmers have been cultivating mixed with the bananas, within the same area. For that reason, carbon absorbed in the soil and in the banana trees biomass was not assessed. In addition, it was considered that the amounts of carbon content in soil organic matter and the biomass produced by banana trees were very similar among the different production systems.[5] The general mathematical model utilized for the estimation is based on the power function $M = aD^b$ where a and b are the allometric coefficients previously determined by empirical data, and M is the aboveground tree dry biomass associated with a specific DBH, D (Brown et al. 1989; MacDicken 1997; Brown 2002a; Zianis et al. 2004; Martins 2005).

The following equations were utilized:

1. $Y = \exp[-1.996 + 2.32\ln(D)]$
2. $Y = \exp[-3.1141 + 0.9719\ln(D^2H)]$, where H is the tree height in meters and D is the DBH in centimeters
3. $M = aD^b$

3a) a = 0.1357 and b = 2.4128

3b) a = 0.1627 and b = 2.37

3c) a = 0.0811 and b = 2.4257

3d) a = 0.0671 and b = 2.5996

3e) a = 0.1657 and b = 2.4206

3f) a = 0.1081 and b = 2.5105

3g) a = 0.0934 and b = 2.5392

3h) a = 0.1681 and b = 2.3651

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[5] In fact, there is no noticeable discrepancy in banana biomass production among the different management systems in the region. Some soil samples that were analyzed also suggested that organic matter content is very similar among the regional banana production systems. Moreover, the use of ten different allometric equations prevents any possible bias and assures the validity of the findings.

5.2.2.3 Synthetic fertilizers and pesticides

The utilization of synthetic fertilizers and agrotoxics was analyzed according to the official recommendations for banana production in southern Brazil, and then projected to the area where banana is actually cultivated in this region (Table 5.2). More specifically, what would be the amount of chemical inputs going into the banana system in southern Brazil if all farmers followed the instructions of the conventional research units and official rural extension service? To allow a comparison, two other general situations based on different management systems were devised. In the first, the technologies adopted by farmers who have been implementing sustainable practices with some recommendations from the extension service provided by the local NGO were considered. Some farmers, in fact, do adopt this "ecological package" while others are more reluctant. A second situation was conceived based on the management practices adopted by farmers who had the best conventional production performance, in physical terms (Mg ha^{-1}), in the area of this investigation. Since the entire banana production is situated in areas that were originally covered by the Atlantic Forest, some inferences in terms of biodiversity conservation and carbon sequestration also are made.

Table 5.2: Area of banana production in southern Brazilian states (IBGE 2007)

State	Area (ha)
Espírito Santo	20,456
Rio de Janeiro	24,077
São Paulo	52,700
Paraná	9,849
Santa Catarina	31,164
Rio Grande do Sul	10,501
TOTAL	**148,747**

5.3 Results and discussion

5.3.1 Biodiversity

5.3.1.1 Sampling

The species accumulation curve, or collector's curve, is the cumulative number of species plotted over the number of sampled units (Hayek et al. 1997). An analysis of the curve obtained for the collection of systems (Figure 5.2) demonstrates that sufficiency sampling was reached, as the curve show a rapid accumulation of species in the first sampled units (steeply increasing curve), followed by fewer representatives of new species (curve becomes almost horizontal). This pattern indicates that the effort measurements suffice. The curve was adjusted by the regression equation Y = -24.65 + 18.59 Log(X); R^2 = 0.96.

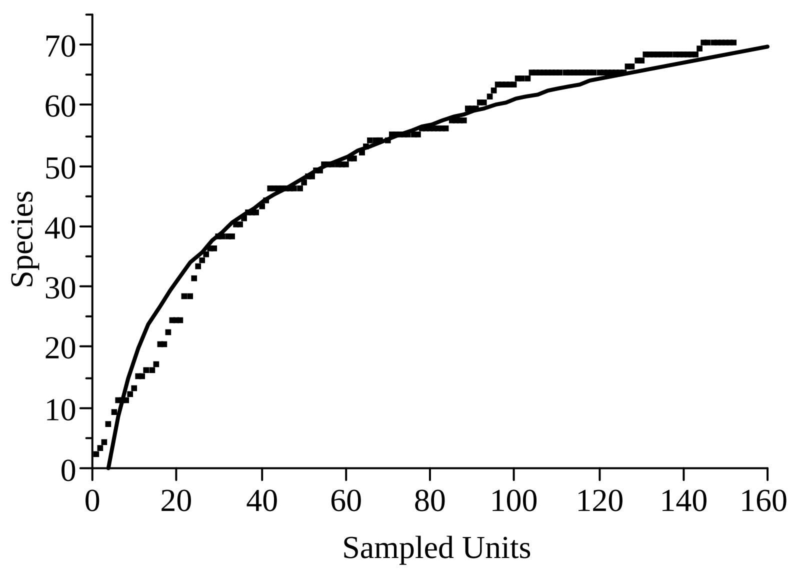

Figure 5.2: Collector's curve for the total sampled units

5.3.1.2 Floristic composition

The total number of species, or alpha diversity, appraised through the phytosociological inventories varied from 16 to 30 for each of the plots. Collectively, 70 species, 65 endemic and 5 exotic, belonging to 29 families were encountered. However, this number increased to 118 species and 37 families with the new individuals found through the walking survey. This is partially explained because shrubs were included in the latter method. Also, as some arboreal species have a sparse distribution over the area, they did not occur in the sampled units.

For the studies carried out in the forest fragments, Nunes (2001) found 82 trees species, distributed over 32 families at Dom Pedro, while Jarenkow (1994) sampled a total of 114 arboreal species in 44 families at Morrinhos. Such numbers are similar to the continuous forest inventory of Rio Grande do Sul, which found in the physiographic region of the Mampituba watershed, 44 families containing 108 species (UFSM/SEMA-RS 2007). These values are similar to the combination of banana agroforestry areas in terms of plant assemblages, suggesting the role that these systems might have in conservation. As the Atlantic Forest is a highly fragmented area, agricultural management practices that retain trees within the system, particularly in areas adjacent to forest patches, may contribute to the integrity of remnants (Cullen-Jr. et al. 2004; Schroth et al. 2004; Tabarelli et al. 2005a; Vandermeer et al. 2007).

The most numerous families in terms of species diversity were the Fabaceae and the Euphorbiaceae with six each, followed by the Moraceae and Meliaceae families with five species (Table 5.3). Six families were represented by two species, and 12 families were only characterized by a single species in the whole sampled community. Morrinhos and Dom Pedro seem to have different plant guilds with the Myrtaceae and Lauraceae being the most representative families (Jarenkow 1994; Nunes 2001). The same tendency was found in the continuous forest inventory as well as in other phytosociological studies carried in the Atlantic Forest (UFSM/SEMA-RS 2007).

Table 5.3: Distribution of tree species per families in the eight agroforestry systems

Family	Number of Species
RUBIACEAE	3
RUTACEAE	3
SAPINDACEAE	3
URTICACEAE	3
LAURACEAE	4
MYRTACEAE	4
SOLANACEAE	4
MELIACEAE	5
MORACEAE	5
EUPHORBIACEAE	6
FABACEAE	6

A quantitative analysis demonstrates that the most abundant species found in the banana systems is *Euterpe edulis* Martius (*palmiteiro*), from the Arecaceae family, with 126 individuals sampled, corresponding to approximately 20% of the total number of observations (Table 5.4). Also abundant were *Cecropia glaziovii* (Urticaceae), *Cedrela fissilis* (Meliaceae), and *cabralea canjerana* (Meliaceae) with 62, 49, and 42 individuals, respectively (Table 5.4). Likewise, *palmiteiro* was the most abundant species sampled in the study carried on by Nunes (2001). The Arecaceae and Meliaceae families were the families with the greater number of individuals, 135 and 96, respectively, as shown in Table 5.5.

Table 5.4: Families and species occurring in the phytosociological inventories for the eight agroforestry systems (A-H systems selected for the study; see Table 5.1)

FAMILY	SPECIES	SYSTEM A	B	C	D	E	F	G	H	TOTAL
ANACARDIACEAE	*S. terebinthifolius*	0	1	0	1	0	0	0	1	3
APOCYNACEAE	*A. olivaceum*	0	0	0	0	1	0	0	0	1
ARECACEAE	*E. edulis*	6	8	24	6	24	18	32	8	126
	S. romanzoffiana	4	1	0	1	0	0	3	0	9
ASTERACEAE	*P. axillaris*	0	0	0	0	1	0	0	0	1
BIGNONIACEAE	*J. micrantha*	2	10	5	3	0	0	0	0	20
	J. puberula	0	0	0	0	0	1	1	0	2
BORAGINACEAE	*C. trichotoma*	0	0	6	4	1	0	0	0	11
CANNABACEAE	*T. micrantha*	7	0	0	5	2	1	0	0	15
CUNONIACEAE	*L. ternata*	0	0	0	0	0	1	0	0	1
EBENACEAE	*D. inconstans*	0	0	0	1	0	0	0	0	1
ERYTHROXYLACEAE	*E. argentinum*	0	2	1	3	0	0	0	0	6
EUPHORBIACEAE	*A. glandulosa*	0	3	1	0	0	2	0	0	6
	A. triplinervia	3	0	2	1	0	1	0	0	7
	A. fordii	0	1	0	0	0	0	0	0	1
	G. concolor	0	0	3	0	0	0	0	0	3
	S. glandulatum	3	0	0	0	0	0	0	0	3
	T. rubrivenium	2	0	0	0	2	0	0	0	4
FABACEAE	*A. edwalli*	0	2	1	0	0	0	0	0	3
	C. leptophylla	0	0	1	0	0	0	0	0	1
	I. marginata	1	0	2	0	0	0	0	0	3
	I. sessilis	0	1	0	0	0	0	0	0	1
	L. cultratus	1	0	0	0	0	0	0	0	1
	M. stipitatum	0	1	2	9	1	14	2	1	30

Table 5.4 (Continued)

FAMILY	SPECIES	SYSTEM								TOTAL
		A	B	C	D	E	F	G	H	
LAURACEAE	*N. lanceolata*	0	2	0	0	3	0	4	6	15
	N. megapotamica	0	0	1	0	1	0	0	0	2
	N. oppositifolia	0	0	0	0	0	0	0	1	1
	O. puberula	1	3	0	0	0	0	0	0	4
MAGNOLIACEAE	*T. ovata*	0	0	0	0	0	0	1	0	1
MALVACEAE	*L. divaricata*	0	2	0	0	0	2	0	0	4
	P. grandiflorus	1	0	1	0	0	0	0	1	3
MELIACEAE	*C. canjerana*	15	3	2	3	4	1	14	0	42
	C. fissilis	1	7	4	17	1	3	5	11	49
	G. macrophylla	0	0	0	1	0	1	0	0	2
	M. azedarach	0	2	0	0	0	0	0	0	2
	T. lepidota	1	0	0	0	0	0	0	0	1
MORACEAE	*B. lactescens*	0	0	0	0	1	0	0	0	1
	F. adhatodifolia	4	0	4	1	0	0	2	1	12
	F. glabra	1	0	0	0	0	0	1	0	2
	F. organensis	0	0	0	1	0	0	0	0	1
	M. tinctoria	0	0	0	1	0	0	0	0	1
MYRSINACEAE	*M. coriacea*	2	1	1	1	3	10	1	1	20
	M. guianensis	1	1	0	1	1	0	0	5	9
MYRTACEAE	*E. involucrata*	0	0	0	0	1	0	0	0	1
	E. pyriformis	0	0	0	0	0	0	1	0	1
	E. uniflora	0	0	0	0	0	0	1	0	1
	P. cattleyanum	0	0	1	0	4	0	0	0	5
	P. myrtifolia	0	1	0	0	0	0	0	0	1

