Farming like we're here to stay

The mixed farming alternative for Cuba

Promotor:
Prof. dr. ir. H. van Keulen
Hoogleraar bij de leerstoelgroep Plantaardige Productiesystemen
Wageningen Universiteit

Co-promotor:
Dr. ir. E.A. Lantinga
Universitair hoofddocent bij de leerstoelgroep Biologische Landbouwsystemen
Wageningen Universiteit

Promotiecommissie:

Prof. dr. ir. P.C. Struik	(Wageningen Universiteit)
Dr. ir. J.B. Schiere	(La Ventana Consultancy, Bennekom)
Dr. ir. J. Daane	(ICRA, Wageningen)
Dr. J. Wright	(HDRA, UK)

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Fernando R. Funes-Monzote

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To my mother –in memory– and to my father,
for their everlasting example of integrity
To Claudia
To Diego and Fabio

Most of the ideas contained in this thesis are the result of more than ten years of joint research with my mother, Dr. Marta Monzote. I had the pleasure to share with her, in her double role of mother and colleague, the most inspiring moments in my professional career thus far. I am honored to continue exploring our common research questions and societal concerns, with her memory as a pillar of strength within me.

Abstract

Specialization, as opposed to diversification, and export orientation have been historically the basis for patterns of dependence on external inputs and centralized decision-making in the Cuban agricultural model. Low autonomy in farmers' decision-making (centrally-planned collective farms), scarcity of production inputs and extensive areas of abandoned land on the one hand, and increasing food imports on the other, are threatening sustainable development in the country. However, small farmers and an emergent sector of land tenants under a usufruct system are showing that food for the Cuban population can be produced efficiently and sustainably at home. These small-scale producers, cultivating about 25% of the available agricultural land, generate more than 65% of domestic food production, putting increasing pressure on the collective sector.

Over the last 15 years, agro-biodiversity and food self-sufficiency have been officially recognized as drivers for increasing productivity and autonomy in decision making. The economic crisis that started in 1990 in Cuba had a strong negative impact on agriculture, but at the same time created conditions for emergence of a new model strongly based on principles of organic agriculture and agro-ecology. Various alternative systems, aimed at sustainable development, were developed during that period, but most of these lacked an integrative perspective on farming system development and followed an input substitution scheme in which high-input industrial practices were substituted by low input agro-ecological ones. Conversion from specialized (monoculture) farming systems into mixed (diversified) farming systems is considered by that model to be an effective step towards implementation of sustainable practices in agriculture. Thus, the current research is aimed at filling some of the conceptual, practical and methodological gaps that constrain a comprehensive transition from specialized dairy farming systems to mixed crop-livestock systems at farm and regional levels. For that purpose a methodological framework was tested for evaluating, monitoring, comparing, analysing and designing land use management strategies for the conversion of specialized dairy farming systems into mixed crop-livestock farming systems.

Our results show that in comparing different systems, the issue is not simply one of high or low input, specialization or diversification, but that farming system-specific characteristics and the way in which inputs and agro-diversity are interrelated and managed also are at stake. We found that even in low external input agriculture, when comparing specialized and mixed farming systems, the latter achieved higher levels of food production and higher energy and protein production, as a result of more efficient use of natural resources available on farm (or locally). The unique position of the

Cuban agricultural sector, both nationally and internationally, provides a context in which these results are highly relevant. High oil prices, climate change and high prices for food in the international markets, combined with national awareness of the necessity to substitute food imports for nationally grown food, as well as a recent government decision to make all unproductive land available for cultivation, open a wide spectrum of possibilities for adoption of alternative technologies. Diversification, decentralization, and movement towards food self-sufficiency are major trends in Cuban agriculture. However, these trends must be translated into systematic and consistent policies to ensure reliable and sustainable production, as well as agriculture's contribution to a viable economy. Therefore, changes in Cuban agriculture should be driven by conscientious and scientifically-based policies.

Keywords: Crop-livestock, agro-diversity, mixed farming, dairy production, agro-ecological indicators, sustainability, energy efficiency, local development, Cuba

Preface

Ten years ago, in September 1998, I came for the first time to Wageningen to participate in the 26th International Course on Dairy Farming in Rural Development. At that point I couldn't imagine that two of the main organizers of the workshop 'Mixed Farming Systems in Europe', part of the APMinderhoudhoeve project, taking place the same year, prof. dr. ir. Herman Van Keulen and dr. ir. Egbert Lantinga, would guide me as supervisors through the process of my PhD completion. While participating in the course at the former International Agricultural Centre, a journalist from the local newspaper interviewed me and published this article below.

Ecological self-sufficiency best way forward for Cuba[1]

> *"Cuba is on the brink of a major economic transition. Now is the critical moment to set a plan of action for an alternative agriculture." Agronomist Fernando Funes from the Cuban Association of Organic Agriculture (ACAO) believes his country should continue along the road towards ecological self-sufficiency.*

"A mistake that Cuba has made in the past is to allow itself to depend too heavily on external inputs for its food security." So concludes Fernando Funes, whose country has been hampered by a severe economic and food security crisis since 1990 when its main trading partner, the Soviet Union, dissolved. This loss came on top of the already existing trade embargo imposed since the 1960s by Cuba's powerful neighbour the United States.

The scale of the Cuban ecological agriculture alternative is unusual, according to PhD student Julia Wright, who is analysing the ecological movement in Cuba for her research at the WAU. "Being internationally isolated has compelled Cuba to make inroads on ecological agriculture in a way not seen elsewhere", explains…

… ACAO is also an unusual agriculture network, Wright finds, because it has targeted researches right from the start to work together with farmers. Funes has been involved with ACAO since its inception, and now sits on the seven-member executive board, in charge of international relations as well as documentation.

The network includes over 900 members and its aims include redesigning Cuban agriculture on a more sustainable basis, to create an ecological certification system, and to raise awareness among the population to the possibilities and advantages of ecological agriculture. The ACAO, along with other Cuban institutes, has been

[1] Extracts from the interview by journalist Amunda Salm appeared in: Wub, No. 34, 1998. p. 6.

> conducting experiments on 17 farms over the last three years, to investigate the possibilities of integrating crop and livestock systems as promoted by ecological agriculture… Funes hopes to continue this research to investigate trends over a longer term for a PhD in Wageningen.
>
> For Funes, these developments are a race against time. There are many reasons to believe that Cuba is now on the brink of a major economic transition. A recent vote by the United Nations showed a record level of support from 92% of its members to end the trade embargo against Cuba. "If ACAO can prove the benefits of a self-sufficient ecological model before international markets open up again, then support will already be in place for choosing an alternative path instead of going back to the old model of external input-dependent conventional production", Funes maintains.

It is satisfying to see that ten years later, most of the ideas contained in this interview are finally part of the Cuban official political agenda. This thesis is about progress and failures, but it is also a call for further changes in the Cuban agricultural sector. Reflecting on these 15 years of transition, the greatest gain from this period is that Cubans have started to think more in terms of innovation and change. Many of us involved in Cuban agriculture today have been inspired to concertedly and consciously promote "farming like we're here to stay": that is, in a way that reflects our shared dreams. My hope is that this thesis is a useful contribution towards realizing those dreams.

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Chapter 1

General introduction

1. The context of Cuban agriculture

Cuban agriculture is in a process of profound and unavoidable change. The main drivers for the changes in agricultural practices have been economic pressures, i.e. scarcity of capital and external inputs to continue development according to a 'green revolution' paradigm, rather than a conscious desire for environmental conservation or the development of sustainable technologies based on scientific approaches. Studies in the fields of agronomy, economics, and the social sciences have demonstrated chances for the development of sustainable agricultural systems that combine technical feasibility, economic viability, ecological maintainability and social acceptability. However, in their implementation, an integrated inter-disciplinary perspective is lacking. The current study aims at filling some of the conceptual, methodological and practical gaps that constrain a smooth transition to more sustainable farming systems in Cuba, using the dairy sector as an example for the purposes of research.

Current developments in the Cuban agricultural sector are influenced by three fundamental drivers: diversification, decentralization, and the aim for national food self-sufficiency. These drivers emerged at the beginning of the 1990s as a consequence of the economic crisis associated with the collapse of the Soviet Union. In the period 1960–1990, the mainstream of the Cuban agricultural sector was characterized by industrial, intensive production technologies, dependent on external inputs. This industrial model, while productive in the short term, was inefficient and harmful to the natural environment.

Figure 1 shows four major aspects of 'technical progress' in the Cuban agricultural sector as a result of the implementation of the high-input system. During the 1980s, intensity in the use of fertilizers (A) reached levels comparable to that in European countries, but declined at the beginning of the 1990s as a result of the collapse of the economy. In the early 1970s, tractor density reached a value of one per about 50 ha, comparable to that in most developed countries (B). Note that in 1960 the situation in Cuba was already favourable compared to the Central America & Caribbean region, but support from the socialist countries allowed a tripling in tractor density within a decade. Labour intensity declined by half between 1960 and 1975, to reach at the end of the 1980s a value only slightly above that in Europe, i.e. about five hectares per agricultural worker (C). The proportion irrigated land in agriculture doubled between 1960 and 1985 (D).

The conventional model achieved substantial increases in land and labour productivity; however, at the expense of high input levels that were acquired at subsidized prices from the socialist countries of Eastern Europe and the USSR. In turn, Cuba exported to those countries raw materials and food products at preferential fixed prices. At first, that seemed a favourable situation for Cuban agriculture: an

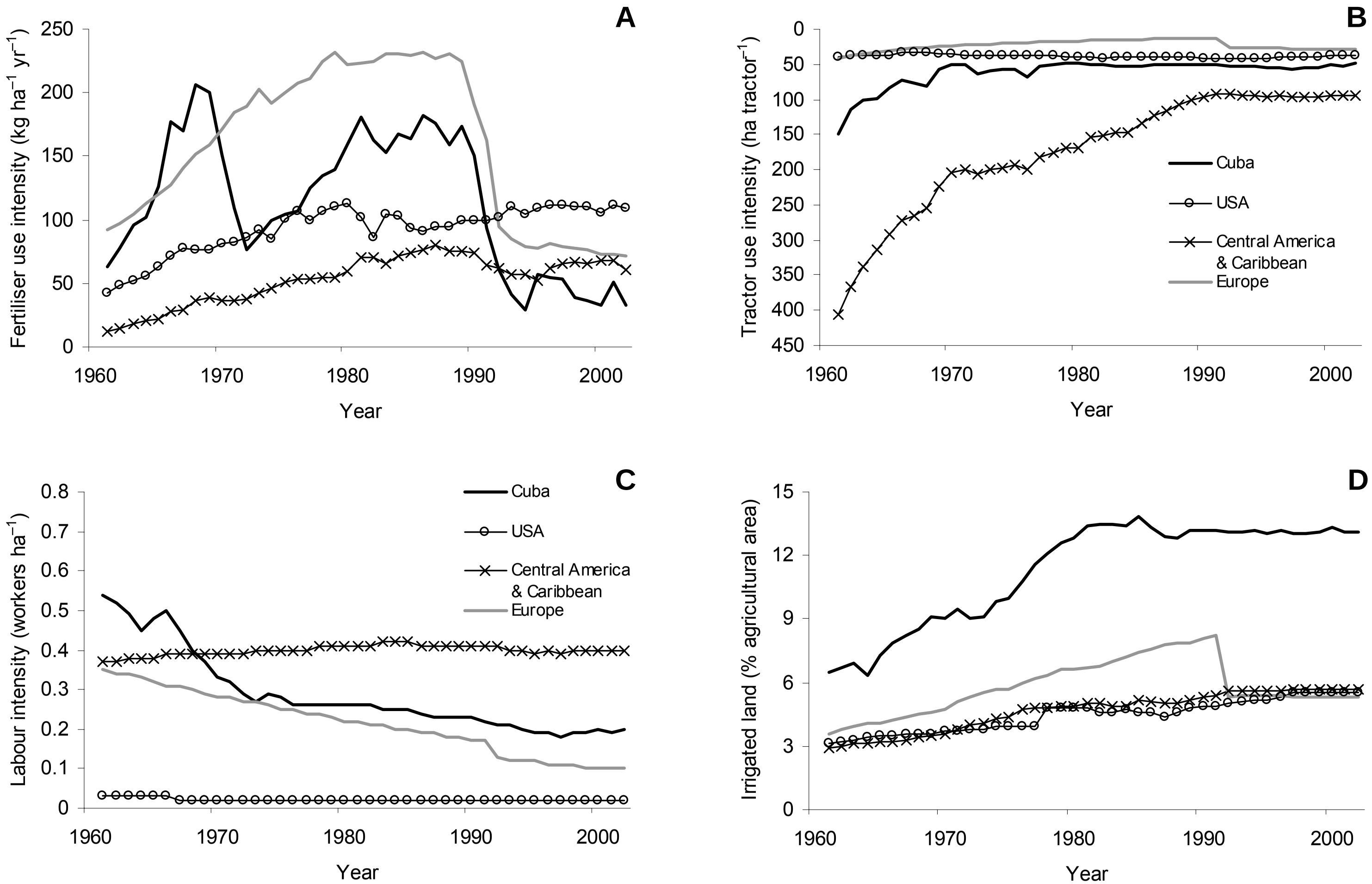


Figure 1. Technical evolution of the Cuban agricultural sector before and after the collapse in 1990. Source: FAO, 2006. Fertilizers use intensity was calculated as the total amount of fertilizer nitrogen (N), phosphate (P_2O_5) and potash (K_2O) per hectare of agricultural land per year.

almost unlimited access to technology and resources such as energy and capital to develop the sector. However, it created an enormous dependence with serious consequences in terms of food insecurity that became apparent at the onset of the crisis. On the other hand, the results from the input-intensive and expensive technologies did not live up to the expectations, and they had serious negative environmental impacts, i.e. loss of biodiversity, contamination of groundwater, soil erosion and deforestation (CITMA, 1997). These impacts also had serious socio-economic consequences, such as large-scale migration of the rural population to the cities, resulting in loss of many experienced farmers with their indigenous knowledge and rural traditions that will take a long time to recover. Undoubtedly, many of the inequities characteristic of rural Cuba before 1959 were abolished. The rural population was concentrated in rural towns, access to medical care and education became guaranteed, roads were constructed and electrification of the countryside was implemented.

Despite the high-quality infrastructure and the increasing input of capital, fertilizers and concentrates, land productivity started to decline in the mid-1980s, a development that was under discussion just prior to Cuba's economic collapse, when the government was engaged in formulation of a national food programme (ANPP, 1991; Monzote et al., 2002). The fragility of the model emerged in 1990 after the collapse of the Soviet Union. The economic crisis triggered a search for more sustainable agricultural systems within the framework of an impressive national movement (Funes et al., 2002; Wright, 2005).

According to official data, the overall Cuban economy grew on average at about 10% annually over the period 2005–2007. This was achieved despite adverse climatic conditions, such as the worst drought in 100 years, and three hurricanes that caused damages estimated at 3.6 billion US$ (some 7.9% of the Gross Domestic Product in 2005); (CEPAL, 2006). The highest rainfall ever was recorded in the rainy season of 2007. Agricultural production was strongly negatively affected, but the presence of a substantial low-input small-scale farming sector, that was less severely affected, somewhat cushioned the shock (Funes-Monzote, 2007). Cuba's tourism sector, with an increase from about 0.2 billion US$ in 1994 to 2 billion US$ in 2004 (Quintana et al., 2005), and its social capital (physicians, teachers, sports trainers, technicians) are leading drivers for economic growth. For example, in 2005 the service sector accounted for 70% of the gross national product (EPS, 2006). Economists interpreted this as an indication for a shift from an economy based on production to an economy based on services. In addition, the political and economic alliance with Venezuela, the fifth largest oil exporter in the world, a fair degree of self-sufficiency in energy requirements, with 50% of Cuba's oil consumption extracted locally, trade agreements with China and Brazil, and the diversification of import and export markets, are features of the recovery of the national economy. But, what does this imply for agriculture?

Despite the acknowledged advances in the low-input alternatives for food production, the country still imports about 50% of its food needs. Food imports have been rising steadily over the past ten years from about 0.7 billion US$ in 1997 to 1.5 in 2007, proportional with the improved purchasing capacity of the country. However, increasing food prices in the international markets of about 40% in 2007 and growing dependence on food imports threatening the country's economic independence, have led to recent political statements stressing the need for prioritization of the domestic food production sector (Castro, 2008). In fact, it is contradictory that in a period of economic growth, to achieve food security, most resources are invested in importing food, instead of in stimulating local food production.