Table 5.4 (Continued)

FAMILY	SPECIES	SYSTEM								TOTAL
		A	B	C	D	E	F	G	H	
PHYLLANTHACEAE	*H. alchorneoides*	0	0	0	0	1	0	2	2	5
RHAMNACEAE	*C. glandulosa*	4	0	4	1	0	10	0	0	19
	H. dulcis	0	1	1	0	0	0	0	1	3
ROSACEAE	*E. japonica*	0	3	0	0	0	1	1	1	6
	P. myrtifolia	0	1	0	0	0	0	0	0	1
RUBIACEAE	*C. arabica*	0	1	2	0	0	0	0	0	3
	C. hexandra	0	1	0	0	0	0	0	0	1
	R. armata	0	1	0	0	0	0	0	0	1
RUTACEAE	*C. reticulata*	0	1	1	0	0	0	1	1	4
	C. sinensis	0	1	0	0	0	0	0	1	2
	Z. rhoifolium	0	0	1	1	0	0	0	3	5
SALICACEAE	*C. sylvestris*	0	0	0	0	0	0	0	1	1
SAPINDACEAE	*A. edulis*	0	0	0	1	0	1	1	0	3
	C. vernalis	0	4	1	6	0	0	1	0	12
	M. elaeagnoides	0	1	0	0	0	0	0	0	1
SOLANACEAE	*C. intermedium*	1	0	0	1	0	0	0	0	2
	S. mauritianum	0	0	0	2	0	0	0	0	2
	S. pseudoquina	2	1	1	2	7	0	0	1	14
	V. brevifolia	0	0	1	0	0	0	0	0	1
URTICACEAE	*B. caudata*	0	1	0	0	0	0	0	0	1
	C. glaziovii	7	12	1	6	19	11	6	0	62
	C. pachystachia	9	0	0	0	0	1	0	1	11
VERBENACEAE	*C. myrianthum*	1	0	2	0	2	1	0	0	6

Table 5.5: Distribution of individuals per families in the eight agroforestry systems

Family	Number of individuals
ARECACEAE	135
BIGNONIACEAE	22
EUPHORBIACEAE	24
FABACEAE	39
LAURACEAE	22
MELIACEAE	96
MYRSINACEAE	29
RHAMNACEAE	22
SOLANACEAE	19
URTICACEAE	74
OTHERS	123

The floristic similarity among the eight systems, estimated by the Jaccard and Sørensen indexes, resulted in a range of similarity values between 0.072 and 0.508 for the first, and between 0.134 and 0.674 for the latter (Table 5.6). These numbers reveal that, in general, the banana agroforestry systems are similar among themselves, differing from the forest fragments. However, the combination of systems compared collectively with the fragments shows some analogous composition. Such a pattern was expected as the agroforestry systems are relatively young, compared to the fragments. Moreover, farmers have their preferences in selecting the trees to manage, as demonstrated by the abundance of *palmito* trees and species of the Meliaceae family.

Table 5.6: Jaccard and Sørensen indixes for eight banana agroforestry systems (A-H systems selected for the study; see Table 5.1) compared to those from Jarenkow (1994) and Nunes (2004)

Lower triangle: Jaccard; upper triangle: Sørensen

	A	B	C	D	E	F	G	H	Total	Nunes	Jarenkow
A		0.559	0.444	0.472	0.525	0.519	0.418	0.436	0.416	0.159	0.138
B	0.388		0.368	0.462	0.558	0.437	0.412	0.381	0.468	0.185	0.288
C	0.286	0.225		0.484	0.505	0.500	0.382	0.412	0.595	0.136	0.134
D	0.309	0.300	0.319		0.556	0.505	0.416	0.523	0.534	0.146	0.142
E	0.356	0.387	0.338	0.385		0.459	0.459	0.521	0.578	0.214	0.245
F	0.350	0.279	0.333	0.338	0.298		0.418	0.411	0.595	0.136	0.134
G	0.264	0.260	0.236	0.263	0.298	0.264		0.449	0.674	0.211	0.218
H	0.279	0.235	0.260	0.354	0.352	0.259	0.289		0.561	0.171	0.174
Total	0.263	0.305	0.424	0.364	0.407	0.424	0.508	0.390		0.250	0.345
Nunes	0.087	0.102	0.073	0.079	0.120	0.073	0.118	0.093	0.143		0.469
Jarenkow	0.074	0.168	0.072	0.076	0.140	0.072	0.123	0.095	0.208	0.307	

One of the main findings, which accentuates the role of such systems in preserving biodiversity, is the presence of endangered and vulnerable species. According to the state decree number 42,099 (January 1st 2003), in Rio Grande do Sul, the following species have the status of vulnerable: *Rollinia sylvatica*, *Jacaranda puberula*, *Nectandra lanceolata*, *Talauma ovata*, *Pseudobombax grandiflorus*, *Colubrina glandulosa*, *Psychotria carthagenensis*, and *Verbenoxylom reitzii*. *Euterpe edulis*, *Ocotea odorifera*, *Lafoensia pacari*, *Brosimum lactescens*, and *Ficus glabra* are considered endangered species. Some evidence suggests that the maintenance of trees on farms plays a significant role in *in situ* conservation, preserving genetic viability of many native trees species, conserving particular genotypes, holding minimum viable populations, and working as an alternative habitat for pollinators and seed dispersers (Vandermeer et al. 1997; Harvey et al. 1998; Boshier 2004)

5.3.1.3 Phytosociological parameters

The number of trees per hectare, total density, varied in the banana systems from 459.2 to 1,501.3 individuals (Table 5.7). When all sampled units were considered as a single system, the total density was 816.8. Such densities are considered low, compared with those found by Jarenkow (1994) for Morrinhos, and Nunes (2001) for Dom Pedro, which were 2,822 and 2,812 trees per hectare, respectively. This difference was understandable, as a higher tree density would preclude a reasonable banana production. A similar study of agroforestry systems in Indonesia, where the authors investigated the role of traditional farming practices in promoting environmental conservation and agricultural development, found a tree density ranging from 270 to 477 trees per hectare in the plots sampled (Garcia-Fernandez et al. 2003).

Table 5.7: Total tree density for the eight agroforestry systems (A-H systems selected for the study; see Table 5.1)

Agroforestry system	Tree density
A	1028.3
B	627.3
C	520.4
D	690.3
E	459.2
F	1501.3
G	663.2
H	1408.1
Total	816.8

Species with higher populations were, in general, those with the highest importance values (IVI). *Euterpe edulis* (*palmiteiro*) and *Cecropia glaziovii* (*embaúba*) were the two most important species, confirming empirical evidence from the field work (Table 5.8). Also scoring a high IVI were *Cedrela fissilis* (*cedro*) and *Cabralea canjerana* (*canjerana*). Similarly, in Morrinhos and Dom Pedro, *Euterpe edulis* was also one of the most important species (Jarenkow 1995; Nunes 2001).

Table 5.8: Importance value (IVI) relative to the species found in the eight agroforestry systems

Species	Importance value
E. edulis	49.6
C. glaziovii	39.6
C. fissilis	20.0
C. canjerana	17.7
C. glandulosa	12.0
M. stipitatum	9.9
J. micrantha	9.0
C. pachystachia	7.8
N. lanceolata	7.7
C. vernalis	7.6
S. romanzoffiana	6.9
M. coriacea	6.6
T. micrantha	6.5
M. tinctoria	6.5
S. pseudoquina	5.9

General results (Table 5.9) indicate that the majority of species in the systems have very low relative frequencies, in most of the cases less than 1%. This is consistent with the findings of Jarenkow (1994) and Nunes (2001) suggesting a similar pattern in terms of plant distributions. Moreover, farmers have preferences for species of plants that they understand as useful to keep inside their banana systems. The species with highest frequencies were *Euterpe edulis* and *Cecropia glaziovii* (Table 5.10). The first is characteristically from the Atlantic Forest, and has been increasingly recognized as a keystone[6] species with a crucial role in the forest conservation (Orlande et al. 1996; Simberloff 1998; Reis et al. 2000b; Fantini et al. 2007). *Cecropia*, on the other hand, is typically a pioneer species, appearing in abandoned areas, which in some way indicates the early development stages of the systems.

[6] Keystone species play a fundamental role in ecosystems' integrity. The suppression of such species may cause a detrimental effect disproportionate to its abundance, or even a collapse of the whole system (Simberloff 1998). Specifically, in the case of *Euterpe edulis*, the fatty and high protein content of its fruits is an importance source of food for many insects, birds, and small mammals (Reis et al. 2000; Fantini et al. 2007).

Table 5.9: Phytosociological parameters for the eight agroforestry systems (ni: number of individuals; no: occurrence in the sampled units; Ft: total frequency; Fr: relative frequency; Dt: total density; Dr: relative density; To: total dominance; ABM: species basal area mean; Dm: relative dominance; Abte: total species basal area; IVI: importance value; IVIr: relative importance value; see section 5.2.2.1, item b)

Species	ni	no	Ft	Fr	Dt	Dr	To	ABM	Dm	Abte	IVI	IVIr
Euterpe edulis	126	74	48.68	15.29	170.11	20.72	1.15	0.01	13.56	0.85	49.57	16.52
Cecropia glaziovii	62	46	30.26	9.50	83.71	10.20	1.68	0.02	19.85	1.24	39.56	13.19
Cedrela fissilis	49	41	26.97	8.47	66.15	8.06	0.29	0.00	3.44	0.22	19.97	6.66
Cabralea canjerana	42	30	19.74	6.20	56.70	6.91	0.39	0.01	4.61	0.29	17.72	5.91
Colubrina glandulosa	19	14	9.21	2.89	25.65	3.13	0.51	0.02	6.03	0.38	12.04	4.01
Machaerium stipitatum	30	22	14.47	4.55	40.50	4.93	0.24	0.01	0.37	0.02	9.85	3.28
Jacaranda micrantha	20	18	11.84	3.72	27.00	3.29	3.34	0.12	1.97	0.12	8.98	2.99
Cecropia pachystachia	11	11	7.24	2.27	14.85	1.81	0.32	0.02	3.76	0.24	7.84	2.61
Nectandra lanceolata	15	15	9.87	3.10	20.25	2.47	0.18	0.01	2.10	0.13	7.66	2.55
Cupania vernalis	12	11	7.24	2.27	16.20	1.97	0.28	0.02	3.32	0.21	7.57	2.52
Syagrus romanzoffiana	9	9	5.92	1.86	12.15	1.48	0.30	0.02	3.53	0.22	6.87	2.29
Myrsine coriacea	20	16	10.53	3.31	27.00	3.29	0.04	0.00	0.05	0.00	6.65	2.22
Trema micrantha	15	11	7.24	2.27	20.25	2.47	0.15	0.01	1.77	0.11	6.51	2.17
Maclura tinctoria	1	1	0.66	0.21	1.35	0.16	0.02	0.01	6.09	0.38	6.46	2.15
Solanum pseudoquina	14	14	9.21	2.89	18.90	2.30	0.06	0.00	0.75	0.05	5.95	1.98
Citharexylum myrianthum	6	5	3.29	1.03	8.10	0.99	0.33	0.04	3.84	0.24	5.86	1.95
Alchornea triplinervia	7	7	4.61	1.45	9.45	1.15	0.26	0.03	3.02	0.19	5.62	1.87
Ficus adhatodifolia	12	11	7.24	2.27	16.20	1.97	0.10	0.01	1.20	0.08	5.44	1.81
Cordia trichotoma	11	9	5.92	1.86	14.85	1.81	0.11	0.01	1.35	0.08	5.02	1.67
Jacaranda puberula	2	2	1.32	0.41	2.70	0.33	0.03	0.01	4.09	0.26	4.83	1.61
Myrsine guianensis	9	8	5.26	1.65	12.15	1.48	0.12	0.01	1.37	0.09	4.50	1.50
Alchornea glandulosa	6	6	3.95	1.24	8.10	0.99	0.10	0.01	1.16	0.07	3.38	1.13

Table 5.9 (Continued)

Species	ni	no	Ft	Fr	Dt	Dr	To	ABM	Dm	Abte	IVI	IVIr
Zanthoxylum rhoifolium	5	5	3.29	1.03	6.75	0.82	0.11	0.02	1.33	0.08	3.19	1.06
Citrus sinensis	2	2	1.32	0.41	2.70	0.33	0.16	0.06	1.95	0.12	2.69	0.90
Eryobothria japonica	6	5	3.29	1.03	8.10	0.99	0.05	0.01	0.62	0.04	2.64	0.88
Citrus reticulata	4	4	2.63	0.83	5.40	0.66	0.10	0.02	1.12	0.07	2.61	0.87
Hyeronima alchorneoides	5	5	3.29	1.03	6.75	0.82	0.10	0.02	0.74	0.05	2.60	0.87
Psidium cattleyanum	5	3	1.97	0.62	6.75	0.82	0.07	0.01	0.85	0.05	2.29	0.76
Erythroxylum argentinum	6	6	3.95	1.24	8.10	0.99	0.00	0.00	0.00	0.00	2.23	0.74
Tetrorchidium rubrivenium	4	4	2.63	0.83	5.40	0.66	0.06	0.01	0.66	0.04	2.15	0.72
Ocotea puberula	4	4	2.63	0.83	5.40	0.66	0.04	0.01	0.49	0.03	1.97	0.66
Talauma ovata	1	1	0.66	0.21	1.35	0.16	0.12	0.09	1.45	0.09	1.83	0.61
Inga marginata	3	3	1.97	0.62	4.05	0.49	0.03	0.01	0.63	0.04	1.74	0.58
Pseudobombax grandiflorus	3	3	1.97	0.62	4.05	0.49	0.05	0.01	0.61	0.04	1.72	0.57
Luehea divaricata	4	4	2.63	0.83	5.40	0.66	0.02	0.00	0.05	0.00	1.53	0.51
Sapium glandulatum	3	3	1.97	0.62	4.05	0.49	0.03	0.01	0.34	0.02	1.45	0.48
Allophylus edulis	3	3	1.97	0.62	4.05	0.49	0.02	0.00	0.23	0.01	1.35	0.45
Schinus terebinthifolius	3	3	1.97	0.62	4.05	0.49	0.01	0.00	0.15	0.01	1.26	0.42
Albizia edwalli	3	3	1.97	0.62	4.05	0.49	0.00	0.00	0.00	0.00	1.11	0.37
Gymnanthes concolor	3	3	1.97	0.62	4.05	0.49	0.00	0.00	0.00	0.00	1.11	0.37
Hovenia dulcis	3	3	1.97	0.62	4.05	0.49	0.00	0.00	0.00	0.00	1.11	0.37
Coffea arabica	3	2	1.32	0.41	4.05	0.49	0.00	0.00	0.02	0.00	0.93	0.31
Nectandra megapotamica	2	2	1.32	0.41	2.70	0.33	0.00	0.00	0.02	0.00	0.77	0.26
Cestrum intermedium	2	2	1.32	0.41	2.70	0.33	0.00	0.00	0.00	0.00	0.74	0.25
Ficus glabra	2	2	1.32	0.41	2.70	0.33	0.05	0.02	0.00	0.00	0.74	0.25
Guarea macrophylla	2	2	1.32	0.41	2.70	0.33	0.00	0.00	0.00	0.00	0.74	0.25
Melia azedarach	2	2	1.32	0.41	2.70	0.33	0.00	0.00	0.00	0.00	0.74	0.25

Table 5.9 (Continued)

Species	ni	no	Ft	Fr	Dt	Dr	To	ABM	Dm	Abte	IVI	IVIr
Solanum mauritianum	2	2	1.32	0.41	2.70	0.33	0.00	0.00	0.00	0.00	0.74	0.25
Inga sessilis	1	1	0.66	0.21	1.35	0.16	0.01	0.01	0.35	0.02	0.72	0.24
Casearia sylvestris	1	1	0.66	0.21	1.35	0.16	0.02	0.02	0.29	0.02	0.66	0.22
Nectandra oppositifolia	1	1	0.66	0.21	1.35	0.16	0.02	0.01	0.22	0.01	0.60	0.20
Lamanonia ternata	1	1	0.66	0.21	1.35	0.16	0.01	0.01	0.22	0.01	0.59	0.20
Prunus myrtifolia	1	1	0.66	0.21	1.35	0.16	0.01	0.01	0.16	0.01	0.54	0.18
Lonchocarpus cultratus	1	1	0.66	0.21	1.35	0.16	0.01	0.01	0.11	0.01	0.48	0.16
Piptocarpha axillaris	1	1	0.66	0.21	1.35	0.16	0.01	0.01	0.10	0.01	0.47	0.16
Trichilia lepidota	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.02	0.00	0.39	0.13
Eugenia involucrata	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.01	0.00	0.38	0.13
Aleurites fordii	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Aspidosperma olivaceum	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Boehmeria caudata	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Brosimum lactescens	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Cassia leptophylla	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Coutarea hexandra	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Dyospiros inconstans	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Eugenia pyriformis	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Eugenia uniflora	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Ficus organensis	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Matayba elaeagnoides	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Randia armata	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12
Vassobia brevifolia	1	1	0.66	0.21	1.35	0.16	0.00	0.00	0.00	0.00	0.37	0.12

Table 5.10: Relative frequency of trees found in the eight agroforestry systems

Species	Relative frequency
Euterpe edulis	15.3
Cecropia glaziovii	9.5
Cedrela fissilis	8.5
Cabralea canjerana	6.2
Machaerium stipitatum	4.5
Jacaranda micrantha	3.7
Nectandra lanceolata	3.1
Colubrina glandulosa	2.9
Cecropia pachystachia	2.3
Cupania vernalis	2.3

5.3.1.4 Specific diversity

Specific diversity determined through the Shannon index varied among the banana production systems. The highest score for an individual system was 2.84 and the lowest 2.05 (Table 5.11). Nunes (2001) found an index of 3.55 for Dom Pedro, and Jarenkow (1994) determined a Shannon index of 3.67 for Morrinhos, which is one of the highest for similar studies in areas of Atlantic Forest (Jarenkow 1994).

Table 5.11: Shannon diversity index[7] for the eight agroforestry systems (A-H systems selected for the study; see Table 5.1)

System	Shannon
A	2.79
B	2.25
C	2.84
D	2.62
E	2.27
F	2.80
G	2.28
H	2.05
Total	3.17

These numbers indicate that agroforestry systems might be playing a role in preserving the diversity, considering that the index for the total area is an intermediary number between the values found for the systems analyzed individually and the forest fragments. In addition, some of the systems have a relatively high score, which emphasizes a conservation function. As the Atlantic forest is a highly fragmented ecosystem, as previously mentioned, farming practices that incorporate native species are certainly important in helping to preserve the last remnants (Murniati et al. 2001; Huang et al. 2002; Cullen-Jr. et al. 2004; Laurence et al. 2004; Schroth et al. 2004; Nair 2007; Vandermeer et al. 2007).

5.3.1.5 Dynamic Features

The great majority of sampled species have diameters between 5 and 15 centimeters (Table 5.12). In fact, a significant number of individuals were not included because the stem size was less than the minimum value established (5 cm). Only 25 trees, out of 608 sampled, had a diameter greater than 25 cm.

[7] It should be reinforced that bananas are usually cultivated under monocropping, and therefore the Shannon diversity index of such systems is 0. This aspect accentuates even more the role of banana agroforestry system in preserving remnants of the Atlantic Forest.

Table 5.12: Number of individuals per diameter class (cm) found in the eight agroforestry systems

Diameter Class	Number of individuals
5-10	104
10-15	104
15-20	61
20-25	37
> 25	25

Similarly, in terms of tree height, there is a preponderance of individuals less than three meters high (Table 5.13). Approximately 15% of the trees were more than 10 meters tall, with many ranging between three and eight meters high. Such figures are somewhat different from the findings of Jarenkow (1994), where most of the trees heights were between six and ten meters. In the forest fragment at Dom Pedro, trees were distributed in deferent strata, but most of the species were between seven and twelve meters tall (Nunes 2001).

These data reveal that compared with mature forest fragments most of the agroforestry systems are in their initial stages of development. Also, banana tolerates a certain amount of shade, but systems totally covered by trees would have their production hindered. In reality, some farmers reported that in shaded banana systems, the fruits do not turn yellowish when ripe, which limits their commercial value.

Table 5.13: Number of individuals per height (m) found in the eight agroforestry systems

Height class	Number of individuals
< 1	121
1-2	60
2-3	80
3-4	47
4-5	44
5-6	44
6-7	44
7-8	39
8-9	29
9-10	15
>10	82

Another problem for farmers implementing agroforestry systems in areas of the Atlantic Forest is, paradoxically, legislation that protects the ecosystem. The Forest Code prohibits the cutting of trees taller than three meters. Therefore, if farmers allow native trees to grow inside their banana plantations, they will be unable to legally harvest the timber or even to manage the vegetation.

This situation shows the incongruence of some environmental legislation. Farmers are allowed to cultivate banana in immense monoculture plantations and spray pesticides to kill regenerating vegetation. Even endangered species such as *palmito* (*Euterpe edulis*), which commonly grows spontaneously in banana areas, can be removed when it is in its initial stage. But if banana producers cultivate native species inside banana plots, they will probably be forbidden to manage the plants. Actually, a number of organic farmers mentioned that they did not plant trees in their systems to prevent legal problems with the environmental protection agency.

5.3.2 Carbon sequestration

The total amount of carbon sequestered aboveground varied among the systems and according to the allometric equation utilized. Such numbers ranged from 4.1 to 123.9 Mg ha^{-1} (Table 5.14). This discrepancy is explained by the difference in maturity among the agroforestry systems, and the equations employed to estimate carbon based on tree biomass. In spite of such differences, these values are within the range of carbon sequestered in other tropical agroforestry systems, determined in analogous studies (Brown 2002b; Albrecht et al. 2003; Oelbermann et al. 2004). Moreover, taking into consideration that there is no specific equation available to estimate the aboveground carbon for this region, the values can be deemed as quite acceptable.

Land-use systems based on agroforestry have the potential to make a significant, if limited, contribution to mitigating and reducing greenhouse gas emissions (Niles et al. 2001; Albrecht et al. 2003). Taking the most conservative estimation of carbon sequestered in the banana agroforestry systems, i.e., 4.1 Mg ha^{-1}, and multiplying by the total area under banana plantation in southern Brazil, 148,747 ha, yields a value of approximately 600,000 tons of carbon.[8] Furthermore, it is expected that in these systems the additional benefits of increasing soil organic matter contents and reducing the use of petroleum-based inputs, will also contribute to mitigating carbon release.

[8] Certainly, it can not be expected that all banana producers in the southern region of Brazil will adopt agroforestry practices. However, considering that the value used for the estimation was the lowest, and that the carbon trapped belowground was not computed, such a value appears realistic for an intellectual exercise.