The accumulated experience in the small-scale agricultural sector during the 1990s is a valuable starting point to up-scale policies towards that goal. In Cuba, enough land is available to meet the food needs of the population. Despite occurrence of soil erosion, deforestation and loss of biodiversity over the last fifty years, conditions in Cuba are still exceptionally favourable for agriculture. About 6 million hectares of land in plain areas and another million in slightly hilly areas are suitable for agriculture for a population of 11 million. Currently, more than half of this land is not cultivated and on most of the remaining area, labour and land productivity and resource use efficiency are low. Labour and capital shortages, the main constraints for agricultural production, are the result of inappropriate rural policies, based on the green revolution model, that have led to depopulation of the rural area. In 1959, about 75% of the population lived in rural areas, which declined to about 25% in the 1980s, where it stabilized (ONE, 2007).

In summary, during the last 50 years, Cuban agriculture has experienced two extreme models for food production. First, an intensive high-external input approach, followed, post-1989, by a low-external input model (Figure 1). Cuba has been the only country in the world to experience such a dramatic downward shift in intensity, which however, may turn out to be a blessing in disguise, as it can serve as a starting point for development of sustainable agriculture at national scale.

2. Sustainable agriculture in Cuba

Since 1990, a transition towards sustainable agriculture is taking place all over Cuba. This transition, by necessity driven by input substitution, i.e. biological replacing chemical inputs, is being guided by practices and methods derived from organic agriculture and agro-ecology. Within this setting, small-scale traditional farmers and 'new' urban dwellers that cultivate small plots in the urban and peri-urban area, have developed innovative technologies to adapt their farming systems to the limited external resource availability, with a strong emphasis on environmental protection and agro-diversity (Murphy, 1999; Cruz and Sánchez, 2001). Various combinations of the resulting set of technologies have been adopted by an extensive group of engaged farmers, supported by researchers, policy makers and development agents of several NGOs (Rosset and Benjamin, 1994; Sinclair and Thompson, 2001; Funes et al., 2002; Wright, 2005). Management of natural resources according to agro-ecological principles, with a strong emphasis on participation, appeared an effective methodology in the conversion of Cuban agriculture from the export market-oriented, centralized, high external input model to a local market-oriented, decentralized, low input model.

Mixed farming systems (MFS) in particular, appeared to be a technology that provided solutions to many of the current problems in 'Low External Input' specialized dairy farming systems (DFS). Benefits accrue from more intensive use of available natural resources at farming system level, through more diversified and complex system interactions. Sustainable intensification of MFS, through best use of resources for both crop and animal production, allows attainment of food self-sufficiency and concurrently yields marketable products that contribute to household income without degrading the environment.

The highly diverse, heterogeneous and complex small farms in Cuba have demonstrated substantially higher land productivity and resource use efficiency than the specialized crop and livestock systems that are centrally managed. About 65% of the marketed locally produced food is being grown by small farmers that cultivate half of the total land in use by agriculture (Granma, 2006a). In 2006, small farmers, using about 13% of the grazing land (some 0.3 million ha), owned 43.5% of the national cattle herd (González et al., 2004; ONE, 2007) and in March 2008 they owned even 55% of the herd (ONE, 2008).

Probably the success of small farmers resides in the continuous innovation process they are involved in, in which they generate day to day solutions to problems as they emerge (Chambers et al., 1998). Facilitating and documenting such processes of local innovation, as well as implementing joint research looking for appropriate management strategies, are major challenges. An eventual opening of the agrarian economy may stimulate implementation of locally-based strategies on a larger scale. Furthermore, incorporation of scientific methodologies and application of scientific knowledge within a more integrative framework are relevant in the process. Hence, scientists must participate in and learn about the multifaceted and dynamic process for which classical science alone does not possess all the answers. This research documents ways in which local 'lay' knowledge does work from a scientific standpoint.

3. ECOFAS: General approach for studying and developing MFS

Due to the multifaceted and dynamic characteristics of agro-diverse farming systems in less favourable and favourable environments in today's Cuba, a broad sustainability analysis is required. Socio-economic conditions in the country are fairly homogeneous, while basically all citizens are fully integrated in society and have equal opportunities to participate in the national economy and equal access to social services. According to Pretty (1995), 'sustainability is a complex and contested term and precise and absolute definitions are impossible'. He states that in any sustainability analysis it is important to clarify first what is being sustained, for how long, for whose benefit and at whose cost, over what area, and measured by what criteria.

To examine the possible role of MFS in sustainable development in Cuban agriculture (*over what area*) this thesis focuses on comparison of the performance of specialized DFS and MFS at experimental station, regional and national scales. The process of conversion to and adoption and adaptation of MFS is taking place for an 'indefinite period of time', i.e. new approaches and paradigms for sustainable agricultural production are developing continuously, in response to the dynamic context (*for how long*). Agro-diverse farming practices at small and medium scale aim at optimizing internal resources management such as maximum recycling of nutrients and energy and production of environmental services. Conversion from large-scale to smaller-scale farming systems requires investments in adaptation of infrastructure, i.e. building houses and improving transport facilities and in creation of incentives to start farming, i.e. provide credit for purchase of inputs, guarantee product prices, etc. (*at what costs*). Such investments should improve opportunities to increase land productivity and the quality of life for rural populations, thus providing a positive socio-economic impact. The conversion strategies to MFS should be designed with all relevant stakeholders and be motivated by the objective to solve local critical points for sustainability and with the ultimate goal of benefiting society in general (*for whose benefit*).

Ultimately, MFS integrate the specialized knowledge of plant and animal production with the benefits of crop and livestock diversity. Therefore, many individual technological approaches are combined into a more holistic management programme. Agro-ecology, claimed as the 'science for sustainable agriculture' (Altieri, 1995), provides the basic ecological principles to study, design and manage agro-ecosystems that combine production and natural resource conservation, and are culturally sensitive, socially just and economically viable. One way of integrating these specialized management concepts into a holistic system based on agro-ecological principles, has been developed in Cuba as the DIS (diversified, integrated, and self-sufficient) systems approach (Funes-Monzote, 2004). In fact, these three terms encompass the main principles guiding adaptation of farming systems to the site-specific and continuously changing situation.

Starting in 1994, this approach has been developed and tested at farm and cooperative levels (Monzote et al., 1999). Seven research teams from different parts of the country took part in the three stages of a project, designated 'Designs for crop-livestock integration[2] at small and medium scale' coordinated by the Ministry of Science, Technology and Environment (CITMA).

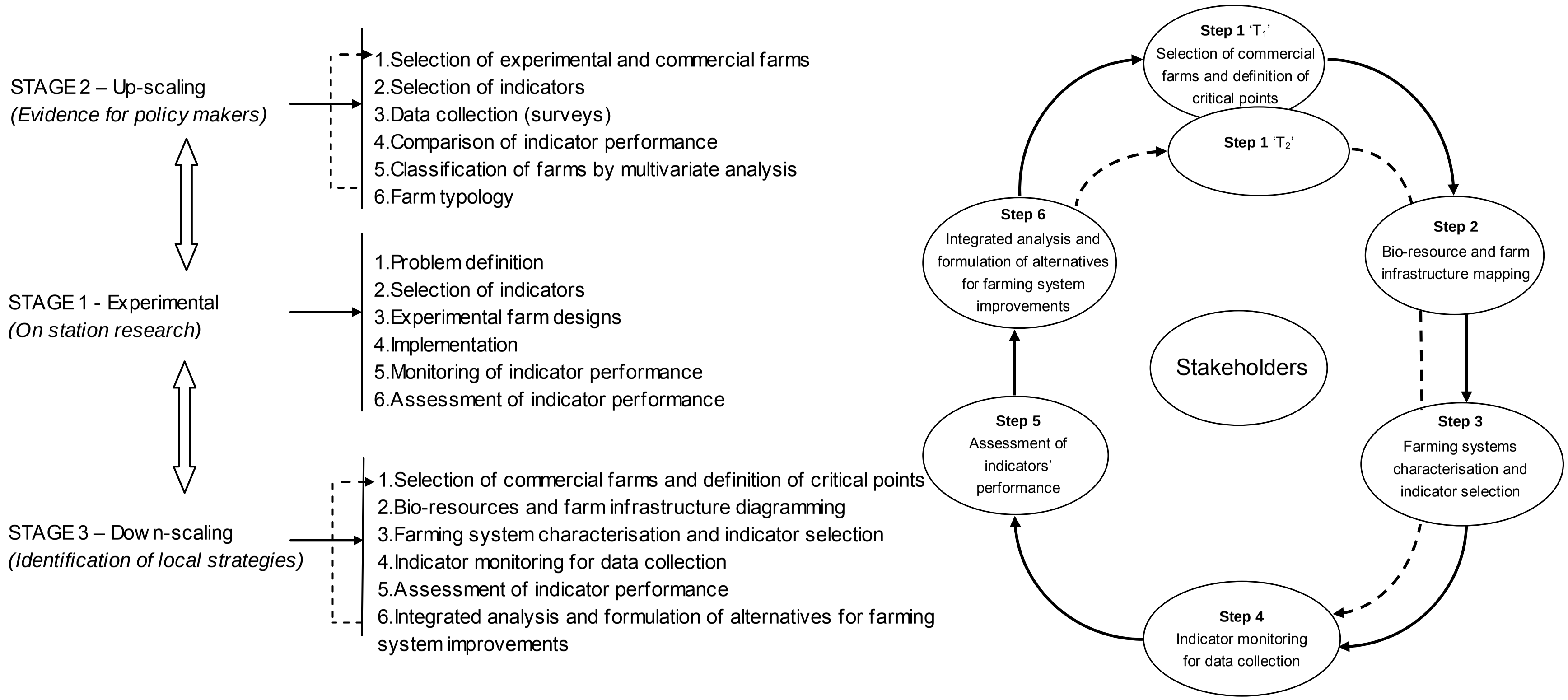
Each of the three components of DIS systems has its particular system-specific characteristics, but all DIS systems share several basic principles, including: (i) maximize system bio-diversification, (ii) emphasize soil fertility conservation and management, (iii) maximize use of renewable energy and optimize energy (re-)cycling processes, (iv) emphasize efficient use of locally available natural resources, and (v) maintain high levels of resilience.

Diversification refers to the process of combining different crop, animal and tree species, which provides possibilities for development of diversity in other organisms, such as soil biota, associated with the decomposition of organic matter, and insects and other fauna involved in biological control. In addition, throughout the year a variety of commercially viable products is produced. Characteristic for the DIS systems is that in selection of species and races, emphasis is on adaptation to stress conditions, local market demands and farmers' aspirations and preferences.

Integration refers to strengthening the links among the various biophysical components. The system, once fully integrated, operates and reacts as a whole, and its potential is only realized when interactions among all its components are optimal. Integration of crops, livestock and trees provides opportunities for system multi-functionality as an operationalization of agro-ecological principles (Altieri, 1995, 2002; Gliessman, 2001).

Self-sufficiency refers to the extent to which the system is able to satisfy its own needs without requiring considerable external inputs. A self-sufficient system thus produces enough high quality foods and feeds to satisfy the nutritional requirements of the household, while at the same time generating products and services for commerciali-zation to satisfy its non-food requirements. The ultimate goal of any sustainable production system is to achieve its self-sufficiency at the smallest possible cost, with minimum environmental impact and maximum satisfaction.

[2] In this thesis, the term 'Integrated Farming System' is used interchangeably with the term 'Mixed Farming System'.



A **B (STAGE 3)**

Figure 2. Schematic representation of The Ecological Framework for Assessment of Sustainability for the conversion from specialized dairy farming systems towards mixed crop-livestock farming systems (A) and the operational cycle of STAGE 3 for the identification of integrated strategies for local farming systems development (B). Adapted from: Vereijken, 1999; Van Ittersum et al., 2004; López-Ridaura et al., 2005.

The applicability of the DIS approach in the conversion of Cuban agriculture has been assessed by applying the Ecological Framework for the Assessment of Sustainability (ECOFAS). This is a dynamic framework developed over a period of about 10 years, with the aim of guiding technological implementation and methodological adaptation during conversion from specialized DFS into MFS (Figure 2). Using the ECOFAS methodology, each of the research teams identified locally-adapted strategies that could potentially impact society, environment and economy. ECOFAS consists of a comprehensive three-stage programme for evaluating, monitoring, comparing, analysing and designing management strategies for converting specialized farming systems into mixed farming systems. Each stage is related to a different hierarchical level of analysis. Stage 1 (Chapter 3) is the experimental assessment of the conversion process. In Stage 2 (Chapter 4), multivariate statistical methods are used to analyse various agro-ecological variables and indicators of sustainability in a larger set of systems. This second stage, as a scaling-up of the results achieved in Stage 1, provides a framework for policy makers. In Stage 3 (Chapter 5), participatory methods of research and action are used to diagnose and characterize farms and monitor their progress towards achieving multiple objectives using a set of agro-ecological, economic, and social indicators. The final goal of ECOFAS is identification of local strategies to alleviate constraints (critical points) and definition of appropriate venues to attain the objectives of sustainable agricultural production (Chapter 5).

4. This thesis

4.1 Objectives

The general objective of this thesis is to test ECOFAS as a methodological framework for evaluating, monitoring, comparing, analysing and designing land use management strategies for the conversion of specialized dairy farming systems into mixed crop-livestock farming systems. A three-stage research programme including the following specific objectives was carried out:

1. To assess the consequences of conversion of a ‘Low External Input’ DFS into MFS by monitoring the dynamics of 15 Agro-Ecological and Financial performance Indicators (AE&FIs) over a six-year period (Stage 1).
2. To examine whether the results from the small-scale experiment are also attainable under commercial conditions, and for a larger number of farms (Stage 2).
3. To identify alternative local MFS strategies to guide the process of conversion towards more integrated and sustainable land use (Stage 3) with the ‘San Antonio de Los Baños’ municipality as an example.

4.2 Outline

Chapter 2 presents a general overview of Cuban agriculture and describes the transition process from intensive specialized farming systems to low-input mixed farming systems during the 1990s. Perspectives of integrated approaches for attaining sustainability in the future are discussed. Chapter 3 describes a six-year study at experimental scale, in which a set of agro-ecological and financial indicators are evaluated for a small-scale specialized and two mixed farms with different proportions of land allocated to arable farming. Chapter 4 scales up the results of the study at experimental station scale and examines to what extent they also hold for larger commercial farms, in different climate and soil conditions. Chapter 5 presents a six-step cyclical process for the operationalization of sustainability of mixed crop-livestock farming. Farmers' perspectives are considered by using participatory methods of diagnosis, monitoring, and analysis while locally based strategies are defined. Chapter 6 discusses the general ideas that emerged from the results and projects future prospects for the development of the proposed methodology and its application.

Chapter 2

Towards sustainable agriculture in Cuba

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1. Introduction

Cuba has a long tradition as an exporter of agricultural crops produced under conditions of monoculture and natural resource extraction (Le Riverend, 1970; Moreno Fraginals, 1978; Marrero, 1974–1984). Practised over approximately four centuries, these agricultural patterns have generated a dependence on imported inputs and caused an enormous negative environmental impact on soils, biodiversity, and forest cover (CITMA, 1997; Funes-Monzote, 2008). During the last 15 years, however, agricultural development has been reoriented (Rosset and Benjamin, 1994; Funes et al., 2002; Wright, 2005). Today, agricultural production in Cuba is concerned, as never before, with food self-sufficiency and environmental protection. In 1994, the National Programme for Environment and Development (the Cuban adoption of United Nations Division for Sustainable Development-Agenda 21) was instituted, and two years later the National Environmental Strategy was approved (CITMA, 1997; Urquiza and Gutiérrez, 2003). In 1997, "The Cuban Law of Environment" became the environmental protection policy of the State (Gaceta Oficial, 1997). Although environmental protection is still not practised as fully as it might be, government support for preserving the environment has helped put Cuban agriculture on a more sustainable course.

A principal goal of the Revolution of 1959 was to resolve what were perceived as long-standing problems of Cuban agriculture, mainly national and foreign (basically North American) ownership of large farms and lack of agricultural diversification (Anon., 1960; Valdés, 2003). However, the rapid industrialization of State-controlled agriculture based on conventional methods after the Revolution tended to concentrate land in large State enterprises, and consequently resulted in environmental problems similar to those caused by the old *latifundios.* Although on one hand, this model successfully increased both levels of production and rural well-being owing to the social goals of the political system, on the other hand it produced negative economic, ecological, and social consequences that cannot be ignored.

The excessive application of externally-produced agro-chemical inputs (i.e. produced outside the country), the implementing of monocultural, large-scale production systems, the concentration of farmers in the cities or rural towns, and the dependence on few exports conferred a high vulnerability to the nationally established conventional agricultural model. This vulnerability became evident at the beginning of the 1990s with the disintegration of socialist Eastern Europe and the USSR, when the majority of the favourably-priced inputs, both material and financial, disappeared. Cuban agriculture, along with the other branches of the national economy, entered into its greatest crisis in recent history; at the same time, however, these factors provided exceptional conditions for the construction of an alternative –and far more sustainable– agricultural model at a national scale.