Table 5.14: Aboveground carbon sequestered in the eight agroforestry systems according to ten allometric equations (A-H systems selected for the study; see Table 5.1)

System	Allometric Equations (tons carbon ha^{-1})									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	40.6	33.8	53.0	56.2	32.9	45.2	66.2	56.1	52.7	57.2
B	20.3	16.9	26.5	28.1	16.4	22.6	33.1	28.0	26.3	28.6
C	10.2	8.4	13.3	14.0	8.2	11.3	16.6	14.0	13.2	14.3
D	5.1	4.2	6.6	7.0	4.1	5.7	8.3	7.0	6.6	7.2
E	25.4	25.9	33.2	35.2	20.6	28.4	41.5	35.2	33.1	35.9
F	16.9	8.4	22.5	23.6	14.0	19.7	28.1	24.2	22.8	24.1
G	36.4	34.9	47.7	50.5	29.6	40.7	59.6	50.5	47.5	51.4
H	67.3	63.2	98.2	98.8	61.9	105.7	123.9	117.3	114.2	100.1
Average	27.8	24.5	37.6	39.2	23.5	34.9	47.2	41.5	39.6	39.8

Agricultural carbon sequestration might benefit farmers as an alternative source of income (Antle et al. 2007; Perez et al. 2007). Under the Kyoto protocol, one of the Clean Development Mechanisms (CDM) is the carbon market where carbon offsets can be negotiated (UNFCCC 2007). Based on the phytosociological inventory undertaken in the studied systems, and considering the time that these areas have been managed under agroforestry methods, it is reasonable (if not conservative) to expect a carbon fixation of approximately 0.4 Mg ha^{-1} per year. This figure is consistent with related studies for humid tropical forests (Phillips et al. 1998; Chave et al. 2001; Martins 2005). Assuming a central value of U$ 5.00 per ton of carbon (Niles et al. 2001),[9] 600,000 tons of carbon potentially sequestered if some agroforestry practices were adopted in areas of banana plantations in southern Brazil (148,747 ha) would represent an asset of about three million US dollars over a time-span of ten years.

Evidently, there are several costs involved in developing institutional capacity to implement carbon offset mechanisms (Perez et al. 2007), and not many studies have evaluated the potential for smallholders to participate in carbon contracts (Niles et al.

[9] The value of carbon stocks varies as any other commodity. The use of a (conservative) central value of U$ 5.00 follows the criteria adopted in similar studies (Martins 2005).

2001; Antle et al. 2007). However, with the aggravation of global warming and the uncertainties of the negative effects, it is expected that every available possibility to mitigate greenhouse gases will have to be explored. Additionally, carbon compensation can represent an extra income source for developing countries if appropriate changes in land-use are promoted (Niles et al. 2001). This also can constitute a promising strategy to revitalize some rural areas, particularly impoverished ones (Antle et al. 2007; Perez et al. 2007).

5.3.3 Chemical inputs – synthetic fertilizers and pesticides[10]

Based on the general technical recommendations of EPAGRI (*Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina S.A.*),[11] the research and rural extension agency of Santa Catarina state, southern Brazil, to fertilize one hectare of banana[12] in one year the following quantity of macronutrients are required: 54 kg of N, 45 kg of P_2O_5, and 99 kg of K_2O (Lichtemberg et al. 2002). These values are equivalent to 500 kg of N-P-K fertilizer (10-6-20 formulation), and approximately 1,500 kg of poultry manure. In addition, 500 kg of lime per year is also recommended. In terms of agrochemicals, the main inputs are mineral oil and fungicides to control

[10] It should be noted that the methodology adopted for this section, i.e., to project the amount of exogenous inputs (synthetic fertilizers and pesticides) based on official recommendations to the total area of banana cultivated in southern Brazil, serves the exclusive purpose of a theoretical exercise. It is recognized that there is a substantial variation among the banana management systems (soil types, geographic localization, weather conditions, access to technologies, information, marketing issues, etc.), which inevitably affects the use of such production inputs.

[11] The research and extension agency of Santa Catarina state, EPAGRI, is one of the most recognized services of this type in Brazil. They have done extensive work on the banana culture, and the information utilized as a background for this section was based on a compilation of the main technical recommendations for the crop, prepared by a team of EPAGRI's experts as resource material for the staff of extension agents and other practitioners.

[12] These general recommendations are based on a productivity of 15,000 kg ha^{-1} per year of banana (variety *enxerto*, group AAB), for a medium fertile soil, and under ordinary weather conditions. The recommendation for fertilizer application follows the ROLAS method (*Rede Oficial de Laboratórios de Análise de Solo e Tecido Vegetal dos Estados do Rio Grande do Sul e de Santa Catarina*), which considers the available nutrients in the soil system and the total quantity exported by the crop (Lichtemberg et al. 2002) .

sigatoka disease, and herbicides. A very conservative estimation is to assume 30 L of mineral oil, 1 L of fungicide, and 1 L of herbicide per ha per year.

On the other hand, Centro Ecológico, the local NGO working with ecological farmers, recommends 2,000 kg of poultry manure or compost, 20 L of mineral oil associated with 20 L of biofertilizer, 300 kg of lime, and 50 kg of rock phosphate per year for one hectare of banana (CE 2000). Such values are comparable with the amount of production inputs used by ecological producers during the agricultural year considered in this investigation. On average, they applied 2,087 kg of poultry manure, 26 L of mineral oil, 15 l of biofertilizer, and 31 kg of rock phosphate for a mean productivity of 9,200 kg ha^{-1}.

The three-best conventional farmers harvested an average of 14,659 kg ha^{-1} of banana, which is very similar to the productivity considered by EPAGRI to determine the amount of fertilizers and pesticides applied to one hectare of banana. The averages of inputs that they have utilized to reach such a production on one hectare were: 0.6 L of fungicide, 0.9 L of herbicide, 37.7 L of mineral oil, 600 kg of fertilizers (N-P-K), 2,000 kg of lime, 2,200 kg of cattle manure, and 1,600 kg of lime. Such values are consistent with the technical recommendations of the state rural extension service. If such reference values were projected to the equivalent area where banana is actually cultivated in southern Brazil, i.e., 148,747 ha,[13] it would be required the total amount of chemical inputs summarized in Table 5.15.

Evidently, the amount of external production inputs required in both conventional systems, official recommendation and conventional farmers, is much higher than in the “ecological package.” Rural extension services, in general recommend the massive use of external inputs to increase physical productivity.

[13] The major Latin American countries in banana export are Ecuador, Colombia, and Costa Rica, with a harvested area corresponding to 221,085, 64,794, and 42,700 ha, respectively. Brazil is the first in the world in terms of harvested area, with 504,074 ha (FAO 2007).

However, the negative externalities of such a production strategy are rarely considered. As previously mentioned, some farmers in the region have complained about health problems since they started spraying pesticides.[14] This is consistent with innumerous studies reporting the negative effects of chemical substances in health and nature (Guillette et al. 1998; Altieri 2000; Guillette 2000a; Guillette 2000b; Krstevska-Konstantinova et al. 2001; Wilson et al. 2001; Daly et al. 2007a; Daly et al. 2007b; Engelhaupt 2007).

Table 5.15: Amount of external inputs required for the total area under banana in southern Brazil, according to different management systems

Inputs	Management system		
	Official recommendation	"Ecological package"	Conventional farmers
Pesticides			
Fungicide	148,747 L		89,248 L
Herbicide	148,747 L		133,872 L
Mineral oil	4,462,410 L	2,974,940 L	5,607,762 L
Biofertilizer		2,974,940 L	
Fertilizers and amendments			
N-P-K	74,374 Mg		89,248 Mg
Poultry manure	223,121 Mg		297,494 Mg
Organic compost		297,494 Mg	322,781 Mg
Lime	74,374 Mg	44,624 Mg	248,407 Mg
Rock Phosphate		7,437 kg	

In a number of rural communities where farmers have adopted the "conventional package" more intensively, frequent conflicts among neighbors are occurring because water is contaminated with pesticides and plastic bags. Farmers are also complaining about the cost of inputs. In most of the discussions with local producers, when the focal groups method was applied to validate and assess the collected data, farmers objected that they had to intensify production, otherwise it

[14] I had the (sad) opportunity to witness several events where farmers were poisoned by the use of pesticides. In one of these cases, a teenager who was hired to spray the plantations went to the hospital completely blind. He recovered his vision several months later, but complications remained.

would be difficult to sell their bananas. A widespread practice in the region, adopted by the majority of banana buyers, is to overload the boxes and pay just a fixed price. In other words, they take 23 kg of bananas but just pay the equivalent of 20 kg. Another common practice used by buyers to deceive farmers is to classify the banana bunches in “first quality” and “second quality”, according to very elusive criteria.

Apparently, the strategy to increase production based on intensification is associated with a number of negative consequences. As demonstrated in Chapter Four, such an approach is not improving the wealth of households, as income is not exclusively related with better production (but principally with better markets). Nevertheless, there are several sustainable agricultural technologies, already available for banana cultivation that can help farmers to reduce the use of external inputs without offsetting productivity.

Synthetic fertilizers might be substituted by organic amendments, green manures, foraging trees, and other strategies that enhance nutrient cycling (Primavesi 2006). In addition, to be generally cheaper and available at the local level, such inputs can boost soil biological processes, which in turn improve the overall plant health (Uphoff 2006). A number of low-input technologies can help in pest and disease control. Farmers should be able to monitor and evaluate the right moment to spray their banana plantations for sigatoka disease control (Lichtemberg et al. 2002). It seems that several producers apply mineral oil associated with fungicides without any factual need (Lichtemberg et al. 2002). Also effective for sigatoka disease control, as many farmers in the region have reported, is the use of biofertilizers. Biological control of one of the main banana pests, the weevil borer (*Cosmopolites sordidus*), is also available (Lichtemberg et al. 2002). The fungus *Beauveria bassiana* is very effective, and it is non-toxic to humans and the environment (Lichtemberg et al. 2002). In summary, there are several sustainable technologies available for banana producers that can help to reduce the use of exogenous inputs without hindering productivity.

5.4 Conclusion

In this chapter, the potential for ecological systems to promote environmental services was studied. Three aspects were analyzed: biodiversity conservation, carbon sequestration, and the reduction of pesticide use. The main findings suggest that ecological systems in the Torres region have a considerably better environmental performance compared with conventional banana production systems.

Most certainly, ecological banana production as managed by local farmers has a role in preserving remnants of the Atlantic Forest. Some of the agroforestry systems implemented are, to some extent, similar to the original vegetation in functional and structural terms. Some species such as *Cecropia sp. (Embaúba), Trema micrantha (grandiúva)*, and *Canjerana sp.* are characteristically from secondary forests. *Euterpe edulis (palmito* or *ripeira)*, which is predominant in forest fragments as well as in the agroforestry systems, is a key species of recognized ecological importance (Orlande et al. 1996; Reis et al. 2000a; Reis et al. 2000b; Pizo et al. 2004; Fantini et al. 2007). In addition, the *palmito* tree has a promising economic potential for smallholders through the extraction of the palm heart and the production of *açaí* pulp.

Another aspect that emphasizes the environmental role of these systems is the presence of endangered species, for example *Ocotea odorifera (canela sassafrás)*. In a highly fragmented ecosystem such as the Atlantic forest, a matrix compounded by forest patches and land-use systems, such as the ecological banana production with native trees, seems to be more effective in preserving and eventually recovering the original vegetation than conventional banana systems. If some of the agroforestry practices adopted by ecological farmers were extended to the whole area under banana plantation in southern Brazil, i.e., 148,747 ha, a number of environmental services would be enhanced. For instance, the planting of a few native trees within the banana plots and in the edges of the plantations could have positive implications for biodiversity conservation and for the integrity of the whole system, without compromising productivity and fruit quality. Some of these trees would provide habitat for birds, bats, insects, etc., and would play an important role in cycling nutrients, increasing soil organic matter, forming windbreaks for the banana trees, providing habitats for seed dispersors, and protecting watersheds, among other environmental benefits. These advancements would favor the banana plantations as well as the overall ecosystem health, demonstrating that some synergistic relationships between agriculture and environmental enhancement are possible.

The amount of carbon measured in the agroforestry systems represents a considerable improvement, compared with the conventional banana production systems. Such a result tends to be important in a scenario of global warming and the need to mitigate greenhouse gases. Potential income from carbon sequestered, as a payment for environmental services, seems not sufficient to justify the adoption of agroforestry practices. However, if the whole area with banana plantations is southern Brazil is considered as a possibility to promote carbon compensation practices, this value would be substantial. It should be noted though that the total amount of carbon fixed by these systems likely was underestimated. The carbon accumulated belowground, which can account for a significant share of the total budget, was not calculated. In addition, the carbon cost of some practices, such as the use of pesticides and the transportation costs for different commercialization strategies, was not estimated. Therefore, the potential role of such systems as a carbon sink seems to be significant.

Considerable reduction in the use of pesticides is another environmental accomplishment accrued by the ecological production systems. Some management practices already available for farmers might help to diminish substantially the use of agrotoxics. The main banana pests and diseases can be effectively controlled through monitoring processes and biologically-based methods. In addition, the main findings also suggest that conventional farmers are poorly assisted in the use of pesticides. As a result, several pesticide applications are performed without any real need, which causes waste of money, time, and unnecessary environmental costs. Reducing pesticide applications would have a positive impact in averting water contamination, improving food quality, and preventing poisoning of farmers, particularly in developing countries where the use of such harmful substances is poorly controlled. This aspect is particularly important in highly diverse and populated areas such as the Atlantic Forest region.

CHAPTER 6

ON TRADEOFFS AND SYNERGIES

6.1 Introduction

In the last few years, with the increasing concern about environmental quality, several methods to assess the performance of agricultural systems based on the general approach of tradeoffs and synergies have been proposed (Viglizzo et al. 1998; Stoorvogel et al. 2001; Stoorvogel et al. 2004; Groot et al. 2007). Specifically, these methodologies intend to measure the relationships among social, ecological, and economic goals. Ecoagriculture, for example, the conceptual framework adopted in this investigation, is based on three main aspects: production, environmental services, and livelihoods. Similarly, as was already mentioned in Chapter Two, a critical triangle where sustainability, growth, and poverty alleviation interact is proposed by other authors (Vosti et al. 1997).

However, there are some caveats associated with these conceptual frameworks which constrain the applicability and complete adoption of evaluative methodologies based exclusively on the assumptions of tradeoffs and synergies. Initially, the allegorical figure of a critical triangle conveys the implicit notion that all three sides (or angles) have the same magnitude. Economic, social, and ecological features are placed on the same level of importance, neglecting contingencies and particular circumstances. The economic paradigm under which ecological services are priced may be valuable and compelling for rich Northern countries, where people can pay for this “luxury.” Conversely, in regions where people live at the limits of survival, such logic may be meaningless. Synergies and tradeoffs analysis must accordingly have different formats in different parts of the world. Moreover, in an attempt to price or allocate numeric values to biosphere processes and services, most of these methodologies submit ecological imperatives to an economic logic (Limburg et al. 2002; Patterson 2002).[1]

A second challenge that these methodologies should cope with is the erosion of the sustainability concept. This notion has been completely appropriated, recast, and instrumentalized by the market and has been distanced from its etymological meaning. Considering the widespread use (and abuse) of the term, it has lost its subversive power (North 2007). This is particularly relevant in the ecological agricultural sphere, with the growing incongruence between ecocertification labels and the potential social and environmental attributes that they might symbolize (Hansen 1996; Teisl et al. 1999; Deaton et al. 2005; James 2006; Lockie 2006).

Furthermore, most of these methodologies are ineffective in distinguishing the structural problems associated with farming activities from those related with particular circumstances in which agricultural production is realized. By its own nature, and with a very few and localized exceptions,[2] agriculture is based on simplification of original ecosystems, which necessarily imposes environmental losses (Gliessman 1998; Magdoff 2007). In addition, some agricultural practices can be relevant in a given situation, under some specific conditions, but they can cause structural problems if their use persists for years. One very illustrative example, described in Chapter Three, is the slash-and-burn (*coivara*) agriculture practiced by indigenous people all over the world. Within a certain time period, and considering the

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[1] It is necessary to clarify that the purpose is not to criticize the idea of pricing nature, or eventually using market mechanisms such as paying for environmental services. The intention here is to point out the hegemony of the economic logic over other dimensions.

[2] There are a few exceptions restricted basically to traditional populations, as was pointed out in Chapter Three. Also, if extractive activities such as rubber tapping in the Amazon region or any other form of collecting non-timber forest products is considered as a type of agriculture, indeed agriculture does not necessarily imply system simplification.

space where it is used, it can be considered a sustainable agricultural option for tropical regions. However, if slash-and-burn is systematically repeated without allowing time for the system to recuperate, it can provoke irremediable negative impacts on the environment. Therefore, any assessment should consider the time frame and appraise if the system is showing symptoms of sustainability based on criteria previously established (Rasul et al. 2004).

In addition to these caveats, there is a general problem associated with quantitative methods. Sustainability is a subjective concept that encompasses qualitative attributes and human values, which is difficult, if not impossible, to express with numeric values. For the sake of illustration, during the field work, while collecting data and making measurements in the agricultural systems, several situations where farmers had conflicting views about similar matters emerged. This was particularly relevant with respect to activities associated with the marketing of products. Some farmers reported that they were very pleased about selling their products directly in street markets, and were honored to be recognized as ecological producers. On the other hand, other producers mentioned that they preferred to sell their products directly to intermediaries, considering that this is more practical and less troublesome. Hence, one specific practice that is considered for one group of farmers as a factor to improve their living conditions is at the same time judged as problematic for other producers in the same rural community. In addition, as pointed out in other studies, some farmers express altruistic behavior and affirmed that they cannot spray pesticides on a product that is likely to be consumed by children and the elderly (Uphoff 1996). Such feelings are (expectedly) not espoused by all farmers.

Allocating numeric values to system performance has, therefore, the objective of showing some homogeneous or average quality based on some arbitrarily selected criteria. But by such means one cannot state categorically that some systems are more sustainable than others. They are too multidimensional and value-infused. One might like to show evidence that particular practices and processes are leading the whole system towards a status of "sustainability likelihood." But the reality is somewhat complex and subject to subjective assessments. In statistical language, the objective of quantified analysis is to reject the null hypothesis that states that all systems have the same performance or, that there is not enough evidence indicating a general tradeoff relationship. Such a Popperian approach prevents proving an assumed synergetic relationship among the three dimensions of the ecoagriculture conceptual framework.

Another similar objective is to demonstrate that the farming practices and commercialization strategies adopted by the group of ecological farmers are leading to a "likelihood of sustainability." Conversely, practices adopted by conventional farmers are, in general terms, "likely-to-be structurally unsustainable." Therefore, the overall purpose of this chapter is to assess the tendency of sustainability for the ecological agricultural systems by comparing them with conventional ones. More specifically, the aim is to demonstrate whether or not such systems have the potential to simultaneously favor, over the years, both farmers and the environment.

6.2 Methodology

There are numerous methodologies for assessing the sustainability of agricultural systems by attributing numeric values to certain performance indicators. Among the options available, the French method IDEA – *Indicateurs de Durabilité des Exploitations Agricoles* (Sustainability Indicators of Agricultural Exploitations), developed by a cadre of scientists from different disciplines as a framework to operationalize these issues (Vilain 2003), was one of the methods selected as a source of inspiration. The method has been considerably simplified and further adapted to meet the circumstances of the present study, as well as to make use of the available information.

The IDEA method proposes three general assessment scales: agroecological, social-territorial, and economic. Each of these scales is divided into various components which synthesize the necessary characteristics using a diagnostic of sustainability (Vilain 2003). In turn, such components are evaluated by a number of specific indicators. The general performance of the system is established by aggregating the individual scores.

Accordingly, to evaluate the general performance of the systems under investigation, a sustainability index is created based on some selected indicators for environmental services, production, and livelihood. The indicators constructed were ones based on the analytical chapters. It must be noted though that a significant vulnerability of such a method – to transform results into indexes and produce a general score – is that indicators have different levels of importance, and therefore it should have different weights. Nevertheless, for the present study indicators were considered equivalent, and given the maximum score of 100. Reaffirming the general approach previously described, the intention was to generate some evidence supporting the likelihood of the system to be sustainable.

Some analytical approaches from the framework developed by the Alternatives to Slash and Burn (ASB) program were also utilized to compare the two management systems (ASB 2007). Specifically, the assessment of economic performance of the households and its relation with land-use systems, as well as the construction of matrices to evaluate *best bet* practices were adopted to compare the two management systems under investigation (Vosti et al. 2000; Buck et al. 2006). Similar to the ecoagriculture paradigm, ASB suggests a positive correlation between poverty reduction and biodiversity conservation (Buck et al. 2006; ASB 2007).[3]

Taking into consideration that the two management systems (conventional and ecological) are essentially different, and therefore almost impossible to make straightforward comparisons, it was decided to use an analytical strategy that may be called "disaggregated equivalences." Effectively, the indicators corresponding to the different management systems are grouped in two "bundles", and the ones that are common in both groups are compared. Each of the criteria previously determined is compared individually using the insights of the two methods above-mentioned (IDEA and ASB). Attributes that are not shared by the two "bundles", i.e., those that are exclusive to a specific management system adopted by farmers, may indicate a comparative advantage. This analytical approach permits a rigorous comparison between quantitative indicators. Finally, to facilitate inferences as to whether or not the system has a "tendency to be sustainable," the indicators are re-aggregated and synthesized in a matrix-table, and overall performance is visually depicted in radar-type diagrams (Buck et al. 2006).

6.2.1 Indicators

6.2.1.1 Production

The productive dimension of the systems was assessed according to the amount of calorie and protein outputs. Ultimately, this is a single indicator of physical production, but expressed in different units. Taking into consideration the importance of food security, particularly in a context of growing population, impoverished rural areas, and depletion of the productive capacity of agricultural systems, it is opportune

[3] ASB is a global partnership operated system-wide by the Consultative Group for International Research in Agriculture (CGIAR) that focus on improving the living conditions of rural households in the humid tropics without harming the environment The program's mission is "prosperous people and flourishing forests across the tropics", explicitly reveals an approach that proposes a positive relationship between livelihoods and environment (ASB 2007).

to emphasize this characteristic. An energy aspect also was considered in this dimension. As mentioned in Chapter Four, the efficiency of the system can also be measured by the amount of energy used to produce these outputs.

1) Food production: calories/ha (CP)

Objective: food security, food sovereignty

Comment: As provided in Chapter Four, output was transformed to its energetic equivalent (MJ/ha). Such a measurement is more consistent with the objectives of the study as it allows a straight inference in terms of calorie availability and the number of people who could be potentially fed.

2) Food production: protein/ha (PP)

Objective: Objective: food security, food sovereignty

Comment: Similarly to the amount of energy, output was transformed into protein equivalent (kg/ha). The objective was also to infer the number of people whom the system is likely to sustain in terms of available food.

3) Total energy inputs (TE)

Objective: system reliance on external inputs

Comment: One important component in terms of sustainability is the dependence of the system on external inputs. A system that relies on internal processes to guarantee production and on sunlight as the main source of energy is likely to be more sustainable. In a context of petrol scarcity, such an indicator tends to be more relevant. Total energy inputs were measured in terms of their energy equivalents (MJ/ha).

4) Energy ratio (ER)

Objective: productive efficiency

Comment: Following the same approach adopted in Chapter Four, productivity was evaluated based on the ratio between output and input. Such a criterion is important as it reveals the amount of energy utilized to produce each unit of food.

6.2.1.2 Livelihood (Income)

Livelihood was evaluated by the two most common criteria used to measure the economic efficiency of agricultural systems: net income/ha and labor productivity (Chapter Four). A third criterion was added, human labor intensity, which assesses the amount of labor devoted to the considered activity. Higher prices accrued by farmers suggest better access to markets, an imperative for livelihood enhancement, therefore it was also included as one of the indicators.