The transformation that occurred in the Cuban countryside during the last decade of the 20th century is an example of a large-scale agricultural conversion from a highly-specialized, conventional, industrialized agriculture, dependent on external inputs, to an alternative input-substitution model based on principles of agro-ecology and organic agriculture (Altieri, 1993; Rosset and Benjamin, 1994; Funes et al., 2002). Numerous studies of this conversion attribute its success to both the form of social organization employed and the development of environmentally sound technologies (Rosset and Benjamin, 1994; Deere, 1997; Pérez Rojas et al., 1999; Sinclair and Thompson, 2001; Funes et al., 2002; Wright, 2005).

Unlike the isolated sustainable agriculture movements that have developed in most countries, Cuba developed a massive movement with wide, popular participation, where agrarian production was seen as key to food security for the population. Still in its early stages, the transformation of agricultural systems in Cuba has mainly consisted of the substitution of biological inputs for chemicals, and the more efficient use of local resources. Through these strategies, numerous objectives of agricultural sustainability have been serendipitously reached. The persistent shortage of external inputs and the surviving practices of diverse production systems have favoured the proliferation of innovative agro-ecological practices throughout the country.

Under current conditions, however, with about 5000 enterprises and cooperatives and nearly 400,000 individual producers (Granma, 2006b), neither the conventional model nor that of input substitution will be versatile enough to cover the technological demands of such a heterogeneous and diverse agriculture. Consequently, the author believes it is necessary to develop a more integrated, participatory, long-term agro-ecological focus and to more strongly combine the economic, ecological, and socio-political dimensions of agricultural production. A mixed-farming systems approach is presented here as the next step toward sustainable agriculture, one that can address these needs at national scale.

2. Geographic and biophysical background

Cuba, the biggest of the Caribbean islands, is strategically located between the two Americas, which allowed it to play an important role for the Spaniards in their conquest of the New World. Cuba is approximately three times the size of The Netherlands, and half the size of Minnesota, the 12th-largest state in the US. With a total area of 110,860 km^2, the country is dominated by expansive plains (occupying about 80% of the total) and three well-defined mountain ranges (Figure 1).

Cuba may even be considered a micro-continent, owing to the highly diverse nature of its natural biodiversity, soil types, geographic landscapes, geological ages, and microclimates (Rivero Glean, EAEHT, Ministry of Tourism, Havana, pers.

comm.). The country comprises 48 well-defined natural regions, each with specific characteristics of climate, vegetation, and landscape, ranging from rainforest to semi-desert (Gutiérrez Domenech and Rivero Glean, 1999). Such heterogeneity favours a high natural biodiversity: the island supports 19,631 known plant and animal species, of which 42.7% are endemic (ONE, 2004).

A

B

Figure 1. Cuba in the Caribbean region (A) and its physical features (B).

Cuba is long (1,250 km) and thin (the average width is less than 100 km, with a maximum of 191 km and minimum of 31 km). This physiography facilitates sea transport. The most important cities, connected by some 5,700 km of railway, are located an average of less than 40 km from the coast, with its more than 200 bays and coves.

According to the climate classification system recognized by the Food and Agriculture Organisation (FAO) (Köppen, 1907), Cuba's climate is tropical savannah (Aw). However, it is also considered to have a tropical oceanic climate (Alisov and Paltaraus, 1974). These and other general classification criteria have been adapted in various forms to heterogeneous Cuban conditions (Lecha et al., 1994). Except for some specific areas, the whole island is influenced by the ocean. Near to the Tropic of Cancer and the Gulf Stream, the island receives the destructive effects of tropical storms and hurricanes (with winds of 150 to 200 km h^{-1} and more) as well as severe droughts that directly affect agricultural activity and the infrastructure in general. The climate is characterized by a wet season, with high temperatures and heavy rains, between May and October (70% of the total annual rainfall) and a dry season from November to April with low rainfall and cooler temperatures (Table 1).

Although Havana is the main economic center, each of the country's 14 provinces is important agriculturally, culturally, and economically. Population density is higher in Cuba (101.7 inhabitants km^{-2}) than in Mexico (50), Central America (68), and South America (17), but lower than the average for the Caribbean region (139) (FAOSTAT, 2004). More importantly, Cuba has a high percentage of arable land, so that each arable hectare only needs to feed less than two people per year. Whereas agricultural land accounts for about 34% of the total land area in Latin America as a whole, in Cuba approximately 60% of the land is appropriate for agriculture (ONE, 2004; FAOSTAT, 2004). However, according to the last national census, currently less than 25% of the population live in rural settlements, only 11% work in the agricultural sector, and probably less than 6% is directly linked to farming activities (ONE, 2004).

Soils in Cuba are heterogeneous. Soil fertility, as based on available nutrients and classified as a percentage of the total arable land, is 15% high fertility, 24% fair

Table 1. Demographic, physiographic and climatic features of Cuba.

General data		Climate		
Length of country, km	1250		Season	
Area, km^2	110,860		Wet	Dry
Highest elevation, m	1974	Rainfall, mm	1104	316
Total population (millions)	11.3	Mean temperature, °C	26.9	23.2

Source: ONE, 2004.

Table 2. Principal limiting factors of Cuban soils.

Factor	Affected agricultural area	
	million ha	percent of total
Salinity and sodicity	1.0	14.9
Erosion (very strong to medium)	2.9	43.3
Poor drainage	2.7	40.3
Low fertility	3.0	44.8
Natural compaction	1.6	23.9
Acidity	2.1	31.8
Very low organic matter content	4.7	69.6
Low moisture retention	2.5	37.3
Stony and rocky areas	0.8	11.9

Sources: CITMA, 1998; ONE, 2004.

fertility, 45% low fertility, and 14% very poor fertility (CITMA, 1998; Treto et al., 2002; ONE, 2004). According to these sources, Cuban soils are predominantly Oxisols and Ultisols (68%) and the remaining areas are mostly Inceptisols and Vertisols. The primary limiting factors of soils used for agricultural activities are low organic matter content, low fertility, erosion, and poor drainage (Table 2). Despite these limitations, Cuba possesses an exceptional natural environment for agriculture. Due to its continuous growing season and diversity of plants and animals used for agricultural purposes, crop cultivation and raising animals in open air are possible throughout the year.

The ample infrastructure of roads and railroads with access to the sea, the existence of high water reservoir capacity for irrigation, electrification of the countryside, and high investment in agricultural facilities are all valuable pre-conditions for greater agricultural production in Cuba. In addition, the extensive network of scientific institutions is a considerable asset in carrying out agricultural changes. However, these resources are not being efficiently used for several reasons, including a lack of maintenance of the agricultural infrastructure, continued specialized organization of agriculture, a scarcity of agricultural labour, and the high cost (or lack of availability) of necessary inputs for production.

3. Brief history of Cuban agriculture

3.1 Migratory aboriginal groups

The first inhabitants of Cuba arrived about 10,000 years ago from North America through the Mississippi River watershed, via Florida and the Bahamas (Torres-Cuevas and Loyola, 2001). Called *Guanahatabeyes,* these groups were hunters, fishers, and gatherers. The second migratory stream came from South America about 4,500 years ago. Known as *Ciboneyes*, they were also fishers and gatherers, but introduced a variety of more advanced instruments for hunting and food processing. Some 1,500 years ago, a third group of people called *Taínos* came to the island. Part of the South American aboriginal family known as *Arawaks*, they were advanced hunters and fishers but they also practised agriculture (Le Riverend, 1970). They were the most numerous and dominant Native Americans when the Spanish arrived on the island in 1492. One of their most productive agricultural systems utilized raised beds, called *camellones*, which were planted mounds of earth and organic matter. These communities applied the system of small-scale slash and burn for the cultivation of crops, especially cassava and corn, and those used in their rituals, such as tobacco and cotton.

3.2 Spanish colonization of Cuba

At the time of the Spanish arrival, an estimated 60 to 90% of Cuba was covered with forest (Del Risco, 1995). Initially, the conquerors resettled indigenous people in *vecindades* or reserves. In these reserves, most inhabitants continued using traditional agricultural methods. As colonists, the Spanish became landholders, employing predominantly mixed crop-livestock systems called *estancias* with a high proportion of crops (Le Riverend, 1970). The transition from indigeous agriculture to the new form implemented by the Spanish may be considered the first major step in the process of conversion to European agricultural practices.

The small population of Spaniards focused on cattle raising as their principal economic activity. To this end, they distributed lands in extensive circular areas called *hatos* and *corrales.* At the same time, around their population centers they established less extensive areas of crop cultivation (Le Riverend, 1992). In the middle of the 1500s, increasing demand for wood for ship construction, swelling populations in the main villages of the island, and the growing external market for agricultural products led to an expansion in timber extraction and sugar and tobacco production and processing. These activities extended into the interior of the cattle ranches, transforming the original Spanish agrarian structure.

Beginning in the early 1600s, commercial agriculture experienced more rapid development with the advent of sugar cane and tobacco production in the *estancias* (Le Riverend, 1992; Marrero, 1974–1984; Funes-Monzote, 2008). The outbreak of the Haitian slave revolt in 1791 gave Cuba the opening it needed to begin competing with the French colonies as the principal producer and exporter of sugar worldwide. The consequent establishment of sugar processing plants in the Cuban countryside meant a radical transformation in the structure of agriculture and a definitive jump in the economy of colonial Cuba. The great expanses of land dedicated to cattle ranching, interspersed with forest and grassland, were subdivided into smaller properties. The increased scale of production and the specialization in sugar cane accentuated the social and environmental impacts in the countryside that had accompanied the industry from the beginning. Early criticism of the system was based on damage to the natural resource base, specifically forest destruction and the abandonment of "tired" unproductive lands (De la Sagra, 1831; Reynoso, 1862).

3.3 Neocolonial agricultural patterns and their consequences

Concentration and centralization of sugar production continued into the 1900s. After Cuba achieved independence from Spain in 1898, North American capital flowed into the country, helping to establish giant sugar *latifundios* on the eastern half of the island, which until this time had been the area least affected by agriculture. During the first two decades of the 20th century, the planting of sugar cane produced the most intense deforestation in Cuba's history. By around 1925, most of the extensive plains of Cuba had been planted with sugar cane. The largest ranches, both foreign and nationally owned, were predominantly sugar cane and cattle, and these occupied 70% of the agricultural land. A little more than 1% of the landowners owned 50% of the land, while 71% held only 11% (Valdés, 2003).

However, the lands managed by the *latifundios* were inefficient at producing food, and many of these large farms (around 40%) were gradually abandoned. Meanwhile, the campesino sector, which practised a diversified agriculture with traditional mixed farming strategies, was having a considerable impact on the agrarian economy. According to the agricultural census of 1946, almost 90% of the farms were diversified. These 5 to 75 ha farms, with their mixed crop-livestock production and better organizational efficiency, generated about 50% of the country's total agricultural production but occupied only 25% of the total agricultural area (CAN, 1951).

Despite the existence of many diversified small farms, the structure of land tenure and the export-oriented economic model combined to create an agriculture sector that as a whole specialized in only a few agricultural crops. Rural Cuba was characterized by an economic and political dependency on the United States, a scarcity of subsistence foods, social inequity, and a high rate of unemployment during the "dead period" (months where there was no sugar processing). This unstable situation greatly influenced the emergence of the Cuban Revolution of 1959, which was grassroots, agrarian-based and anti-imperialist. During the 46 years since the Revolution, unprecedented events have taken place with arguable relevance to the future of world agriculture.

4. Post-Revolution scenario

4.1 Agrarian reforms

The revolutionary government adopted two Agrarian Reform Laws that passed ownership of rented lands to the peasants who had worked them. This considerably reduced farm size. First, in May 1959, the maximum land holding was reduced to about 400 hectares. Later, in 1963, a Second Agrarian Reform established an upper limit of 67 ha in order to eliminate the landed social class and thus the exploitation of farmers (Anon., 1960; Valdés, 2003). In the first stage, 40% of arable land was expropriated from foreign companies and large landholders and passed into the hands of the State. In the second stage, another 30% of land became State-owned (Valdés, 2003).

At that point, there were four prioritized objectives for the transformation of Cuban agriculture: (1) to meet the growing food requirements of the population; (2) to generate monetary funds through the exportation of products; (3) to obtain raw materials for the food processing industry; and (4) to eradicate poverty from the countryside (Anon., 1960). A number of educational, cultural, and economic approaches were developed, including literacy campaigns, the development of planned rural communities to supply social and health care services to farmers, the building of thousands of kilometers of new roads, and the extension of electricity to rural areas (Anon., 1987). The government's will to change was reflected clearly in the first decree of the First Law of Agrarian Reform: "The progress of Cuba is based on the growth and diversification of industry to take more efficient advantage of its natural and human resources, as well as the elimination of the deep dependency on monocultural agriculture that is a symptom of our inadequate economic development" (Gaceta Oficial, 1959).

4.2 The conventional agriculture model

Although the government expressed its official desire for diversification, its actual on-the-ground administration of agriculture supported large-scale monoculture. The commitments to export primary materials such as sugar, citrus, coffee, tobacco, etc. to the countries of the Council for Mutual Economic Assistance (COMECON), the economic block of the former socialist countries, forced Cuba to fulfil five-year plans at high environmental costs. Consequently the dependency on processed food imported from Eastern Europe reached unprecedented levels (Espinosa, 1992).

The application of Green Revolution concepts was facilitated by Cuba's strong relationship with the Soviet Union (USSR) and socialist countries of Eastern Europe. As a national policy, Cuba adopted the worldwide trend of substituting capital for labour in order to increase productivity. This method was characterized by the physical and agro-chemical management of agricultural processes –specifically large-scale, mechanized production with a high application of external inputs to a monocultural crop. The application of the industrialized model of agriculture, along with the 10-fold increase in food imports over a 30-year period (1958–1988), was successful in achieving increases in per-capita energy consumption from 10.7 MJ day^{-1} to 11.9 MJ day^{-1}. Protein consumption per capita also increased in the same period from 66.4 g day^{-1} to 76.5 g day^{-1}. In spite of this progress, however, per-capita consumption rates still fell short of the calculated nutritional needs of 12.4 MJ day^{-1} for energy and 86.3 g day^{-1} for protein (Pérez-Marín and Muñoz Baños, 1991).

These improvements were achieved and sustained through a model that relied on high external inputs, a few export crops, and trade with the socialist countries of Eastern Europe. Throughout the 1980s, 87% of external trade was undertaken at favourable prices with socialist countries, and only 13% at world market prices with other countries (Lage, 1992). In 1988, Cuba sent 81.7% of its total exports to the socialist block while 83.8% of its total imports came from those countries (Pérez Marín and Muñoz Baños, 1991). The COMECON agreement allowed Cuba to sell its goods in the socialist market at high prices while imports were purchased from them at low cost.

Consequently the dependency of the agricultural economy on a few export products was impressive; and the land dedicated to these crops was enormous. Three of the principal export crops –sugar, tobacco and citrus– covered 50% of agricultural land. Importing energy (petroleum), machinery, and diverse raw materials in large amounts was favourable for Cuba in economic terms, but not for its food self-sufficiency. Under these conditions the country imported 57% of its protein requirements and more than 50% of its energy, edible oil, dairy products and meats, fertilizers, herbicides, and livestock feed concentrates (PNAN, 1994).

As early as the 1970s, Cuban scientific research institutions had become aware of the concepts of low external inputs and input substitution. Policies and research began to focus on the economic implications of substituting local raw materials for imported. Nevertheless, at the end of the 1980s, Cuban agriculture was characterized by a high concentration of State-owned land (80% of total land area was in the State sector), high levels of mechanization (one tractor for every 125 ha of farming land), crop specialization, and high input usage (13 Tg diesel, 1.3 Tg fertilizers, US$ 80 million in pesticides, and 1.6 Tg livestock feed concentrates applied per year) (Lage, 1992).

4.3 Consequences and collapse

The continued application of this agricultural model resulted in several economic, ecological, and social consequences. Among the most important were soil salinization (one million hectares affected), an increased frequency of moderate to severe soil erosion, soil compaction with its resultant soil infertility, loss of biodiversity, and deforestation of agricultural land (CITMA, 1997). From 1956 to 1989, an accelerated rural population exodus to urban areas caused a drop in the rural population from 56% to 28% and then to less than 20% by the mid 1990s (Funes et al., 2002).

As result of this situation, at the end of the 1980s crop and livestock yields and subsequent economic efficiency started to decrease (Pérez Marín and Muñoz Baños, 1991). The conventional agricultural model, which had been applied for about 25 years, demanded higher amounts of chemical inputs and capital to keep yields stable. The depression of agricultural production provoked a shortage of goods in the agricultural markets. To counter this situation, an ambitious Food Programme was initiated in order to recuperate the infrastructure and subsequent volume of production and cover internal demand (ANPP, 1991). This programme essentially carried on the conventional high-input focus because it could count on abundant externally-derived inputs. Even when the disintegration of Eastern European and Soviet socialism resulted in the loss of these inputs, the government decided “to continue developing the Food Programme despite whatever difficult conditions might have to be faced” (ANPP, 1991). Without the expected aid, however, it would be necessary to seriously adjust the technology and structure of production.