5) Net income/ha (NI)

Objective: local development, quality of life, social reproduction, access to better markets, economic efficiency

Comment: In several regions of the world, access to land is one of the constraints for smallholder production. Systems that have better remuneration per unit of land are a reliable indicator of efficiency.

6) Labor productivity (LP)

Objective: local development, quality of life, social reproduction, access to better markets, economic efficiency

Comment: The main production factor in smallholder agriculture is the work force available from the household. This factor affects the economic performance of the system, and therefore livelihood. In addition, it allows comparisons among different activities within the farming unit. For this assessment, the total amount of labor devoted to production was considered.

7) Human labor intensity (HL)

Objective: quality of life

Comment: Similarly to the previous indicator, this criterion indicates the area that the labor available in the household can manage (area per total labor). Since a limiting factor in smallholder production is the labor force, this criterion is needed to adequately assess livelihood.

8) Price (PR)

Objective: access to better market, better remuneration, labor and land productivity

Comment: A crucial element to guarantee livelihood enhancement is access to better markets. The price at which farmers can sell their products is a key factor to determining the viability of agricultural production.

6.2.1.3 Environmental Services

Three indicators were selected to evaluate a system's potential to contribute to environmental enhancement: biodiversity, assessed by the Shannon index, pesticide use, and carbon sequestration. These criteria were the ones adopted in Chapter Five. However, it should be noted that this set of indicators is specific to ecological systems, particularly the eight agroforestry systems examined in this study. Therefore, inclusion of these indicators in the analysis serves to highlight the comparative advantage of ecological systems over conventional ones.

9) Biodiversity – Species Diversity (SD): Shannon index

Objective: biodiversity conservation, landscape preservation

Comment: Biological diversity is an imperative for food security and environmental services. In addition, biodiversity is indispensable for the stability among different trophic levels (vegetal, animals, herbivores, carnivores, etc.), and ecosystem self-regulation. The Shannon index, utilized to quantify the plant diversity in the ecological banana systems (Chapter Five), considers the number of species and the proportion of individuals in the sample (Kent et al. 1992). Some other criteria utilized in Chapter Five to assess biodiversity, such as the vegetational structure, floristic composition of the agroforestry systems, occurrence of endangered species, presence of keystone species, and dynamic features, where not employed to compare the two management systems. Such aspects are specific for phytosociological studies, and the objective of this chapter is just to point out whether or not ecological systems (particularly the agroforestry ones) are promoting biodiversity enhancement. These qualitative attributes were already covered in the referred chapter.

10) Pesticide use (PU)

Objective: soil and water protection, biodiversity conservation, prevention of greenhouse gases, product quality, and farmer health

Comment: One of the conditions for sustainable agricultural systems is the reduction in the use of pesticides. The deleterious effects of such substances on the environment and human health are well documented (Descalzo et al. 1998; Guillette et al. 1998; Guillette 2000a; Guillette 2000b; Meeker et al. 2004; Meriles et al. 2006; Daly et al. 2007a; Daly et al. 2007b). The toxicity of pesticides is determined by the active ingredients and by the amount applied. However, as a general approach to assessing the systems' performances in this specific criterion, it was only the use or non-use of such inputs was registered.[4]

11) Carbon sequestration (CS)

Objective: green house gases mitigation

Comment: Farming methods that incorporate a tree component into the system have the potential to contribute to carbon sequestration (Albrecht et al. 2003). In a scenario of global warming, practices that can mitigate the emissions of greenhouse gases are especially relevant. Similarly to the approach adopted in Chapter Five, only the amount of carbon aboveground (sequestered by the trees) was considered.

[4] Indeed there are some drawbacks to considering a general use of pesticides, instead of evaluating the type and quantities applied. However, a full toxicological evaluation is beyond the scope of this study.

6.2.2 Analytical procedures

Two comparisons were carried out to evaluate the efficiency of conventional and ecological management systems. In the first assessment, the overall performance of the two land-use systems was contrasted. Specifically, to determine the general performance of the whole group, a numeric score was assigned to each sampled unit based on the indicators previously described. The overall performance was established by aggregating the average of single scores. A maximum score of 100 was established for the production unit that accrued the highest value for a specific indicator. In turn, the minimum value was arbitrarily set at ten.

In an attempt to avoid ambiguous and subjective interpretations, and to allow a rigorous comparison between the two land-use systems, only the quantitative indicators were utilized to establish the overall performance. Precisely, the indicators selected to assess the environmental services were not used to calculate the efficiencies of the systems. Consistent with the analytical approach of "disaggregated equivalence," it is postulated that the environmental services provided by the ecological management systems characterize a comparative advantage. Moreover, it is assumed that if both production systems have similar performance considering the set of indicators for production and livelihood, and the ecological ones also can promote environmental enhancements, such a trend reveals a condition of sustainability likelihood.

The second comparison was established between all the conventional systems and the eight production units managed under agroforestry practices. As demonstrated in Chapter Five, such systems are explicitly playing an important role in protecting some species of the Atlantic Forest (therefore enhancing biodiversity), as well as contributing more efficiently to carbon sequestration and reduction in pesticide use. In general terms, the comparative advantages of these systems contrasted with the ecological ones are evident.

Farmers’ selected for this specific study and sampling techniques were the ones already described in Chapters Four and Five. Reaffirming the general approach adopted in the previous chapters, only cases where the data were consistent (complete and robust) for critical analysis were included. The performance values for each indicator were filled into the proper “cells” in the matrix-tables, and plotted as radar-type graphics.

6.3 Results and Discussion

6.3.1 Overall performance

The total performance of the systems varied considerably, according to the set of indicators (Table 6.1). Following the general approach where each of the criteria is compared individually between the two land-use systems, production was significantly higher in conventional management systems (Chapter Four). The calorie and protein production indicators show that conventional production systems had better performance when these criteria were considered. However, when the indicators for energy use and the energy ratio were included, the systems have a similar overall performance for production. The general score accrued for the production index were 198.4 and 187.5 for conventional and ecological management systems, respectively. These values are consistent with the general findings presented in Chapter Four, i.e., in conventional systems banana production has been subsidized by the use of external energy, principally petroleum-based inputs (synthetic fertilizers and pesticides).

As previously noted, one significant drawback in such a method is to assume that different attributes are comparable. The set of indicators selected to assess the production (or livelihood promotion and environmental services) performance of the systems is directly subjected to a series of circumstances and particular contingencies. In addition, comparison of two different management systems poses an extra challenge, considering that some practices are specific to the production method adopted. However, as a general outcome, it can be affirmed that the two land-use systems, conventional and ecological, have similar performance in production terms. Such a finding also suggests that productivity is not exclusively related with the amount of production inputs utilized in farming activities. Some other factors such as managerial skills, commercialization structure, and price of external inputs, may play a fundamental role.

Table 6.1: Matrix with general results for conventional and all ecological systems

Indicators	Management system			
	Conventional		Ecological	
	Average	**Index**	**Average**	**Index**
Production				
Calorie/ha (MJ ha^{-1})	35,505.3	56.6	28,763.6	39.4
Protein/ha (kg ha^{-1})	108.3	56.6	87.7	39.4
Total energy inputs (MJ ha^{-1})	10,051.4	72.8	5,882.6	84.3
Energy ratio (output $input^{-1}$)	4.4	12.4	18.8	24.4
Sub-total		**198.4**		**187.5**
Livelihood (income)				
Net income/ha (R$ ha^{-1})[a]	4,031.6	25.6	5,418.4	36.4
Labor productivity (R$ unit of $labor^{-1}$)	34,150.2	27.8	42,551.2	35.0
Human labor intensity (area total $labor^{-1}$)	8.8	33.9	8.7	33.7
Price (R$ kg^{-1})	0.5	21.5	0.9	53.4
Sub-total		**108.8**		**158.5**
Total		**307.2**		**346.0**

a) One real (R$), the Brazilian currency, is equivalent to approximately US$ 0.50 (September 15, 2007)

Ecological systems performed better in all indicators utilized to assess the potential for enhancing livelihoods (Table 6.1). As already covered in Chapter Four, ecological systems had higher averages for net income per ha and labor productivity, the two most ordinary indicators used to evaluate economic efficiency of agricultural systems. The results also suggest that both systems required the same amount of time to be managed. In general, conventional and ecological farmers can manage an area of approximately nine hectares of banana (Table 6.1). On average, ecological farmers also accrued better prices for the bananas.

Results transformed into the performance index reveal that ecological systems are more likely to enhance livelihoods. While the conventional systems had an overall performance of 108.8, the ecological ones scored 158.8. Apart from the debilities of the method and the difficulties to carry out such a comparison, these outcomes are in accordance with the general findings, as well as with the information provided by farmers during the field work.

An analysis of the radar-type graph confirms that the ecological systems had a better performance in most of the selected indicators (Figure 6.1). Consistent with the evidence highlighted in Table 6.1, conventional systems performed a little better in terms of overall production. As the graph shows, the energy indicators – total input and ratio, are contributing to a similar performance between the systems. These findings also imply that production in the conventional systems is subsidized by the use of external inputs. Some environmental implications also can be raised, as most of the external inputs derive from non-renewable sources.

As it is also demonstrated by the Table 6.1 and Figure 6.1, the ecological systems have a better performance in terms of livelihood. Human labor intensity is slightly higher in conventional systems. Some of the conventional practices such as chemical weed control might help in reducing the amount of labor needed to manage the banana plots. On the other hand, access to better markets might be favoring ecological farmers to increase net income per hectare, labor productivity, and to accrue superior prices. However, to have the benefit of better marketing opportunities farmers need to spend some extra labor on activities related to selling products. This situation may suggest a tradeoff relationship between better prices and the total time devoted to production and marketing the products.

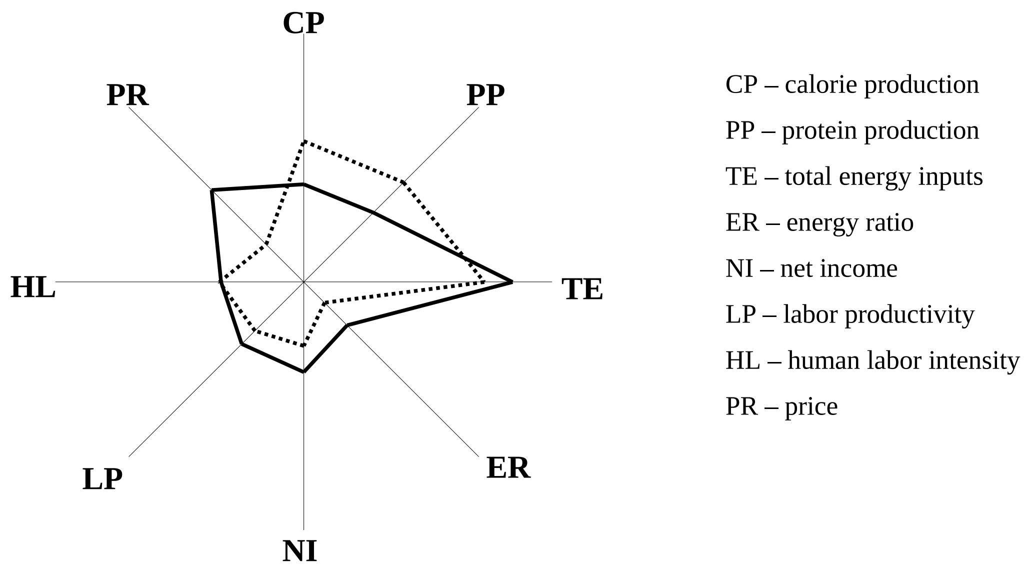

Figure 6.1: Radar-type graph with general performance of all systems (conventional in dashed line and ecological in solid line)

The overall findings comparing production and livelihood performance of the two systems, based on the selected indicators, denote that there is not sufficient evidence to suggest a tradeoff relationship. On the contrary, these results suggest that the combination of all ecological systems are promoting some environmental services and simultaneously improving livelihood aspects. In addition, production was not adversely affected by the ecological farming practices. Overall, conventional production systems accrued a total score of 307.2 points, while ecological systems 346.0. Therefore, this first analysis indicates that ecological farming systems have more prospects for sustainability.