5. Situation after the collapse of the socialist block

Today Cuba faces the most difficult challenge in its history…in addition to the worsening blockade exercised for more than 30 years by the United States; it now has to resist the effects of a second blockade provoked by changes in the international order.

Fidel Castro, 1992

The unexpected collapse of the socialist countries of Eastern Europe and the USSR fully highlighted the contradictions and vulnerabilities of the agricultural model that Cuba had developed. The island lost the principal markets and guarantees that these countries had provided in the past. Foreign purchase capacity was drastically reduced from US$ 8,100 million in 1989 to US$ 1,700 million by 1993, a decrease of almost 80%. In that year, some US$ 750 million was required solely for the purchase of fuel for the national economy and US$ 440 million for basic foods (Lage, 1992; PNAN, 1994).

Cuba’s reduced foreign exchange greatly affected its ability to obtain necessary agro-chemical inputs, leading to a drastic reduction in production. This shortage was most severely felt by the large State farm enterprises that were dependent on high inputs to maintain their monoculture systems. In fact, all farmers suffered under the difficult situation, but small- and medium-size farmers were less affected due to their more locally-oriented agricultural strategies, the practice of a more diversified agriculture, greater control of farm management, and lower dependence on external inputs.

Although small- and medium-scale traditional farming exhibited higher resilience to the crisis, in 1989 this sector of agricultural production represented only 12% of the total agricultural land area. The remaining agricultural lands, which were being managed using high-input, industrialized, and large-scale methods, dramatically collapsed. This led to the drastic reduction of each citizen’s food ration, which seriously affected food security. One of the first effects was caloric deficiency and consequently widespread weight loss amongst the population. In addition, many diseases started to appear as result of low intake of certain nutrients (PAHO, 2002) (Table 3). For example, epidemic neuropathy, caused by vitamin B deficiency, affected the vision of more than 50,000 people (Arnaud et al., 2001). The consequences of the food security crisis would have been far more dramatic without the government’s ration system, which assured equitable food access and avoided famine (Rosset and Benjamin, 1994; PNAN, 1994; Wright, 2005).

Despite the economic difficulties, the government continued to reinforce social programmes. For example, the infant mortality rate during the first year of life was reduced by almost half during this time –from 11.1 per 1000 in 1989 to 6.4 at the close of 1999 (Granma, 2000). During the early 1990s, severe economic actions were necessary in order to maintain the main social guarantees while reconstructing the Cuban economy. This phase was officially called the “Special Period.” In order to deal with the crisis, the Cuban government implemented measures of austerity and changed the strategies to reduce negative impacts on the national economy.

Table 3. Comparison of nutritional levels per capita per day in 1987 and 1993.

Nutrient	Nutritional needs*	Percentage satisfaction of recognized needs	
		1987	1993
Calories	12.4 MJ	97.5	62.7
Protein	86.3 gr	89.7	53.0
Fat	92.5 gr	95.0	28.0
Iron	16 mg	112.0	68.8
Calcium	1,123 mg	77.4	62.9
Vitamin A	991 mg	100.9	28.8
Vitamin C	224.5 mg	52.2	25.8

Sources: PNAN, 1994; Pérez-Marín and Muñoz Baños, 1991.

* The nutritional needs for Cuban population (Porrata et al., 1996) were defined by the FAO standards (FAO/WHO/UNU, 1985).

In response to the precarious food situation, the Cuban National Programme of Action for Nutrition (PNAN) was instigated, as a result of commitments made by the International Nutrition Conference in Rome in 1992. Its overall objective was to buffer the consequences of the crisis using the following basic strategies (PNAN, 1994):

- Strengthen agrarian policy through widespread decentralization of land holdings and management, diversification of agricultural production, and the transformation of land tenure of State lands.
- Encourage the population to participate in agricultural activities for their own nutritional improvement.
- Encourage the creation of *autoconsumos* or on-site farms/gardens to supply the dining halls of residential and educational establishments.
- Promote sustainable development compatible with the environment.
- Reduce post-harvest losses through improved methods, such as direct sales of food from producers to consumers in the cities (e.g. urban agriculture).
- Incorporate nutritional objectives in programmes and plans of agricultural development.

Many of these measures taken by the State were key factors in the proliferation of a more-sustainable Cuban agriculture. However, the success of these strategies has been muted by a variety of factors, including the difficulty of adapting specialized large-scale agriculture to new practices, a lack of monetary resources and materials to enact these solutions, and a small work force in the countryside.

6. Changes in agrarian productive structures

In general, certain technical and organizational measures were taken to reduce the impact of the crisis on agriculture. Decentralization and reduction in the scale of big State enterprises was a necessity due to their inefficiency. In 1993, the government created Basic Units of Cooperative Production (UBPC). This effective measure gave usufruct rights (land use free and for an “indefinite” time) to farmers who were previously workers of State farm enterprises. Other forms of land distribution were also developed that provided interested urban dwellers the opportunity to return to the countryside. Eventually, ten distinct forms of organization in Cuban agriculture were created; these coexist within three sectors: the State sector, the non-State sector, and the mixed sector (Table 4).

These changes in the agrarian structure of the country were characterized by transfers of land from the State to the other sectors. By January 1995, the State had granted usufruct rights to 58% of the arable land it had controlled at the beginning of 1990 (which had constituted, at that time, 83% of total arable land). This shift in land ownership is informally called the "silent third Cuban agrarian reform." During a five-year period, about 150,000 workers were incorporated into the UBPC (Pérez Rojas et al., 1999). A chronological analysis of the percentage of national agricultural area shows that the UBPC quickly predominated (Table 5). The private, campesino sector also increased its land area in the distribution process, an acknowledgement of its management capacity and increasing role in food production. Compared to State enterprises, the UBPC is a more decentralized form of production (Villegas, 1999).

With the creation of the UBPC, the State was able to both better manage production and save on scarce resources. The size of large mixed-crop enterprises was reduced 10-fold, while the size of livestock enterprises was reduced on average 20-fold, reaching a size similar to that of the Agricultural Production Cooperatives

Table 4. Organization of Cuban agriculture.

<table>
<tr><td colspan="2">State sector</td><td>State farms
New-type State farms (GENT)
Revolutionary Armed Forces (FAR) farms, including farms of the Young Workers' Army (EJT) and the Ministry of Interior (MININT)
Self-provisioning farms at workplaces and public institutions</td></tr>
<tr><td rowspan="2">Non-State sector</td><td>Collective Production</td><td>Basic Unit of Cooperative Production (UBPC)
Agricultural Production Cooperatives (CPA)</td></tr>
<tr><td>Individual Production</td><td>Credit and Service Cooperatives (CCS)
Individual Farmers, in usufruct
Individual farmers, private property</td></tr>
<tr><td colspan="2">Mixed sector</td><td>Joint ventures between the State and foreign capital</td></tr>
</table>

Source: Martin, 2002.

Table 5. Percentage of arable land in Cuba by form of land ownership, 1989–2008.

<table>
<tr><th>Form of land ownership</th><th>1989–92</th><th>1993</th><th>2000</th><th>2008</th></tr>
<tr><td>State</td><td rowspan="2">83</td><td>47.5</td><td rowspan="2">33.1</td><td rowspan="2">23.2</td></tr>
<tr><td>Other State-sector organizations</td><td>9.0</td></tr>
<tr><td>UBPC</td><td>–</td><td>26.5</td><td>40.6</td><td>39.8</td></tr>
<tr><td>CPA</td><td rowspan="2">12</td><td>7.0</td><td rowspan="2">26.3</td><td rowspan="2">37.0</td></tr>
<tr><td>Private</td><td>10.0</td></tr>
</table>

Sources: PNAN, 1994; Pérez Rojas et al., 1999; ONE, 2004; ONE, 2008.

(CPA) that had existed for more than 20 years with reasonable levels of production and efficiency (Table 6). The strategy of dividing land into smaller plots within the UBPC was based on recognition of the greater efficiency of production at a smaller scale. (However, even with these reductions, the average sizes of UBPC were still large for most of the principal agricultural activities, and the lack of resources made many of them almost unmanageable.)

Following the principle of linking people to the land (i.e. allowing farmers to live on the farm), thousands of families became based on the UBPC, which had been previously uninhabited and controlled by State enterprises. For example, more than 50 families moved to the 1000 hectares that is now the UBPC "26 de Julio" in Bacuranao, Havana –a tract of land occupied some 15 years ago by only two families– after housing was created to attract people knowledgeable about working in agriculture. (Today this UBPC is highly self-sufficient in food production, generates extra production for commercialization, and acheives its commitment of milk production for sale to the State.) The re-population of rural areas has been one of the major contributions of the UBPC.

As agricultural enterprises worked and managed by the people who live on them, UBPC facilitated better natural resource management and local farmer decision-making. The reduced scale of the UBPC, along with their greater diversification and more rational use of inputs, machinery, and infrastructure, allowed increases in efficiency and productivity, and this helped mitigate the losses in external inputs and capital.

However, the UBPC model, as a new form of agriculture in Cuba, is still far from achieving its potential benefits. Many organizational methods employed in the State

Table 6. Average size (ha) of State enterprises, UBPC and CPA.

Principle activity	State enterprises 1989	UBPC 1994	CPA 1994
Various crops*	4,300	416	483
Citrus and fruit	17,400	101	577
Coffee	–	429	470
Tobacco	3,100	232	510
Rice	27,200	5,040	–
Cattle	28,000	1,597	631

Source: PNAN, 1994.

* Tubers, roots, vegetables, plantain, grains, and seeds (beans, corn, soybean, sunflower, sesame, etc.).

enterprises were replicated in the UBPC (Pérez Rojas and Echavarría, 2000). The lack of a sense of ownership, the persistant dependency on external inputs, and limited decision-making affect the functioning of UBPC (Granma, 1997). In summary, even though the UBPC in their essence have continued to form part of a structure that operates under the direction of the State enterprises, this form of production has created mechanisms favouring the transition to decentralized production that tends to imitate the values, efficiency, and potential of traditional *campesino* (small farmer) production.

7. Contribution of the small farmer sector

In Cuba, private farming (carried out by *campesinos* at mostly small and middle scales) can be undertaken individually or in groups under two types of cooperative production: CPA and CCS. The first type, the CPA, is composed of farmers who have given their land to the cooperative so that it can be transformed into social or collective property. The second type is composed of farmers who form a cooperative in which they continue to own land and equipment on an individual basis, buy inputs from the State, and receive credit and services (Álvarez, 2002). Both types of producers sell to the State based on agreements over their production potential, and also cultivate crops and raise animals for self-provisioning. They may also sell agricultural products directly in the local market or to middlemen.

Compared to State farms, private farmers have greater experience and a longer tradition with Cuban agriculture, and unsurprisingly, their agricultural systems proved to be more resilient in the face of the crisis. While the State agricultural enterprises were strongly impacted by the loss in inputs and funding, and delayed adapting to change, the *campesino* sector was able to buffer the scarcity of material resources. At the end of the 1980s, the private sector in Cuban agriculture accounted for 18% of the country's arable land; ten years later it occupied 25% of the agricultural area and participated significantly in production for both internal consumption and export. The relatively high percentage contribution of *campesino* production to total sales in the national agricultural sector during the years of crisis (Table 7) demonstrates how efficient its use of land is. It also shows the capacity of small farmers' methods of production and organization to contribute to the national food balance, even with scarce external inputs.

Abolished at the end of the 1980s, the *Mercado libre campesino* (farmers' free market) was re-opened at the beginning of 1994 as the *Mercado Agropecuario* (agricultural market). Despite the new name it was in essence the same institution. This agricultural market functioned under the law of supply and demand and became an important distribution channel for agricultural products. In 1996, some 70.7% of the total agricultural direct sales to the population were by individual or cooperative farmers (Martin, 2002).

The small farmer sector was particularly successful with livestock. From 1995 to 2000, the number of livestock animals under private sector management increased, as did the production of livestock products, while during the same period State and UBPC livestock production showed no signs of recovery (González et al., 2004). In 2006, the small farmer sector, with only 13% of the grazing land, owned more than 43% of Cuba's livestock (Table 8), a fact that demonstrates the efficiency of *campesino* management.

Table 7. Percentage contribution of *campesino* production to total sales to the State for various products in Cuba.

Product	% of sales to the State	Product	% of sales to the State
Roots, tubers, and vegetables	43	Milk	32
Sugar cane	18	Rice	17
Tobacco	85	Fruit	59
Coffee	55	Citrus	10
Cocoa	61	Pork	43
Beans	74	Fish	53
Corn	64	Honey	55

Source: Lugo Fonte, 2000.

Table 8. Structure of livestock production in Cuba, 2006.

Type of production	Land area ($\times 10^3$ ha)	% of land area	Owners	Head ($\times 10^3$)	% of national herd	Head/ owner
State enterprises*	1,221.6	48.3	4,569	1,082.5	27.3	236.9
UBPC	780.1	30.8	2,470	969.6	24.4	392.5
CPA	201.7	8.0	1,063	191.8	4.8	180.5
CCS + Individuals	325.8	12.9	236,088**	1,728.4	43.5	7.3
Total	2,529.3	100		3972.3	100	

Source: Adapted from MINAG, 2007.

* Included are livestock and crop enterprises dedicated to livestock rearing.

** Included are individual owners or in CCS and farmers with or without land.

Although cattle production at the national level has been depressed by the scarcity of imported feed and adverse climatic conditions such as prolonged drought, hurricanes, and other natural events, *campesino* production has developed ways of working around these conditions. Consequently, the small farm sector has, for many, served as a model for restructuring Cuban agriculture (Álvarez, 2002).

The Cuban *campesino* is a key link in the preservation of traditional crop and livestock varieties, which are indispensible to genetic improvement and sustainable agriculture from a local perspective (Ríos, 2004; Wright, 2005). Within the National Association of Small Farmers (Asociación Nacional de Agricultores Pequeños, ANAP), the Agro-ecological Farmer to Farmer Movement (Movimiento Agroecológico Campesino a Campesino, MACAC) has systematized much traditional agricultural experience and reinforced sustainable principles in Cuban agriculture. This movement is represented in 155 municipalities (i.e. 85% of total) at the national level, and at the end of 2004 employed 3,052 facilitators and 9,211 promoters (Perera, 2004). In a parallel effort, more than 4,000 farmers were involved in the Local Agriculture Innovation Programme of the National Institute for Agricultural Sciences (INCA), which is based on participatory grassroots processes (Humberto Ríos, National Institute for Agricultural Sciences, Havana, pers. comm.).

However, the positive impact of the *campesino* sector in the transformation of Cuban agriculture has not been yet sufficiently addressed. Many *campesino* agro-ecological experiences throughout the country are still undocumented despite the fact that they are undoubtedly the main resource necessary for the implementation of a sustainable and agro-ecological approach at a national scale.

8. Urban agriculture and food security

8.1 Foundation, structure and objectives

A major new initiative for the promotion of food self-sufficiency has been urban agriculture. This form of agriculture was almost neglected in Cuba when food was affordable. However, urban gardening was the first reaction of the population to overcoming food shortages (Murphy, 1999). By growing within and around cities, people could make use of local resources and not have to pay transportation costs for either inputs or products (Cruz and Sánchez, 2001). At the beginning of the crisis, people organized themselves to cultivate vacant lots, backyards, and rooftops in the cities. Animals were even reared inside houses in order to assure families' food supply. At first a matter of subsistence production, urban agriculture by the mid-1990s had been transformed into a practice that also included commercial activities and made a significant contribution to the country's food security.

As urban agriculture became more widespread, it also became more organized and began to receive government support. The "Horticultural Club" formed in the Havana suburb of Santa Fe in 1992–1993 was the first to organize urbanites for the purpose of providing them with technical assistance and creating a framework for urban production. This movement grew very fast in Havana city and subsequently spread around the whole country. By 1995, there were already 1,613 organoponics (i.e. small plots of abandoned land in the cities where beds of soil and sources of organic matter are used to produce fresh vegetables), 429 intensive gardens, and 26,604 community gardens. In 1997, a network of municipal enterprises and State institutions (the National System of Urban Agriculture) was created to organize the people already involved in urban agriculture. Spatially, this system covers a radius of 10 km from the center of the capital city of each province, a radius of 5 km from the center of municipal capitals, a radius of 2 km around population centers of more than 10,000 residents, and local production for settlements of less than 1,000 people. The government still plays an important role in the promotion and support of this massive movement towards food security.

The principal objective of the Cuban urban agriculture movement is to reach a daily consumption of 300 grams of vegetables per citizen; this amount is recommended by UN FAO. The following basic principles of urban agriculture in Cuba define its objectives and organization (Companioni et al., 2002):

- A fresh supply of good quality products offered directly to the population, guaranteeing a balanced production of not less than 300 g of vegetables daily per capita and an adequate variety of animal protein.
- Uniform distribution throughout the country (i.e. in every area of the country with an urban population, urban agriculture should be developed).
- Local consumption by the urban population of local production in each region.
- Crop-animal integration with maximum synergy (i.e. internal cycling of nutrients) to boost production.
- Intensive use of organic matter to increase and conserve soil fertility.
- Use of biological pest controls.
- Use of all available land to produce food, guaranteeing intensive but not import-dependent high yields of crops and livestock.
- Multidisciplinary integration and intensive application of science and technology.
- Maximum use of food production potential, including available labour, as well as wastes and by-products for plant nutrients and animal feed.

The urban agriculture programme is composed of 28 sub-programmes, each related to a type or aspect of animal or plant production. These sub-programmes form the organizational and administrative base of the programme (GNAU, 2004). They include, for example, management and conservation of soils, use of organic matter, seed production, vegetables and fresh herbs and spices, fruit trees, grassroots or *arroz popular* production of rice, grains, animal feed, apiculture, livestock, aquaculture, marketing, and small agro-industries (Companioni et al., 2002). Taken together, Cuban urban agriculture has the components to achieve a systems approach; however, each programme is supervised separately, responding to its specific factors and providing specialized technical assistance.

8.2 Arroz popular: example of a successful sub-programme

Central to the Cuban diet, rice is consumed together with beans, meat, vegetables and even fruits. Its per-capita consumption exceeds 44 kg annually, or 265 g per day (Socorro et al., 2002). Rice production in Cuba was developed for many years in large State farms and it was also one of the prioritized crops at the beginning of the "Special period," when it appeared "irrefutable" that conventional, high-input methods were the only possible way to supply enough rice to meet the populations' needs (León, 1996). However, even during the 1980s, when unlimited inputs were available, the national demand was not met and it was necessary to import 40% of the rice consumed. High-input rice production proved to be unsustainable at the onset of the crisis of the 1990s. The new "Popular Rice" programme demonstrated that self-organized, low-input agriculture could have a positive impact on national food self-sufficiency (García, 2003).

The "popular" production of rice (*arroz popular*) was originally, like urban agriculture in general, a grassroots movement towards self-provisioning. People started to cultivate this cereal in abandoned areas, in small plots between sugar cane fields, in road ditches, etc. This movement grew rapidly and achieved unforeseen levels of production and efficiency. In 1997, while the severely affected Union of Rice Enterprises (Unión de Empresas del Arroz) produced 150,000 Mg of rice, "popular rice" production achieved 140,600 Mg, involving 73,500 small producers yielding, as a national average, 2.82 Mg ha^{-1} without the use of costly inputs (Granma, 1998). This yield compared favourably to that of conventional rice production during 1980s, which achieved a national average yield of between 2 and 3 tons per hectare (ANPP, 1991). In 2001, *Arroz popular* was responsible for more than 50% of total domestic rice production (García, 2003).

8.3 Recent success and the future

In 2000, urban agriculture produced more than 1.64 Tg of vegetables and employed 201,000 workers (Granma, 2001). Two years later, 326,000 people were linked with

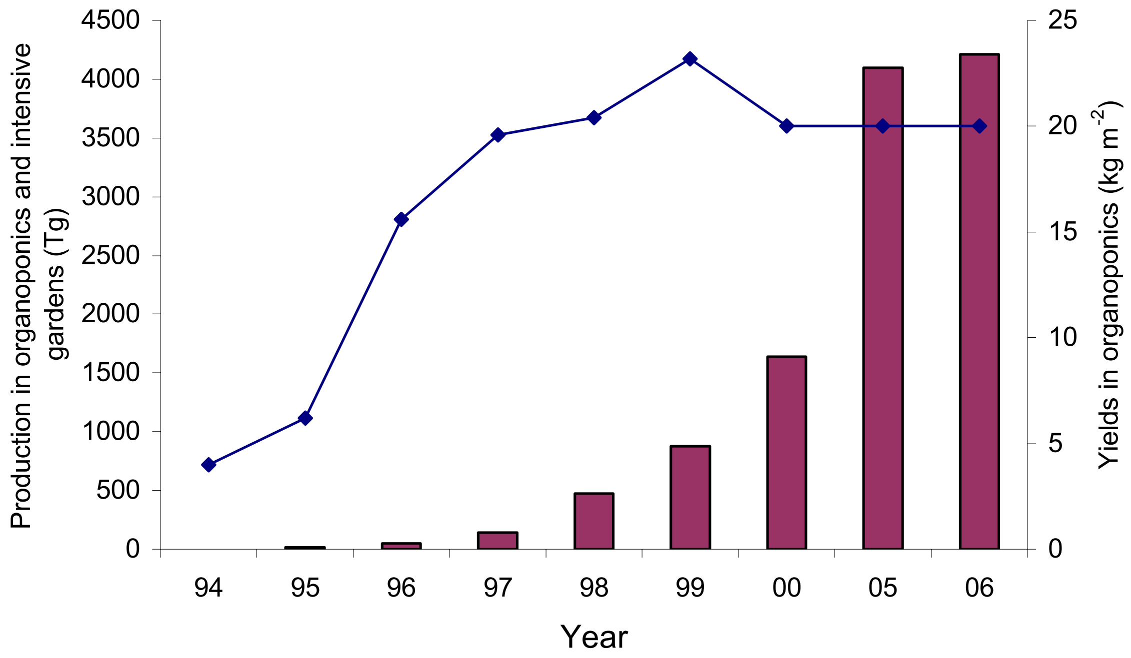

Figure 2. Vegetable production from organoponics and intensive gardens (bars), and yields (♦).

the programme of urban backyard production (Granma, 2003a). In 2005, production was 4.1 Tg, and in 2006, it had risen to 4.2 Tg, employing 354,000 people (Granma, 2006c) (Figure 2). The reported production of 20 kg m^{-2} achieved by urban agriculture exceeded 300 grams of vegetables per citizen per day.

The urban agriculture movement has also contributed to the establishment of a network of 1,270 points of sale of agricultural products in the cities and 932 agricultural markets (Granma, 2003b). The products distributed via this network significantly contribute to food security although the prices are still high considering the average buying capacity of the population.

The quantity of people dedicated to agricultural labour in the city periphery continues to increase. However, Cruz and Sánchez (2001) consider that this type of agriculture, emerging as a solution to food scarcity and unemployment in the cities, ought to look for a more integrated approach that goes beyond a temporary solution to the crisis and toward goals other than food security such as preservation of urban environments, the permanent management of resources in urban settings, avoidance of air and water pollution, and creating a culture of nature conservation.

Although cities became productive in terms of food, urban agriculture still satisfied a small part of the country’s overall needs. Thus, it was necessary to develop participatory, low-input “rural food production” at the onset of the 1990s. An alternative model to the prevailing conventional agriculture paradigm –that of input substitution– was established at a national level, not only in State enterprises and the UBPC, but also in private individual and cooperative production.

9. The input substitution strategy

Gliessman (2001, 2006) describes three levels or stages in the process of converting from conventional to sustainable agro-ecosystems. At level 1, farmers “increase the efficiency of conventional practices” and at level 2 they “substitute conventional inputs and practices with alternative practices.” Input-substituted systems at the second level, though demonstrably more sustainable than conventional systems, may nevertheless have many of the same problems that occur in conventional systems (e.g. the use of monoculture). These problems will persist until changes in agro-ecosystem design (i.e. on the basis of a new set of ecological processes) take place at level 3. This conversion process has been widely analysed by Altieri (1995), who attributes the main cause of ecological disorders in conventional agriculture to monocultural patterns.

During the 1980s, a certain amount of research in Cuba focused on aspects of input substitution –reducing the use of fertilizers, pesticides, and concentrated feed for livestock. These investigations were applied to the most economically important and largest scale agricultural activities (Funes, 2002). Although the main objective was the reduction of production costs in commercial agriculture through the substitution of biological inputs for agro-chemical, these studies –underpinned by ecological principles– formed the basis for scaling up the application of ecological practices when no alternatives were available. As a result, input substitution in Cuba reached a scale never previously attempted in any other country, and its effectiveness and positive impact were significant (Rosset and Benjamin, 1994; Funes et al., 2002).

9.1 Alternatives for the ecological management of soil

Many microbiological preparations had first been developed for a range of crops as part of general research on nitrogen fixation and solubilization of phosphorus. In the search for input substitution, a wide range of these bio-fertilizers have been successfully developed and applied on a commercial, main-crop scale, substituting for a significant percentage of chemical fertilizers (Table 9).

Research results confirmed the effectivness of using green manures and cover crops in commercial crop production. These studies included the use of sesbania (*Sesbania rostrata*) in rice production (Cabello et al., 1989) and the use of crotalaria (*Crotalaria juncea*), jack bean (*Canavalia ensiformis*), velvet bean (*Mucuna pruriens*), and dolichos lablab bean (*Lablab purpureus*) in other commercial crops (García and Treto, 1997). The inclusion of these plants in local systems was found to fulfil most of

Table 9. Principal uses of biofertilizers in Cuba.

Biofertilizer	Crops	Substitution achieved
Rhizobium	Beans, peanuts, and cowpeas	75–80% of the N fertilizer
Bradyrhizobium	Soybeans and forage legumes	80% of the N fertilizer
Azotobacter	Vegetables, cassava, sweet potato, maize, rice	15–50% of the N fertilizer
Azospirillum	Rice	25% of the N fertilizer
Phosphorus-solubilizing bacteria	Vegetables, cassava, sweet potato, citrus fruits, coffee nurseries	50-100% of the P fertilizer
Mycorrhizae	Coffee nurseries	30% of the N and K fertilizers

Sources: Martínez Viera and Hernández, 1995; Treto et al., 2002.

nutrient needs of the crops. These green manures were able to substitute for high levels of nitrogen fertilization (i.e. the equivalent of 67–255 kg ha^{-1} of N; 7–22 kg ha^{-1} of P; and 36–211 kg ha^{-1} of K) and to improve the physical characteristics of the soil (Treto et al., 2002). In commercial tobacco production, chemical applications were reduced through the use of green manures for soil fertility improvement. Other traditional farming practices were also recovered, including the use of oxen teams for cultivation, which avoided soil compaction, conserved physical soil conditions, and eliminated weeds by mechanical means rather than with herbicides.

Worm humus (or vermicompost) and compost production were applied on a large scale. Between 1994 and 1998, national production of these two organic fertilizers together was between 500,000 and 700 Tg yr^{-1}. Small-scale compost and worm humus production became popular, especially in urban agriculture due to the high levels of organic fertilizers demanded by organoponic vegetable production in beds. At the industrial scale, the use of *cachaza* "filter cake" (impurities filtered from cane juice, a by-product from the sugar industry) allowed a considerable reduction or elimination of chemical fertilizer demand in most of the important commercial crops, especially sugar cane, one of the most fertilizer-demanding crops. With an application of 120–160 Mg ha^{-1}, this organic fertilizer completely replaced chemical fertilizers over three years in sandy soils, and the same result was achieved with application of 180–240 Mg ha^{-1} over five years in soils with a higher clay content (Treto et al., 2002).

9.2 Biological control

After 1990, as a response to the scarcity of pesticides, biological control became a principal strategy for pest control in Cuba. The rapid implementation of this broad strategy at a national scale in the 1990s was possible because of long-term experience in biological control and the existence, beginning in 1960, of five laboratories for its study. Entomophagous and Entomopathogenous Reproduction Centres (CREEs) were created throughout the country for the production of biological control agents to manage the most important agricultural pests. Some 276 CREEs were widely distributed throughout the nation: 54 for sugar cane cultivation areas and 222 for lands producing vegetables, tubers, fruits, and other crops (Pérez and Vázquez, 2002). The actual production of these bio-control agents (fungus, bacteria, nematodes, and beneficial insects) was small scale and decentralized, and the CREEs provided services to State farms, cooperatives and private farmers (Fernández-Larrea, 1997). Their use was widespread, covering about one million hectares in the non-sugar sector in 1999 (Pérez and Vázquez, 2002).

Although Cuba never halted pesticide imports, they were reduced to about one-third of what was previously purchased before the 1990s (Pérez and Vázquez, 2002). Integrated pest management (IPM) programmes, combining biological and chemical pest control together with cultural management, were the most common strategy for confronting the pesticide shortage. The effectiveness of biological control strageties, however, has allowed a continuing decrease in the use of pesticides. Pesticide applications on cash crops were reduced twenty-fold in a 15-year period, from 20 Gg in 1989 to around 1 Gg in 2004 (Granma Internacional, 2004). This indicates not only the effectiveness of the biological practices developed, but also the countrywide need to strengthen sustainable strategies and innovate for non-chemical pest control.

9.3 Animal traction

At the end of the 1980s, the number of tractors in Cuba had reached almost 90,000, with imports of 5,000 per year. After 1989, the number of tractors in operation dropped dramatically due to a lack of spare parts, maintenance, and fuel to keep them working. The traditional practice of using oxen for cultivation and transport was revived. About 300,000 oxen teams were trained, conferring a lower fossil fuel dependency to the new production systems. In 1997, 78% of oxen teams were being used in the private sector, this covering only 15% of national agricultural acreage; later the use of oxen was extended to all agricultural sectors (Ríos and Aguerrebere, 1998).

Lowering fossil fuel use was not the only benefit of using oxen for cultivation. Oxen offer effective mechanical control of weeds, and, thus, serve as a substitute for herbicides. Substitution of oxen teams for machine power was successful in achieving many agro-ecological goals; however, the use of oxen is appropriate for traditional small to mid-size farming systems, less for large-scale monoculture. Thus, changes in land use patterns were necessary to allow the benefits of animal traction to reach their full potential.

The systematic use of oxen in cropping areas required an integration of land for pasture and animal feed production, i.e. mixed use. Many livestock farms that previously specialized in milk or meat production started using oxen to transport cut forages and to plough land that would grow crops for both subsistence and markets. Specialized crop and livestock farms had to adapt their designs to the new conditions. Similarly, many cooperatives previously dedicated to specialized crops such as potatoes, sweet potatoes, vegetables, etc. created "livestock modules" using dual-purpose cattle that produced milk and meat for farmers and could replace oxen teams over time as a source of traction.

9.4 Polycropping and crop rotation

Crop rotations and polycultures were developed in order to stimulate natural soil fertility, to control pests, to restore productive capacity, and to obtain higher Land Equivalency Ratios (LER[3]). The application of these alternatives –often practised by traditional farmers– proved to be critical in supporting production levels and subsequently was expanded through the country, especially in the cooperative sector (Wright, 2005). Both research results and actual production figures showed that polycropping and crop rotation made possible an increase in the yield of the majority of the economically important crops (Casanova et al., 2002). Experiments confirmed, for example, that the use of soybean (*Glycine max*) in rotation with sugar cane increased yields of the latter from 84.4 to 90.6 Mg ha^{-1} with an additional production of 1.7 Mg ha^{-1} of soybean (Leyva and Pohlan, 1995). Polyculture of cassava (*Manihot esculenta*) and beans (*Phaseolus vulgaris*) under different management cropping systems achieved a higher LER when compared to monoculture of cassava or beans (Mojena and Bertolí, 1995). Polyculture of green manures and corn (*Zea mays*) in rotation with potatoes (*Solanum tuberosum*) also increased potato production (Crespo et al., 1997). All these polycropping arrangements made for more efficient land use as well as successful pest control.

9.5 Beyond the input-substitution strategy

The previous examples of input-substitution strategies recognize the positive results of such approaches on national food self-sufficiency and the environment. This model of input substitution prevailed in Cuba during the years of crisis and is considered the first attempt to convert a conventional food system at a national scale (Rosset and

[3] The land equivalent ratio is calculated using the formula LER=Σ(Ypi/Ymi), where Yp is the yield of each crop in the intercrop or polyculture, and Ym is the yield of each crop in the sole crop or monoculture. For each crop (i) a ratio is calculated to determine the partial LER for that crop, then the partial LERs are summed to give the total LER for the intercrop (Gliessman, 2001).

Benjamin, 1994). However, these approaches arguably need to evolve if a higher level of agricultural sustainability is desired.

Many farmers in Cuba, lacking an agro-ecological framework, substitute inputs out of necessity but prefer the use of agro-chemicals when they are available, even though they may recognize the negative effects of these inputs on health (Wright, 2005). Along the same lines, most policy makers in Cuba tend to consider the conventional approach as the most viable way to restore soil fertility, control pests, and increase productivity in agriculture. In fact, one present strategy from the State is the "potentiation" of production –increasing imported agro-echemical, oil, and feed inputs for use in prioritized cropping or livestock activities. These conventional approaches are again becoming policy, and the lower yielding systems still receive much less support from the administrative structures than is necessary. Such political trends in Cuban agriculture make it clear that the national input-substitution strategy has not yet evolved to an agro-ecological stage.