6.3.2 Comparison: conventional systems and eight agroforestry systems

Following the same pattern found in the previous comparison, conventional systems performed better in terms of production (Table 6.2). This result was expected, considering that the eight selected ecological systems were not among the most productive ones in terms of calorie and protein outputs. However, these systems had a better overall production performance compared with the whole sample of ecological systems. The higher averages accomplished for energy use and energy ratio, contributed to increase the overall score performance. Even with this relatively asymmetric comparison, in general terms conventional systems are not performing better than the ecological ones. Consequently, as demonstrated by this example, the tradeoff relationship applies for specific indicators and in particular situations.

Conventional production systems had an average index of 198.4, while the eight agroforestry systems had 193.1 (Table 6.2). Considering these results, and based on the selected criteria, it cannot be argued that there is a tradeoff relationship between environmental services and production. In this specific case, the environmental services promoted by the eight ecological systems are not coming at the cost of higher production (Table 6.2).

The selected ecological systems also had a considerable better performance when the livelihood criteria were considered. In general terms, they had higher scores for net income per ha, labor productivity, human labor intensity, and price. Overall performance indexes were 106.0 and 177.0 for conventional and ecological systems, respectively. Therefore, it is evident that less physical production (Mg ha^{-1}) is not hindering the income of ecological farmers.

Table 6.2: Matrix with general results for conventional and the eight agroforestry systems

Indicators	Management system			
	Conventional		Ecological	
	Average	**Index**	**Average**	**Index**
Production				
Calorie/ha (MJ ha^{-1})	35,505.3	56.6	26,463.2	33.5
Protein/ha (kg ha^{-1})	108.3	56.6	80.7	33.5
Total energy inputs (MJ ha^{-1})	10,051.4	72.8	3,102.7	92.2
Energy ratio (output/input)	4.4	12.4	30.2	33.9
Sub-total		**198.4**		**193.1**
Livelihood (income)				
Net income/ha (R$ ha^{-1})[a]	4,031.6	25.6	5,655.1	38.3
Labor productivity (R$ unit of $labor^{-1}$)	34,150.2	27.8	48,654.6	40.2
Human labor intensity (area total $labor^{-1}$)	8.8	31.1	10.3	38.3
Price (R$ kg^{-1})	0.5	21.5	1.0	60.2
Sub-total		**106.0**		**177.0**
Total		**304.4**		**370.1**
Environmental Services				
Species diversity (Shannon index)	Zero		2.0 – 2.8	
Pesticide use (ml ha^{-1})	> 500		Zero	
Average of above-ground carbon sequestration (Mg ha^{-1})	Zero		23.5 – 47.2	

a) One real (R$), the Brazilian currency, is equivalent to approximately US$ 0.50 (September 15, 2007)

Furthermore, as examined in Chapter Four, it can be inferred that good marketing opportunities are playing a fundamental role in allowing ecological producers to optimize (instead of maximize) production to promote environmental services. Ecological producers have a better income because of their production methods and/or because they can sell their products directly. Either way, these results indicate that commercializing strategies are detrimental to combining environmental protection and sustainable livelihood. Consequently, it can be postulated that, in this case, environmental protection and livelihood promotion may have a positive correlation, if not a synergistic relationship.[5]

The results plotted in the radar graph emphasize the differences between the two systems (Figure 6.2). Ecological production systems performed better in six indicators, out of eight. Conventional production had a higher average only for physical production – calorie (MJ ha^{-1}) and protein (kg ha^{-1}). A visual analysis may suggest a tradeoff relationship between physical production and environmental services, as the agroforestry systems are evidently promoting ecological services – biodiversity, carbon sequestration, and pesticide reduction (Table 6.2). Nonetheless, as already mentioned, it should be emphasized that ecological systems were more efficient in energy use and energy ratio, which are production indicators.

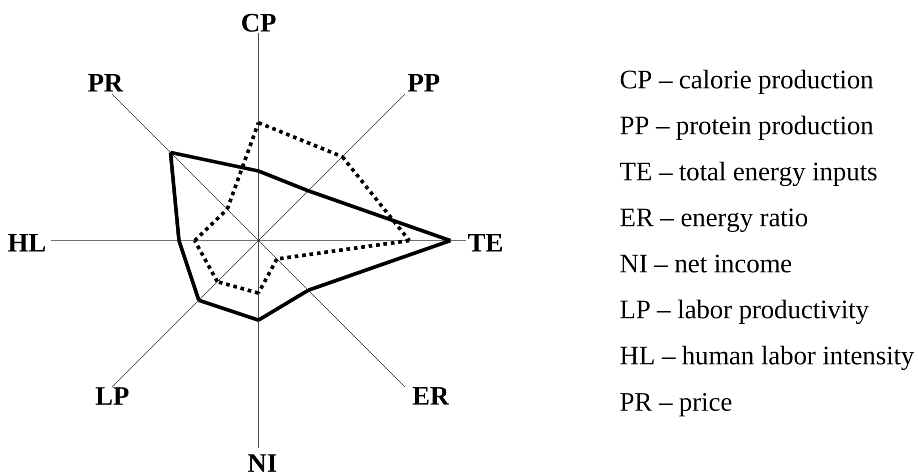

Figure 6.2: Radar-type graph with general performance for conventional systems and agroforestry systems (conventional in dashed line and ecological in solid line)

[5] Throughout the text the use of the term synergy was explicitly avoided, for the sake of consistency with the methodological approach. However, these findings support pointing out a win-win relationship between livelihood and environmental issues.

The overall score for conventional systems was 304.4, and 370.1 for the eight agroforestry systems. These findings confirm the original claim, that is, ecological systems can simultaneously have reasonable production rates, enhance livelihoods, and promote environmental services. If it cannot be affirmed that this trend characterizes a synergistic relationship, it at least suggests the likelihood of sustainability. Moreover, (and perhaps most importantly) it demystifies the idea that high production rates and better livelihoods cause environmental costs.

6.4 Conclusion

In this chapter the relationship among the aspects that define ecoagriculture – environmental services, production, and livelihood – was analyzed. For each of the three aspects, performance indicators were selected, and the overall performance of the two management systems was determined. In general, there is not enough evidence to show that such aspects have a fixed tradeoff relationship, that is, attaining favorable production and/or livelihood is not necessarily precluding environmental services. Conversely, some results suggest that it is possible to combine environmental quality and agricultural production in a non-zero sum relationship.

The comparisons between the conventional with the ecological systems, which are inarguably promoting environmental services, reveal that in some circumstances a tradeoff relationship can occur. Paradoxically, these findings confirm the general assumption that environmental quality, production, and livelihood are not essentially a matter of tradeoff. However, the results indicate that such a relationship occurs under particular conditions.

Consistent with the findings in Chapter Four, some results suggest that marketing strategies can have a positive effect on environmental services. Ecological systems, which certainly have a significant role in biodiversity enhancement, greenhouse gases mitigation, and soil and water conservation, have comparable net income per hectare vis-à-vis conventional production. Considering this relationship, some other market mechanisms can be devised to stimulate good environmental practices.

Payments for environmental services have been proposed as an instrument to promote such changes (Costanza et al. 1997; Balmford et al. 2002; Farber et al. 2002; Turner et al. 2003; Madureira et al. 2007). Farmers would receive financial compensation for preserving biodiversity and promoting carbon sequestration. One of the challenges is how smallholders in developing countries can participate in such markets. Another concern would be the commoditization of environmental services. Some authors, however, advocate that pricing nature and the services provided by ecosystems as well as comparing values is somehow problematic (Amin 1992; Martinez-Alier et al. 1998). Without embarking in the debate whether or not farmers should receive money for promoting environmental services, it is apparent from the main findings that under certain conditions it is possible to promote positive-sum relationships among production, livelihood, and environmental services. Or, in other words, it is possible to promote “likely-to-be-sustainable” agricultural systems.

CHAPTER 7

PERSPECTIVES AND IMPLICATIONS OF AN ECOLOGICAL APPROACH ON THE AGRICULTURAL SECTOR

In the previous chapters, it was demonstrated that the management systems developed by farmers in the Torres Region are simultaneously promoting agricultural production (Chapter Four), income generation (Chapter Four), and environmental services (Chapter Five). In addition, the synthesis provided on Chapter Six attempted to disprove that the tree “pillars” that form the basis for ecoagriculture have a fixed tradeoff relationship. Thus, the question that arises and gives an operational focus for this work is: how and under what conditions can agriculture contribute to the promotion of ecosystems services while guaranteeing food production and livelihood support? More specifically, what kind of institutional arrangements are necessary to generate a positive-sum outcome within the agricultural sector?

Before addressing these specific questions, it is necessary to take into account three basic premises. First, the prevailing agricultural model, mostly based in the use of external inputs, was not unintentionally developed. Neither is it an outcome from the natural evolution of particular circumstances. On the contrary, it is the result of a combination of policies and development options that reflect some theoretical and ideological assumptions (Pádua 2002). As such, I believe that it is realistic to reverse the general incompatibility between agricultural production and biodiversity protection. Second, it is not possible to separate environmental and social issues. Environmental problems are intrinsically connected with social issues, in a cause and effect relationship. Third, the agricultural sector is complex and dynamic, formed by a multiplicity of agents, segments, institutions, and stakeholders who sometimes have conflicting interests. Nonetheless, this universe of complexities and dynamisms in fact contains a wealth of possibilities and opportunities to preserve biological diversity and promote other environmental services. More specifically, my main argument is that ecological agriculture, particularly based on household production systems, can be the integrating nexus between environmental protection and food production. Accordingly, the conclusions and standpoints presented below are based on the practical examples developed by the host organization (Centro Ecológico) with smallholders in the Torres region, supported by the findings of this investigation.

7.1 Social solutions for environmental problems[1]

7.1.1 Markets

"Modern technologies" have been contributing to the disruption of millions of rural livelihoods. Before the introduction of this "modernization," farmers in various regions of the world were living almost under an autonomous economy, producing and consuming locally. Today, farmers are part of an immense and complex global agricultural system, where they must rely upon the consumption of various external inputs to enable production, and they must be connected to a large and vertical commercialization chain to sell their products.

Alternatively, local and regional markets can play a fundamental role in promoting social and environmental advancements (Allen et al. 2000; Hinrichs 2000; Jonathan et al. 2000; Marsden et al. 2000; Pretty 2002; Hinrichs 2003; Morris et al. 2003; Sage 2003; Winter 2003). As it was shown in Chapter Four, farmers who sell their products directly through street markets and/or other initiatives are accruing

[1] The titles of the two final sections were a suggestion of an Argentinean friend, Pipo Lernoud, vice-president of IFOAM – International Federation of Organic Agriculture Movements. Such a proposition is an attempt to be consistent with one of my introductory concerns, i.e., it is not possible to segregate social and environmental issues.

better prices for their goods. In addition, contrary to the pervasive assumption that organic products are only affordable for economic and intellectual elites, in such initiatives consumers pay fair prices. Income-generating activities where farmers have a better economic performance is imperative to making household agriculture viable, and therefore to help in promoting sustainable rural development (Abramovay 2000; Assis et al. 2005; Assis 2006).