The Cuban alternative model needs to be reinforced with a stronger focus on both a systems approach and an ecological foundation. Only by making more profound changes –considering alternative agricultural systems that are truly regenerative rather than merely input-substituted– can long-term sustainability be achieved. The integration of crops and livestock within more diversified production systems –to create what can be called mixed farming systems (MFSs)– is one of these alternatives.

10. Mixed farming systems: an approach to sustainability

The national input-substitution strategy established both infrastructure for and basic knowledge about sustainable farming system management. However, it is necessary to recognize the technological limitations of input substitution to achieve a more integrated and ecologically sound approach. The still-prevalent monoculture systems in agriculture, the continued dependence on external inputs, and the restricted degree of internal cycling in agro-ecosystems are some of these limitations.

10.1 Changes in the structure of land use

The patterns of land use in present Cuban agriculture are of special relevance for more fundamental conversion to an agro-ecological model at national scale. During the past ten years (from 1993), major structural changes in the agricultural sector have taken place in Cuba that create the preconditions for a nationwide application of a mixed farming strategy.

First, as mentioned previously, the effects of the crisis during the 1990s made necessary the decentralization of State enterprises and the promotion of cooperativization in order to keep the people on the land. Giving usufruct land rights, reducing the scale of production, and diversification were key factors in the agricultural changes.

Second, the deactivation of 110 sugar mills out of the existing 155 during the last five years means that half of the more than 1.4 Mha formerly devoted to the monoculture of sugar cane is available for other agricultural purposes, e.g. crop production, fruits, reforestation, and livestock. In the first stage of this structural change only 71 sugar mills remained working, with their lands covering an area of 0.7 Mha. In 2002, the Ministry of Sugar (MINAZ) started a restructuring programme (named *Tarea "Alvaro Reynoso"*) in order to use the lands previously belonging to these sugar mills (Rosales del Toro, 2002). This leads to further reductions in sugar production; today there are only 45 mills in operation.

Third, about 40% of the two million hectares covered by pasture (some 900,000 ha) are now invaded by "marabú" (*Dichrostachys cinerea*) and "aroma" (*Acacia farnesiana*), two thorny, fast-growing, woody leguminous species. These plants are difficult to control by hand and expensive to control with machinery. The main causes of this tremendous invasion are the abandonment of farmlands and inappropriate land use. The incorporation of mixed farming strategies might be an effective control practice for these weeds where conditions permit. Calculations made by García Trujillo (1996) have shown that through mixed-farming-system strategies in the livestock sector, it is possible –even at very low levels of productivity– to fulfil the food requirement of the Cuban population with respect to animal protein and contribute to energy (carbohydrate) needs as well. Under this approach, extensive land use farming systems might be considered a valid strategy for the future of agriculture in Cuba.

Present ecological, economic, and social conditions favour the conversion to agro-ecological MFSs in the livestock sector (Monzote and Funes-Monzote, 1997). Because of the availability of animals, infrastructure, and long-standing pasture land, there can be immediate positive results when livestock units are converted to manure-fertilized crop and livestock systems (García-Trujillo and Monzote, 1995; Funes-Monzote and Monzote, 2001; 2002). In specialized commercial crop production, rotations with an animal component might allow better use of resources such as the fallow biomass, crop residues, or the by-products of food processing.

Although traditional farmers have commonly practised the integration of crops and livestock at small scale, the innovative approaches needed for medium-scale mixed farming systems should be researched, implemented, and disseminated. Moreover, strategies need to be developed for overcoming the major constraints to the development of mixed systems. These constraints include the systems' high need for labour in the context of a sparsely populated countryside, the lack of capital, and the priority still given to conventional agriculture and its specialized infrastructure.

Integration of crop and livestock production can be achieved at different scales in time and space. On a large scale (i.e. regional, national) it requires more capital and inputs than at a middle or small scale. For example, long distance transportation of animal manure, with its high water content, is difficult and costly, and the available machinery makes it difficult to establish polycropping designs in larger areas. The increase in scale will bring decreases in production efficiency as well. In contrast, resource use efficiency is maximized at smaller scales, at the cooperative or farm level, because at these scales, interrelationships (e.g. internal nutrient cycling) can be better facilitated. However, at any scale, the priorities, demands, and capacities of producers to carry out such alternatives are key factors in the successful implementation of the MFS model.

In summary, implementing mixed crop-livestock designs might solve many problems –relating to adverse environmental effects, productivity, and efficiency– that predominate in specialized dairy systems. Much scientific and practical information demonstrates the advantages of the MFS model; however, more attention should be given to the development of adaptations under a variety of local conditions. A physical description of farming systems and quantification of their ecological flows are commonly found in the literature, but more integrated approaches that document agro-ecological, economic, and social dimensions are rare.

The application of agro-ecological approaches through the MFS model can be a further step toward sustainability in Cuban agriculture. Both the technological and practical advantages of MFSs have been scientifically confirmed, and the present economic and social structure of the agrarian sector in Cuba favours this process.

10.2 Primary lessons of the conversion process in Cuban agriculture

The Cuban experiment is the largest attempt at conversion from conventional agriculture to organic or semi-organic farming in human history. We must watch alertly for the lessons we can learn from Cuban successes as well as from Cuban errors.

Rosset and Benjamin (1994).

The recent history of Cuban agriculture demonstrates that agrarian reforms will not be effective in the long term if adaptation to new political situations and ecological perspectives are not taken into account. Therefore, one of the main lessons of the national-scale conversion towards sustainable agriculture in Cuba in the 1990s is that it is necesary to change the prevailing world food production system so that stewardship of natural resources occupies a place as important as socio-economic or political issues.

The elimination of the *latifundio* in 1959 by itself did not eradicate the many historical problems intrinsic to the Cuban agricultural system. Agrarian reform gave much of the land to those who worked it and reduced the sizes of farms, both of which had positive social impacts. However, the lack of an ecological focus and the concentration of lands by the State as never before in extensive monocultures reinforced the dependency characteristic of the inadequate agricultural development prevailing throughout Cuba's history. Although its intentions were to move toward a more socially just system, the new State agriculture, like that of the *latifundio*, created serious environmental and socioeconomic problems.

The enormous economic, ecological, and social crisis that was unleashed at the beginning of the 1990s was the result of the high level of dependency reached in Cuba's relationship with Eastern Europe and the USSR. Many studies demonstrate the depth of the crisis and almost all agree with the conclusion that it would have been much worse had there not been the will to change to centralized planning of material resources and to work toward an equitable social structure. Government assistance, together with its encouragement of innovation, the high educational level of the population, and the exchange of resources and knowledge among the people, permitted the creation of a sustainable agriculture movement and its implementation at a national scale.

However, further steps –indeed, profound changes– are necessary in Cuban agriculture. Although innovation has been present in all branches of agriculture and the scientific institutions have tested environmentally-sound technologies on a large scale, these efforts have tended to focus on the substitution of inputs, and there remains a disjunction between the bio-physical and socio-economic aspects of agricultural development. If this newest stage in Cuban agriculture, characterized by the emergence of diverse agro-ecological practices throughout the country, is to progress further, it must recognize that neither the conventional pattern nor that of input substitution will be versatile enough to cover the technological demands and socio-economic settings of the country's heterogeneous agriculture. Therefore, it is necessary to develop more integrated, innovative, and locally oriented solutions as opposed to solving specific problems from the top-down. The MFS approach, based on agro-ecological perspectives and participatory methods of dissemination, might aid in reaching a higher stage in the transformation of Cuban agriculture as it moves toward sustainability.

Chapter 3

Conversion of specialized Dairy Farming Systems into sustainable Mixed Farming Systems in Cuba

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Abstract

From the 1960s onwards, a ‘High External Input’ dairy production model was applied widely in Cuba. Overall milk production of the national herd increased considerably, but the system was inefficient from both a financial and energetic point of view. In the early 1990s, after the abrupt end of inflow of capital and other resources from Eastern Europe, the dairy sector collapsed. In the short term, the modern infrastructure of milk production deteriorated and the sector experienced profound vulnerability. However, in the longer term, this situation stimulated a search for more sustainable approaches, such as low external input Mixed Farming Systems (MFS). The current study aimed to evaluate two small scale prototype farms to assess the implications of converting ‘Low External Input’ Dairy Farming Systems (DFS) into MFS. Fifteen Agro-Ecological and Financial Indicators (AE&FIs) were selected and monitored over a six-year period. Two configurations of MFS, i.e. the proportion of the farm area occupied by arable crops, were tested: 25% and 50%. Productivity, energy efficiency and cost-effectiveness all improved following conversion. Total energy input was low for both farms and decreased over time, whereas energy efficiency was high and increased over time. Human labour input was high directly following conversion, but decreased by one-third over the six-year period. This study demonstrates, at an experimental scale, the potential of MFS to achieve ecological, productivity, and financial advantages for dairy production in Cuba.

Keywords: Agro-ecological indicators, crop-livestock integration, energy efficiency, farm finance, livestock production, low-external input

1. Introduction

From the 1960s until 1990, cattle husbandry in Cuba was based on specialized 'High External Input' systems, in which advanced technology was applied to produce milk in intensive, industrial systems and development strategies were focused on three fundamental aspects: genetics, infrastructure and feeding (Pérez, 1999). As a result, national milk production increased to about 1 billion (10^9) litres annually (ANPP, 1991). However, production was inefficient, both financially and in terms of energy (Monzote et al., 2002). It has been estimated that in the 1980s, at the peak of industrial livestock production, the ratio of energy output to energy invested was 0.17, i.e. only one-sixth of the energy input was exported in the form of milk and meat (Funes-Monzote, 1998). The major components contributing to the energy inputs were fertilizers and pesticides (40%), followed by molasses and other by-products from the sugar industry (25%), concentrates (20%), fuel (14%) and human labour (1%).

The 'High Input' model of livestock production was economically viable because of the favourable terms of trade with the socialist countries in Eastern Europe, in particular with the USSR. However, following political changes in the socialist block, Cuba plunged into a serious economic crisis (Funes et al., 2002). Moreover, the intensive livestock production systems, in combination with large-scale monoculture of industrial crops, had led to extensive deforestation, soil erosion, and loss of biodiversity (CITMA, 1997).

Awareness of the financial and energy inefficiency of the industrial specialized livestock production systems, and of their negative environmental impacts, combined with increasing scarcity of capital and other inputs, triggered the development of new approaches in animal husbandry, aimed at on-farm feed and food self-sufficiency. The problems also challenged researchers to search for more efficient and environmentally sustainable milk and beef production systems (Monzote et al., 2002). In this search, various approaches have been attempted in order to develop more sustainable and self-sufficient cattle production systems, such as grass-legume associations, legume protein banks, silvopastoral systems, bio-fertilizers and selection of pasture species adapted to different regions. However, the main constraint for success was their isolated application and, in most cases, the lack of an integrative system perspective in technology development. A systems approach to development of a more productive and sustainable model of livestock production, based on principles of mixed farming, appeared a promising method.

Suitable environmental conditions for development of mixed farming systems (MFS) in tropical countries such as Cuba, include the high potential for biomass production because of the possibility of year-round production of highly productive (C_4) species and the high diversity of species with potential use for agriculture. These natural advantages, exploited through the use of high-yielding energy and protein crops and the inclusion of multipurpose leguminous trees, allow the design of promising crop-livestock systems. Such MFS have been widely developed in situations where either environmental conditions or socio-economic conditions were conducive (Van Keulen and Schiere, 2004). In less-favoured areas, lack of external inputs often forced farmers to adopt mixed farming systems to make a livelihood from the limited available natural resources (Altieri, 2002; Pretty et al., 2003; Van Keulen, 2005). Mixed farming systems have also been developed in more favourable environments with market-oriented systems, mainly under pressure of socio-economic (boundary) conditions (Lantinga et al., 2004).

Despite many examples of successful diversified ‘Low External Input’ systems, in Cuba it appeared difficult to convert the large monoculture farms into smaller-scale integrated systems. Low population densities in the rural areas, lack of capital and other inputs and the absence of appropriate infrastructure for smaller-scale livestock production were major constraints. It also appeared difficult to convince the Cuban authorities (particularly the Ministry of Agriculture) of the need for MFS, not only as an ‘alternative’, but as a ‘leading’ strategy for future development of the livestock sector. This could be due to the scarcity of local data. Long-term studies are necessary to gain understanding of the performance of MFS, as well as for evaluation of different combinations of crops and animals in a spatio-temporal framework.

To support this strategy, the current study was designed as the first stage of a broader project at the national level. It aimed to evaluate the conversion of a ‘Low External Input’ Dairy Farming System (DFS) into an MFS by monitoring the dynamics of 15 Agro-Ecological and Financial performance Indicators (AE&FIs) over a six-year period. The final goal is to identify potential integrated strategies for mixed farming, as a basis for sustainable livestock production in Cuba.

2. Materials and methods

2.1 Experimental site

The study was carried out between 1995 and 2000 at the Pastures and Forage Research Institute (IIPF), located in Western Havana City. The soil is a Haplic Ferralsol eutric, clayic, rhodic (WRB, 2006) or Ferralítico rojo típico eutrico in the Cuban classification system (Hernández et al., 1999). Annual precipitation at the experimental site ranged from 1300–1500 mm, of which about 70% fell between May and October (rainy season). Mean temperatures were 26.9 °C and 23.3 °C in the rainy and dry season, respectively. Average relative humidity was between 82–85%, with the highest values during the rainy season.

2.2 Experimental design

Two prototype mixed farms of one hectare each were established on the pasture area of a 15-ha specialized dairy farm, previously managed for about 5 years with low external inputs (i.e. fertilizers, concentrates, fuel, machinery) and low levels of productivity (yields of about 1.5 Mg milk ha^{-1} yr^{-1}). For the purpose of this study, the data collected during the last year of operation of that farm, representing a typical dairy unit for the country, were set to Year Zero of conversion. In the two mixed farms, 25% (C25) and 50% (C50) of the total farm area, respectively, was devoted to arable crops. Descriptions of the mixed farm designs and management practices are given in Figure 1. The livestock sub-systems included pure grass (A1) and grass-legume associations (A2) in both C25 and C50, while a silvo-pastoral system (A3) was established in C25. Legumes in A2 were established by band-sowing at 25 cm distance in the original swards with minimum tillage (Monzote, 1982), and the silvo-pastoral system by planting leguminous trees in A3. Field A1 in C50 was re-planted with king grass (*Pennisetum purpureum*, Schum.) after ploughing down the original sward and establishing living fences of leucaena (*Leucaena leucocephala*, (Lam.) de Wit.). The forage areas in the livestock sub-systems (B1 and B2) of C25 and the annual crop sub-systems (E1 and E2) of both farms were established following ploughing down of the grass sward after removal of the herbage by heavy grazing.

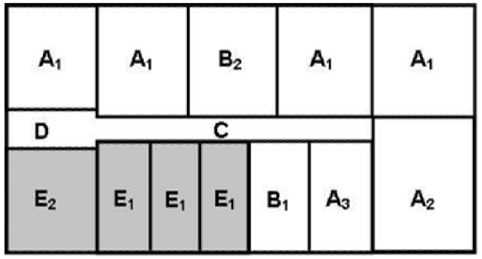
Siboney cattle, a 5/8 Holstein-Friesian and 3/8 Cuban Zebu crossbreed, was used. During the study, one or two cows, depending on herbage availability, were kept in a put and take system on farm C25, and one on C50. Calves, born annually, were reared for four months in a restricted suckling nurse system and subsequently sold. Milk consumed by the calf is not included in the production data, only the sold live weight. Veterinary treatments were based on conventional methods. In addition, natural practices such as the use of entomopathogenic fungi, *Verticillium lecanii* (Rijo, 1996) and Gavac vaccine for cattle tick control (Boue et al., 1999) were implemented.

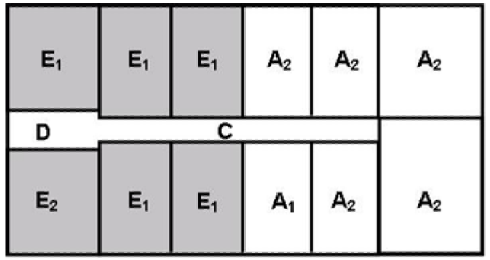
Collected manure (about 10 kg cow^{-1} d^{-1}) and all available biomass, such as crop residues, animal feed refusals, weeds and some fresh legumes, were used for mulching or composted. Composting followed either of two methods: (i) static, aerobic or (ii) vermi-composting using Californian red worms (*Eisenia foetida*) based on the methods described by Ramón et al. (1987). Compost quality control included regular chemical analysis and temperature measurements.