Generation of employment opportunities, both in rural and urban areas, is another aspect related with short circuits of commercialization revealed by this investigation. When farmers are directly involved in the commercialization process through business ventures such as street markets and cooperatives, a number of associated activities are also created. In the Torres region, it was reported that most of the households involved in direct marketing had to contract permanent or temporary local helpers for new farming tasks. They also had to hire or buy trucks to transport the products, and construct or improve post-harvest facilities to prepare products for market. Such activities enhance local economy as they bring new sources of income, in addition to allow the retention of added value at the local level (Guzmán-Casado et al. 1999; Lyson et al. 1999; Lyson et al. 2001). With a general trend all over the world of rural exodus, mainly of women and youngsters, endeavors that create living alternatives in rural areas and prevent the influx of people to urban centers are particularly important (Abramovay 2000).

Another relevant aspect that is facilitated in such initiatives, but rarely recognized, is the straight connection between rural and urban dwellers. Direct interaction between farmers and consumers can create relationships based on values of solidarity, cooperation, and friendship, which go beyond a simple commercial transaction (Nygard et al. 1998; Jarosz 2000; Dollahite et al. 2005; Sumner 2005; Wilkins 2005). As mentioned in Chapter Four, some farmers declared that they like to participate in street markets not only to "sell stuff", but because they are also renowned as nature's stewards. Moreover, such contacts can propitiate the establishment of strategic alliances to advance the environmental agenda (Conner 2004; Wilkins 2005).

Biodiversity enhancement can be favored as well by direct commercialization initiatives. While the global market of commodities is an underlying cause for biodiversity loss, as it tends to homogenize and favor high value crops, local markets have the potential to stimulate agrobiodiversity products (Thrupp 1998). Several varieties of vegetables, particularly underutilized crops, are not sold in mainstream markets. In local commercialization endeavors, however, farmers have the opportunity to make some profits from these crops. Also, consumers are favored as they can have access to products that are not found in supermarkets.

Some other environmental benefits are potentially promoted with local and regionalized markets. The short distance between producers and final consumers represents less energy consumption for transport, and therefore a decrease in the emission of greenhouse gases (Cowell et al. 2003). In a growing context of global warming, systems that reduce food-miles are particularly important (Pretty et al. 2005). Pesticide use and all its associated negative impacts also tend to be reduced, as consumers can demand better products directly from farmers.

Certainly, it is not realistic (nor reasonable) to postulate for a food supply system exclusively based on local and regional initiatives. The exchange of agricultural commodities among regions and countries is a requisite for the progress of humankind. However, considering that market is one of the most important economic institutions, and it is also a socially constructed structure, it is imperative that it addresses the social and environmental needs of present time (Swedberg 1994;

Abramovay 2004; Conner 2004). What is necessary though is a network of complementary initiatives, based on local, regional, and global endeavors.

7.1.2 Organizations

Another aspect reveled by this investigation, which has been extensively referred to in literature as an imperative condition to promote sustainable rural development, is the capacity of farmers to create representative organizations (Cernea et al. 1985; Wilkening 1985; Chambers et al. 1991; Uphoff 1993; Pretty 1995a; Pretty 1995b; Uphoff 2000; Uphoff et al. 2000; Pretty et al. 2001; Krishna 2003; Dollahite et al. 2005; Brodt et al. 2006). In the Torres regions, conventional and ecological farmers who were participating in any type of organizational initiative were more likely to have better economic performances. However, those belonging to ecological farmers associations had, in general, better financial returns.

Organized farmers can build relationships based on values of trust, cooperation, solidarity, and altruism (Pretty 1995b). They also can be more vocal about their social and economic demands. Pragmatically, organized farmers can articulate more efficiently their interests, defend their rights vis-à-vis state, and meet their needs directly (Uphoff et al. 2004). They also can build strategic alliances with organizations sharing similar values, and create networks to promote sustainable agriculture. Participation and collective actions are requirements for the succeed of sustainable agriculture (Pretty 1995b).

7.1.3 Information/Management

Whereas modern farming systems based on the Green Revolution paradigm are predominantly input-intensive, i.e., production is mostly based on the use of external inputs, a contemporary challenge in the agricultural sector is to design knowledge-intensive production systems (Altieri 1987; Pretty 1995b; Uphoff 1996; Gliessman 1998; Altieri 1999; Uphoff 2002; Uphoff et al. 2006). The negative social and environmental impacts of modern technologies, associated with the raising costs of petroleum-based inputs (synthetic fertilizers and agrochemicals), will lead farmers to optimize the use of resources available at the local and regional levels (Pretty 1995b; Pretty 2002; Kabir et al. In Press). Contrary to technological packages where producers merely follow some simple recipe-like instructions, the quest for sustainable farming systems will require an integrative approach, where farmers will have to articulate different knowledge systems (Uphoff et al. 1998; Gallopín et al. 2001; Uphoff 2002; Eshuis et al. 2005).

As demonstrated by this investigation, economically successful farmers were those who were able to decrease production costs by limiting purchased inputs, while simultaneously accessing better markets. By relying upon and optimizing the use of endogenous resources, freely available at the farm unit (sunlight, soil, water, seeds, biodiversity, labor, and knowledge), farmers do not need to spend their earnings on production inputs. On the other hand, access to better markets provides higher incomes for farmers. Such a simple (and paradoxically complex) prescription is an imperative to enhance the livelihoods of marginalized farmers.

It is necessary, though, to bridge traditional and indigenous knowledge with formal research and extension organizations through participatory schemes and synergistic partnerships among producers, researchers, and extension agents. The challenge to improving rural livelihoods is beyond individual capacities and responsibilities, therefore it is essential to overcome the dichotomy between traditional and scientific knowledge systems. Both are relevant in their specificities and they can complement each other (Pretty 1995a; Pretty 2002; Uphoff 2002).

7.2 Environmental solutions for social problems

7.2.1 Nature as a technological matrix

One of the main causes of the social and environmental problems associated with the agricultural sector is indeed related to the prevailing paradigm where technologies and management systems are designed. So far, the notion of mastering nature to produce food and fiber, neglecting the functional and structural attributes of original ecosystems, has characterized farming practices.[2] In tropical regions, the results of such a production mode tend to be more acute, given the complexity and biological diversity of such areas (Primavesi 2006). Moreover, it is in the rural areas of tropical and subtropical regions where most of the world's poor people are concentrated.

The remedies proposed to alleviate poverty, mostly based on agricultural intensification through the use of technological packages, are at the same time the causes for the depletion of natural resources. Pressure for economic growth is at the root of a series of environmental problems such as deforestation, biodiversity loss, overgrazing, water scarcity, soil erosion, desertification, and land degradation, compromising agroecological functions and the resource base for agricultural production. The consequences are livelihoods under risk and increased vulnerability to environmental risks and to fluctuations in the prices paid for agricultural products, generating a vicious circle.

[2] This assumption is based on the perception that humans and nature are two separate entities, and on the idea that humankind is outside the natural world. Assuming this initial argument as true, it is inexorably the conception of humans mastering nature. The current agricultural model is fully founded on this premise. Even the jargon utilized in agricultural activities reflects this idea. The land should be *cleared* to make way for useful crops; we have to use pesticides to *control* pests and diseases; plants and animals are *domesticated* for use by humans. In addition, it clearly demonstrates a utilitarian approach to nature.

Conversely, the theoretical approach to designing sustainable agriculture systems should consider, as much as possible, the basic patterns of the original ecosystem. Husbandry practices must be able to recuperate functional and structural characteristics of the ecosystem and simultaneously produce marketable products (Gliessman 1998). Agroforestry, as a land-use system that mimics the natural pattern integrating commercially crops with trees is, therefore, more appropriate for tropical and subtropical regions (Nair 1993; Michon et al. 1997; Michon et al. 1998; Hobbs et al. 1999; Schroth et al. 2004; Nair 2007). Such complex land-use practices propitiate the colonization of a variety of below and above-ground organisms restoring ecological processes (Anderson et al. 1993; Rao et al. 1997; García-Barrios et al. 2004; Fernandes et al. 2006; Mafongoya et al. 2006; Schroth et al. 2006). As a consequence, a number of environmental services such as carbon sequestration, soil protection, pollination, habitat for wildlife, and nutrient and water cycling are also promoted (Beer et al. 2003; McNeely 2004; Schroth et al. 2004).

Coupled with the ecological benefits promoted by agroforestry systems, a number of social and economic advantages are enhanced as well. Food security and food sovereignty are likely to be supported, as the diversity and availability of edible products increase (Schreckenberg et al. 2006). Diversified diet also contributes to better health. Consumption of a variety of products, principally some traditional foods, can help to improve the human immune system (Garí 2002). Several products are important in cultural terms, as they have indigenous knowledge systems associated with their cultivation, harvest, preparation, and may form the basis for important ceremonies. Alternatively, some products can constitute new sources of income, principally for women, and create job opportunities (harvest, processing, marketing, etc.). Finally, complex production systems are likely to be more ecologically and economically resilient, which is particularly important for poor farmers (Michon et al. 1998).

7.2.2 The living soil

Despite the advancements and technological improvements in agronomic science over the last few decades, soil management practices still generally reflect a reductionist view. The outcome is a series of threats such as erosion, contamination, reduction of organic matter, compaction, sealing, landslides, flooding, salinization, and biodiversity loss, which in turn make the whole humankind vulnerable (Eijsackers 2004). Soil is a living structure, a diverse and integrated system formed by chemical, physical, and biological components. As such, faming practices should be designed to comply with the complexity and dynamism of the soil system (Uphoff et al. 2006).

A principle that should guide soil management strategies is the reliance upon internal processes, rather than the dependence on external inputs to promote agricultural production (Uphoff 2006). Contrary to the mechanist approach of Green Revolution technologies, where soil constraints are “repaired” with chemical fertilizers and other external amendments, a series of endogenous processes and synergetic relationships such as nutrient cycling from lower soil horizons by trees and shrubs, biological fixation by bacteria, mycorrhizal associations to enhance phosphorous uptake, and organic matter decomposition by micro and macro-organisms can support sustainable food and fiber production (Cardoso et al. 2003b; Cardoso et al. 2003a; Cardoso et al. 2006; Dazzo et al. 2006; Fernandes et al. 2006; Habte 2006; Mafongoya et al. 2006; Oberson et al. 2006; Primavesi 2006; Schroth et al. 2006; Thies et al. 2006; Uphoff 2006; Uphoff et al. 2006). This is very important for the marginalized and poor people, as they tend to live in areas less endowed with production means (less fertile soils, steep slopes, arid zones, etc.).

Another principle of agricultural production that was extensively demonstrated, but rarely reflected in farming strategies, is the connection between soil and plant health (Chaboussou 2004). Pests and diseases are expressions of nutritional imbalances in the plant, which are directly affected by soil health (Ratnadass et al. 2006). A proper supply and conservation of soil organic matter is particularly important in this respect, as it helps to promote plant health. Management strategies such as green manure/cover crops, mulching, application of composts, vermicomposts, and other organic amendments are recommended to increase the soil organic matter content (Bunch 2006; Jack et al. 2006; Primavesi 2006; Ratnadass et al. 2006; Robertson et al. 2006).

Some requirements and recommendations for a vital soil can be summarized as follow (Primavesi 2006; Uphoff et al. 2006):

- An adequate soil structure to support (1) water and air penetration, (2) soil life, and (3) good root development;
- Soil protection to prevent adverse effects of sun and rain;
- A diverse and abundant population of soil organisms;
- An extended root-system to explore the availability of nutrients in a wide soil profile;
- The use of crops adapted to particular environment instead of struggling to suit the environment to crop exigencies;
- The use of windbreaks to protect cropped areas from excessive evapotranspiration; and
- Reducing and avoiding the use of heavy machinery to minimize soil compaction.

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