2.3 Assessment of Agro-ecological and Financial Indicators (AE&FIs)

Fifteen AE&FIs (Table 1) were monitored over a six-year period. Selection criteria for their choice were derived from: (i) critical points for sustainable development of livestock production (De Wit et al., 1995), i.e., relevant aspects that may constrain

Farm type	C25		C50	
Farm area (ha)	1		1	
Stocking rate (AU ha^{-1}) *	1.8 (2.5)		1 (2)	





Reference	Land use type	FFA**	Management	Land use type	FFA**	Management
Livestock Sub-system						
A_1	Pure grass (mixture of star and guinea grass).	**35%**	Rotational grazing. Living fences of gliricidia.	Pure grass (king grass).	**10%**	Occasional grazing. Living fences of leucaena.
A_2	Grass/legume association (star and guinea grass-perennial soybean, centrosema, teramnus).	**10%**	Rotational grazing.	Grass/legume association (brachiaria, guinea grass-tropical kudzu, perennial soybean, centrosema, teramnus).	**40%**	Rotational grazing.
A_3	Silvo-pastoral system (leucaena trees) and grass/legume association (guinea grass-teramnus).	**10%**	Occasional grazing. Pruning for fresh supplies the whole year and leaves for hay.	-	-	-
B_1	Sugar cane	**10%**	Cut and carry system during the dry season. Leaves remain in the field. Chopping of stems.	-	-	-
B_2	King grass	**10%**	Cut and carry system year-round.	-	-	-
C	Corridor for the cattle. Free access to drinking water and grazing areas.					
D	Open stable with drinking facility. Supply of fresh forages and hay. Collection of fresh dung and storage for composting.					
Crop Sub-system ***						
E_1	Annual crops (corn/beans, corn/squash, corn/beans/cassava) and green manures (canavalia and mucuna).	**20%**	Crop mixtures in rotation	Annual crops (corn/beans, corn/peanuts, corn/beans/cassava) and green manures (canavalia, mung bean and mucuna).	**45%**	Crop mixtures in rotation.
E_2	Diversified garden	**5%**	Vegetables, fruit trees, spices and medicinal plants fertilized with worm humus and compost produced from collected dung, crop residues and forage refusals. Compost heap.			

Figure 1. Design and management practices in the two mixed farms (C25 and C50); □ Livestock sub-system; ■ Crop sub-system. * AU = animal unit of 450 kg live weight; between brackets AU per ha livestock area. ** Fraction of Farm Area. *** Use of on-farm produced organic fertilizers (i.e. compost). Fruit trees planted between fields. Crop residues collected for animal feeding. Animal draught for soil preparation and cultivation.

performance of livestock systems, (ii) principal environmental problems identified in the Cuban National Strategy for the Environment (CITMA, 1997), and (iii) earlier assessments by Monzote et al. (1999).

All AE&FIs were calculated (Table 1) on an annual basis for periods ending on October 31, more or less coinciding with the end of the rainy season. Calculations on system productivity (yields per commodity, i.e., fruits, cash crops, animal products, production of energy and protein per ha, number of people that can be fed) and energy balances were performed with the computer system ENERGIA (Appendices 3–6; Sosa and Funes-Monzote, 1998), developed for the purpose of this study.

2.4 Data collection

Animal and crop products were weighed at sale for productivity calculations. Number of species and individuals of plant and animal populations were counted once a year for bio-diversity calculations. Labour spent directly on production activities, and other aspects of farm management were monitored daily. Quantities of compost were weighed before application.

2.5 Soil analysis

Soil analyses were carried out according to Paneque et al. (2002): soil pH (H_2O) by potentiometry in a soil-water suspension (1:2.5), available P by the Oniani method, exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na^+) by the method of ammonium acetate, and soil organic matter (SOM) by the Walkley and Black method. In the latter method, commonly used in Cuba, dried soils are analysed for 'easily oxidizable carbon' using a wet chromic acid oxidation. Therefore, multiplication factors are required to obtain total organic carbon and subsequently SOM. A recovery factor of 77% is commonly used to convert 'easily oxidizable carbon' to total organic carbon (range 59–94%; Allison, 1960) and it is generally assumed that SOM contains 58% carbon (range 30–62%; Houba et al., 1997). For interpretation of the soil fertility characteristics, we used the classification of the handbook for soil interpretation of the Ministry of Agriculture of Cuba (DNSF, 1982).

2.6 Financial analysis

Total Cost of Production was calculated from expenses for salaries of hired labour, contract labour, purchase of animals, veterinary care, equipment and materials, energy and seeds. The Total Value of Production for crop and livestock products was derived from the top retail market price, established by the Cuban Ministry of Agriculture (MINAG, 2003; Appendix 2). Crop product prices not included in this list were set to half the average free market prices, in accordance with the general trend in the list of

Table 1. Definition of the applied Agro-Ecological and Financial Indicators (AE&FIs).

Analysis criterion	Indicator	Unit	Calculation method
1. Diversity			
	SR	Margalef index*	Included are total number of species of crops, trees and domestic animals; excluded are soil biota, spontaneous vegetation or other plants and animals.
	DP	Shannon index*	Included are the yield of each separate farm output and that of the total system
	RDI	Shannon index*	Included are both the numbers of tree species and individuals of fruit trees, timber and living fences.
2. Productivity			
	MY	Mg ha^{-1} yr^{-1}	Total milk production of the farm
	MYF	Mg ha^{-1} yr^{-1}	Milk production per unit farm area directly used for animal feeding (i.e. grazing areas, grass-legume associations, cut forage areas and silvo-pastoral system).
	EO	GJ ha^{-1} yr^{-1}	Total energy in agricultural products
	PO	kg ha^{-1} yr^{-1}	Total protein in agricultural products
3. Energy use			
	TEI	GJ ha^{-1} yr^{-1}	Energy values of all inputs directly used for production purposes
	HLI	hours ha^{-1} d^{-1}	Time spent on farm activities
	ECP	MJ kg^{-1}	Total energy used for production divided by total protein output: TEI×1000/PO
	EE	GJ output GJ^{-1} input	Ratio between energy outputs and inputs
4. Financial performance			
	NPV		NPV = Total Value of Production – Sales Taxes (5%) – Post Harvest Losses (5%) – On farm Price ***
	GM	k€** ha^{-1} yr^{-1}	GM = NPV – Total Costs of Production (fixed costs + variable costs)
	BC		BC = NPV / Total Costs of Production (fixed costs + variable costs)
5. Nutrient regime			
	OFU	Mg ha^{-1} yr^{-1}	Amounts of compost applied to crop areas

SR species richness, *DP* diversity of production, *RDI* reforestation index, *MY* milk yield per unit farm area, *MYF* milk yield per unit forage area, *EO* energy output, *PO* protein output, *TEI* total energy inputs, *HLI* human labour intensity, *ECP* energy cost of protein, *EE* energy efficiency, *NPV* net production value, *GM* gross margin, *BC* benefit/cost ratio, *OFU* organic fertilizer use.

* For calculation procedures of Shannon and Margalef indices see Gliessman (2001).

** 1 € is about 1 CUC (Cuban Convertible Peso); 1 CUC = 24 CUP (Cuban Pesos).

*** The wholesale price was set to 70% of the retailer price. Fluctuating product prices and difficulties to obtain reliable wholesale prices of agricultural products made these estimations necessary.

MINAG. Strongly fluctuating product prices and difficulties in obtaining reliable wholesale prices of agricultural products made it necessary to use these estimates. In the calculations, 5% post-harvest losses and 5% sales taxes were taken into account.

For livestock products, i.e. milk and meat, farm gate prices were set to CUP 1.00 litre^{-1} of milk and CUP 2.05 kg^{-1} of beef. See Table 1 for conversion factors of CUP.

2.7 Data analysis

AE&FIs were presented using time series analyses of averages for the six-year study period, with their respective standard deviations. Soil data were evaluated by ANOVA multiple comparison tests, using HSD-Tukey (Tukey, 1977). Statistical analyses were carried out with SPSS (SPSS, 1999).

3. Results and discussion

3.1 Biodiversity

The selected biodiversity indicators focus on three aspects: *species richness*, d*iversity of production* and *reforestation*. These indicators are closely related to two of the major environmental problems associated with mono-cultural patterns of agriculture identified by the Cuban government, i.e. loss of biodiversity and deforestation (CITMA, 1997).

The converted farms were characterized by the presence of large numbers of plant and animal species, i.e., about six times those at the beginning of the study (Table 2). Grain crops, root and tuber crops, vegetables, tree species, and new pasture and forage species were introduced in the design of the mixed farms. This allowed adaptation of the animal ration in the course of the year in response to seasonal climate patterns, especially rainfall, and the associated fluctuations in pasture production, one of the major problems in tropical livestock production systems (Funes, 1979).

The Margalef index, as a measure of *species richness*, combines the total number of species in the system and the total number of individuals, and reached values of 9.1 and 10.4 on the converted farms, thanks to the large number of species present (44 and 52, respectively), compared to only 8 pasture species in year zero and a corresponding index of 1.6 (Table 2). This index provides a more meaningful measure of the diversity at farm level than one only accounting for the total number of species. The large number of plant and animal species was associated with a large diversity in production (17 and 23 products, respectively), compared to only milk and beef before the conversion (Table 2).

Both farms were characterized by large numbers of trees per hectare (131 and 204, respectively), due to the establishment of trees as forage sources for animals, as

Table 2. Performance of agro-ecological and productivity indicators in the specialized farm (Year zero) and for the two mixed farms (C25 and C50) averaged over the six-year period.

Indicator	Unit	Farm System				
		Year zero	C25	st.dev.	C50	st.dev.
Species richness	Margalef index*	1.6 (8)**	10.4 (52)	0.55	9.1 (44)	1.59
Diversity of production	Shannon index*	0.2 (2)	1.7 (23)	0.37	2.0 (17)	0.17
Reforestation index	Shannon index*	0.0 (0)	1.7 (204)	0.06	1.5 (131)	0.10
Milk yield per unit farm area	Mg ha^{-1} yr^{-1}	1.8	2.4	0.95	2.0	0.50
Milk yield per unit forage area	Mg ha^{-1} yr^{-1}	1.8	3.1	1.25	4.0	0.99
Energy output	GJ ha^{-1} yr^{-1}	7.2	16.4	2.63	27.1	5.89
Protein output	kg ha^{-1} yr^{-1}	91.0	133.5	36.94	191.3	42.90
Labour intensity	hr $ha^{-1}d^{-1}$	1.9	3.9	1.50	5.7	1.17
Total energy input	GJ ha^{-1} yr^{-1}	3.1	2.0	0.93	2.8	0.59
Energy cost of protein production	MJ kg^{-1}	34.1	14.8	4.98	14.9	2.06
Energy efficiency	GJ output GJ^{-1} input	2.3	9.6	3.43	9.8	2.10
Organic fertilizer use	Mg ha^{-1}	-	5.3	1.59	5.0	1.98

* For calculation procedures of Shannon and Margalef indices see Gliessman (2001).

** Between brackets, absolute number of trees, species and products.

well as for living fences and fruit production. Trees are an important component in MFS in the tropics. Research in Cuba and the Central American region (Benavides, 1998; Hernández et al., 2001) has revealed increases in milk and meat production, and improvements in animal welfare in livestock systems following introduction of trees, especially leucaena and other leguminous species. Our results indeed indicate that trees, as major components of MFS diversification, had a positive effect on farming system productivity in terms of milk yield, energy and protein output, as tree products such as leaves, were essential components of the animal ration. Moreover, due to the deeper rooting of trees, nutrients can be 'pumped' from the sub-soil (Breman and Kessler, 1995).

The indicators of *diversity of production* and *reforestation* are both expressed in the Shannon index, which combines either the number of products or of tree species (diversity) with the yield per product or the number of individuals per species (abundance). Shannon indices tend to be higher when the distribution of species and individuals is more even, and for relatively diverse natural ecosystems may rank between 3 and 4 (Gliessman, 2001). In our mixed farms, high values of the indices of diversity of production (1.7–2.0) and reforestation (1.5–1.7) were attained, compared to year zero, when diversity of production was 0.2 and trees were absent. They were also appreciably higher than the values (up to 0.48) calculated for hypothetical multicropping agro-ecosystems, with two or three species and high evenness (Gliessman, 2001).

Application of the Shannon and Margalef diversity indices, originally developed for evaluation of natural ecosystems, for analysis of agro-ecosystem diversity might lead to increased insight in the contribution of crop and animal diversification to the improvements in productivity, efficiency and financial indicators of mixed systems.

The increase in plant diversity also affected diversification in other aspects. In our two mixed farms, 15 natural enemies controlling potential pests have been identified (Pérez-Olaya, 1998). Perennial crops, such as grasses, gliricidia (*Gliricidia sepium*, (Jacq.) Kunth ex Walp.) and leucaena acted as alternative hosts for natural enemies of crop pests. These observations are in line with those of Vandermeer et al. (1998) and Altieri (1999b), i.e. system diversification stimulates emergence of natural enemies controlling pests, contributing to sustainability of agricultural systems.

Moreover, soil fauna biodiversity and the activity of soil biota (diplopods and worms) have been shown to increase following conversion to MFS (Rodríguez, 1998).

3.2 Productivity

Productivity is probably the most extensively used indicator in agronomic performance analyses. This study took into account four indicators for productivity of the farm: milk production per unit farm area and per unit forage area, and total energy and protein output.

Milk yield per unit farm area was somewhat higher than before the conversion to mixed farming (Table 2), although up to 50% of the total farm area was used for arable and horticultural crops, and therefore not directly for producing animal feed. This increase was the result of the introduction of various innovations in the mixed farms; e.g., cultivation of high-yielding perennial forages, grass-legume associations and leguminous trees and use of crop residues as animal feed, resulting in more and better quality animal feed throughout the year. This also led to a high *milk yield per unit forage area* after conversion (Table 2).

Given that the Cuban government has defined the social mandate of the dairy sector as: ‘to produce milk for children, elderly and sick people’, increasing milk production is a political priority. However, biophysical and socio-economic constraints have reduced current total milk production in Cuba to about one-third of that in the 1980s (González et al., 2004) and present-day average annual yields in specialized commercial dairy production units do not exceed 1 Mg of milk per ha of farmland (MINAG, 2006). In commercial dairy farming, based on pasture and medium levels of concentrates, under ‘outstanding management’, production up to 3 Mg per hectare is possible (García Trujillo, 1983). In year zero of this study, the original specialized system produced 1.8 Mg ha^{-1}, while in the mixed farms, annual yields of 3.1 and 4 Mg per ha forage area were attained (Table 2).

In terms of total production (expressed in energy and protein, the two main components in human nutrition), livestock products in the mixed farms exceeded the yields in year zero, on top of which crop products were harvested. The highest *energy* (27.1 GJ ha^{-1} yr^{-1}) and *protein* (191.3 kg ha^{-1} yr^{-1}) outputs (Table 2), achieved at farm C50, were associated with high ‘additional’ crop production.

Productivity can also be expressed in terms of the number of people that can be fed from the protein or energy output of a system. Averaged over the six-year period, in farm C25 the energy produced was enough to adequately feed four people, with protein for up to five, while in C50 these numbers were six and eight, respectively. These numbers are about twice as high as reported in literature for medium-intensity specialized milk production systems (Spedding, 1988; Beets, 1990) and at least four times higher than currently achieved in the ‘Low External Input’ specialized dairy systems in Cuba.

3.3 Energy use

3.3.1 Labour

Human labour productivity is an essential indicator in performance assessment of MFS strategies in dairy farms in Cuba, because of the scarcity of this 'resource' in rural areas. Although labour-intensive designs were implemented, in practice labour input gradually decreased over time on farm C25, while farm C50 showed a parabolic pattern with a maximum in year three (Figure 2A). Concurrently, production was maintained and, therefore, labour productivity increased. The higher labour demand of both mixed farms in the first years can be attributed to the initially higher number of farm activities, such as sowing legumes in grazing areas, conversion of pasture into arable land, fencing, planting of trees, establishing the crop rotation system, weed control, etc. Over the six years, total labour input was lower in C25 than in C50, due to the smaller cropping area.

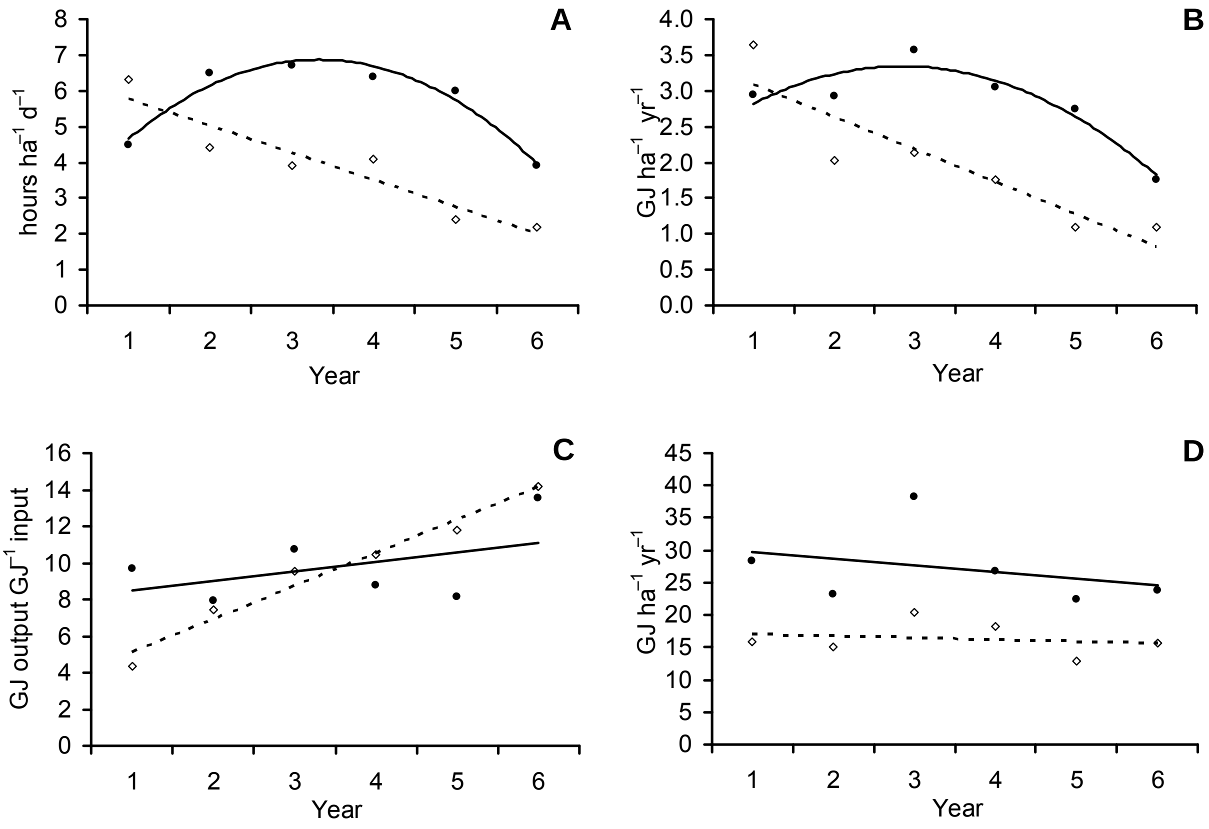


Figure 2. Dynamics of human labour intensity (A), total energy inputs (B), energy efficiency (C) and energy output (D) on mixed farms with 25% and 50% crop area, following conversion from a pasture-based dairy system. Dashed line: C25; solid line: C50.

Our results are relevant for the three major segments of present livestock production in Cuba: (i) the growing sector of small producers that received land from the state in usufruct, currently about 400 thousand (Granma, 2006b), each with up to five ha of land, managed with labour-intensive methods; (ii) the small farmers sector, cultivating private land and producing individually or organized in cooperatives such as Credit and Services Cooperatives (CCS) and Agricultural Production Cooperatives (CPA) at intermediate levels of productivity, but in most cases at low levels of crop-livestock integration; and (iii) the Basic Units of Cooperative Production (UBPC) that started in 1993 under Law 142. This law regulated partitioning of previous state cattle holdings into smaller units, encouraging diversification and adopting a family farm model. In total, these three segments affect about 4.2 million hectares of Cuba's agricultural land. However, recent estimates set the area of abandoned land at roughly 3 million hectares, i.e. about half of Cuba's agricultural area, belonging for the greater part to the UBPC and state enterprises.

Two possible directions to reverse this development are promotion of either extensive or small-scale intensive livestock-crop-tree mixed farming with low environmental impact. Under both scenarios, many of the 'Low External Input', low labour-intensive and high-efficiency natural resource management practices implemented in the current study are applicable. However, further simplifying managerial activities continues to be a goal, considering that labour availability remains a primary constraint, as the population has moved out of the rural areas.

3.3.2 Energy inputs

Increasing the efficiency of input use was identified as an important objective in the management of the prototype mixed farms. The small sizes of the two experimental farms allowed use of animal traction and intensive human labour, instead of mechanized operations. Human labour was the largest component in energy inputs on both mixed farms that were designed as labour-intensive management systems, with the other components (i.e. diesel and feedstuffs) accounting for about 20% of the total (Figure 3).

Energy input linearly decreased with time since establishment on farm C25, while on farm C50 it showed a parabolic pattern with a maximum in year three, in parallel to the labour inputs (Figure 2B), and was lower on farm C25, due to the smaller area devoted to crop production. Realizing high levels of production, at the lowest possible level of inputs (Hilhorst et al., 2001) would indeed be an advantage under the conditions of scarcity and uncertain supply of inputs prevailing in Cuba. This is a strong argument in favour of continuation of MFS, even when the economic situation improves.

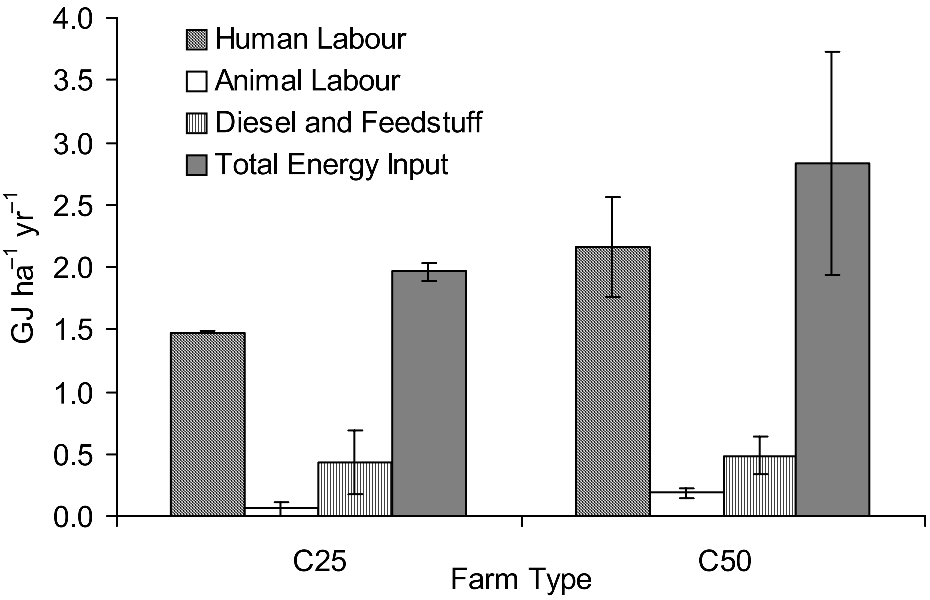


Figure 3. Average energy input use on mixed farms with 25% and 50% crop area for the six-year period following conversion from a pasture-based dairy system. Error bars indicate the standard deviation of the mean.

3.3.3 Energy efficiency

Higher energy efficiencies on the mixed farms were primarily the result of transformation of part of the pasture area into arable crops, leading to an increase in total energy output and a reduction in total energy input (Table 2). *Energy efficiency* shows an increasing trend with time after conversion on both farms, associated with decreases in total energy input, mostly in the form of human labour, while energy output was stable (Figures 2 A, B, C, D).

In energy terms, protein was produced more efficiently in the mixed systems (i.e. lower *energy costs of protein production*) than in the specialized system. Moreover, although energy efficiencies in animal and crop production systems have a different biological basis (Spedding, 1988; Stout, 1990), our results indicate that higher production of animal protein per unit forage area can be attained using MFS strategies. This type of farm-scale energy efficiency analyses is consistent with studies of Pimentel (2004) and Giampietro et al. (1994) who in sustainability analyses, focused on energy flows in food production at system level. Energy conversion analyses should not be considered as an alternative to financial analyses, but rather as a complement to better cover the complex web of interrelationships between finances and the environment in which food systems operate (Giampietro et al., 1994).

In countries where fossil energy is abundantly available or where the use of high energy inputs is subsidized, energy-intensive farming systems do not face many technical constraints. However, for countries such as Cuba, where energy and/or capital are scarce resources, energy efficiency is a critical issue for national food security (Funes-Monzote and Monzote, 2001). Furthermore, economic considerations such as high oil prices on the international market and environmental issues such as global warming associated with CO_2 emissions, and the pollution of water and air, are leading societies worldwide to demand more responsible use of fossil energy. High dependence on fossil fuels is generally considered an indicator of low sustainability. Renewable energy alternatives such as biogas, wind power, solar energy, biomass and biofuels, have high potential applications for the development of energy self-sufficient agricultural systems (Pimentel et al., 2002).

3.4 Financial results

Our two mixed farms achieved higher gross margins and higher *benefit-cost* ratios than the specialized farm (Table 3). This is the result of the inclusion of arable crops, the high productivity per unit farm area, and the higher prices for crop products than for milk and meat (Appendix 1). Therefore, increasing whole farm income by selling crop products in regions where arable farming is possible, might be a suitable strategy for supporting cattle operations and making dairy farming more attractive. This is in line with the results presented by De Koeijer et al. (1995) and Thomson et al. (1995) who have indicated financial advantages of MFS, as a result of a more intensive use of natural resources and beneficial interactions between crop and livestock production.

The *total value of production* was higher in the two mixed systems than in the specialized dairy system in year zero, but the *total costs of production* were also higher, associated with the higher labour costs and the capital demand to establish the crop production activities (Table 3). Economic incentives are important to sustain or to increase the population in rural areas. However, lack of incentives and centralized top-down decisions constrain development of the dairy sector. The price of milk for the consumer in the vulnerable sectors of the population is set to 0.25 CUP per litre by the government, the only official milk processor and retailer, while the producer price is set to about 1.00 CUP per litre, which is low, considering the costs of production. Therefore, milk production is a low-income activity, not economically attractive for producers. While a reduction in the cost price of milk is difficult to realize in low external input DFS, in MFS, milk production tends to become more feasible when combined with other, highly profitable activities such as cash crop and fruit production.

The results of this study are not in contradiction with the national policy of prioritization of the dairy sector. To be politically acceptable, any diversification

Table 3. Performance of financial indicators in the specialized farm (Year zero) and the two mixed farms (C25 and C50) averaged over the six-year period.

Financial Indicator	Farm System				
(kCUP ha^{-1} yr^{-1})	Year zero	C25	st.dev.	C50	st.dev.
Total value of production	2.49	8.65	2.03	15.25	5.34
Value of crop production	–	6.03	2.09	13.02	5.15
Value of livestock production	2.49	2.62	0.92	2.23	0.59
Net production value	2.49	6.11	1.31	9.93	3.29
Total costs of production	1.87	3.51	1.15	4.86	0.81
Salaries	0.79	1.64	0.64	2.38	0.49
Purchase of animals	0.50	0.20	0.32	0.20	0.32
Veterinary treatments	0.04	0.06	0.02	0.04	0.00
Equipment and materials	0.20	0.52	0.02	0.59	0.02
Diesel	0.25	0.17	0.01	0.42	0.02
Seeds	0.09	0.91	0.32	1.23	0.32
Gross margin	0.62	2.60	0.67	5.07	2.83
Benefit-cost ratio (-)	1.33	1.74	0.38	2.04	0.50

1 € is about 1 CUC (Cuban Convertible Peso); 1 CUC = 24 CUP (Cuban Pesos).

strategy should first demonstrate that it does not negatively affect the 'main goal' of producing milk, associated with the 'social mandate' given to livestock enterprises. Hence, any MFS strategy should be able to produce milk with 'minimal environmental damage' and at low costs in external inputs.

Moreover, if economic or political changes lead to price increases for milk and meat, other goals, related to environmental protection and sustainable rural development will be sufficiently important to retain mixed farming on Cuba's future agricultural agenda.

Farms in the UBPC are increasingly turning towards prioritizing diversification for self-sufficiency (feeding workers and their families at low costs and selling possible surpluses in local or external markets to improve their financial sustainability), which makes these results even more relevant. Other emergent activities that might be combined in diversified MFS such as agro-tourism, nature conservation and education are also attractive options and need to be seriously considered. However, as indicated before, structural changes and economic incentives are necessary to stimulate the return of people to the rural areas and make economic use of available land. Our results show that the importance of the financial impact of adopting MFS to promote changes in Cuban agriculture should not be underestimated.

3.5 Soil fertility

Soil fertility of the Ferralsols in year zero was classified as medium. According to DNSF (1982), the content of soil organic matter (SOM) was low and pH moderately to slightly acid. Levels of available P and exchangeable K^+ were medium, while the sum of exchangeable cations (SEC = base saturation) was half the 'typical' values for this type of soil (around 20).

After conversion to mixed farming, SOM contents tended to increase. Although in some fields this increase was statistically significant, these data should be interpreted with caution. In the Walkley and Black analytical method it has been assumed for the calculation of SOM that 77% of the organic carbon is oxidized and that SOM contains 58% carbon. Since these are average values that may vary widely, depending on soil type and management practices, respectively, the results in terms of changes in SOM over time after adaptations in soil management, are highly uncertain.

Soil pH increased slightly and remained moderately to slightly acid, except in the cash crop (C_1) and the diversified garden (C_2), where it increased significantly. Available P decreased to low in A_1 and A_3, remained medium in A_2 and B_2 and increased to high in B_1, C_1 and C_2; however, the differences were not statistically significant. Exchangeable K^+ changed very little, except in sugar cane (B_1) and in king grass (B_2), where it declined. SEC hardly changed, and remained low for all land use types (Table 4).

Table 4. Initial soil fertility status in Year Zero and five years after conversion, soil layer 0–20 cm (mean values with standard errors between brackets).

Land use type	No. of bulk samples *	Soil characteristics						
		pH	SOM	P	K^+	Ca^{2+}	Mg^{2+}	SEC
		H_2O	%	ppm	$cmol_{(+)}\ kg^{-1}$			
Year zero **								
Pure grass	20	5.6^b(0.14)	3.0^b(0.14)	7.7^b(1.32)	0.44(0.03)	8.0^b(0.10)	1.35^c(0.05)	9.78^c(0.10)
After conversion ***								
A1 - Pure grass	2	6.1^{ab}(0.10)	3.6^{ab}(0.65)	6.0^{ab}(0.00)	0.48(0.03)	7.9^b(0.10)	1.35^{bc}(0.15)	9.73^{bc}(0.28)
A2 - Grass/legume associations	2	6.1^{ab}(0.05)	4.0^{ab}(0.07)	7.5^{ab}(1.50)	0.42(0.07)	8.4^b(0.05)	2.15^{ac}(0.15)	10.92^{bc}(0.27)
A3 - Silvo-pastoral system	2	5.7^{ab}(0.10)	3.4^{ab}(0.00)	6.0^{ab}(0.00)	0.36(0.15)	6.7^b(0.15)	2.35^{ab}(0.05)	9.36^c(0.15)
B1 - Sugar cane	4	5.9^{ab}(0.10)	4.2^a(0.31)	15.0^{ab}(1.78)	0.28(0.06)	8.3^b(0.43)	2.30^{ab}(0.45)	10.83^{bc}(0.21)
B2 - King grass	2	6.5^{ab}(0.25)	3.9^{ab}(0.13)	8.5^{ab}(1.50)	0.18(0.04)	8.3^b(0.25)	2.75^a(0.25)	11.18^{bc}(0.04)
C1 - Cash crops	4	6.8^a(0.18)	4.6^a(0.04)	17.5^{ab}(7.01)	0.37(0.04)	9.3^{ab}(0.72)	2.90^a(0.04)	12.57^{ab}(0.72)
C2 - Diversified garden	8	6.7^a(0.12)	3.6^{ab}(0.15)	24.9^a(3.51)	0.30(0.05)	11.1^a(0.70)	2.55^a(0.18)	13.95^a(0.73)

* For each land use type at least five samples were bulked into one sample, from which a sub-sample (about 2 kg) was taken for chemical analysis; ** Soil fertility status before conversion; *** Soil fertility status five years after conversion. Means with different letters in superscripts differ significantly between farm systems components (Tukey-HSD; $P<0.05$).

The application of on-farm produced compost and vermi-compost at annual doses of between 4 and 6 Mg ha^{-1} in the crop sub-system, and other soil-restoring practices such as planting legumes and trees, and mulching, might allow maintaining or even slightly increasing SOM in the arable land (De Ridder and Van Keulen, 1990). However, roughly 40 Mg of compost per ha should have been added annually during five years to increase SOM by 1% (B.H. Janssen, Group Plant Production Systems, Wageningen University, pers. comm.). Such quantities were certainly not incorporated in the mixed systems, confirming the uncertainties associated with the Walkley and Black method.

The slight decrease in available P in the grazing sub-system may be attributed to the continuous phosphorus export through sales of milk and meat, and manure collected in the stable (about 3.6 Mg annually). Increases in SOM, pH and available P have been reported in a silvo-pastoral system in Cuba (Crespo and Rodríguez, 2000). Hence, there was no reason to expect P depletion in the silvo-pastoral sub-system. However, studies in Australia and New Zealand have shown acidification effects as a consequence of biological N-fixation of legumes, leading to a reduction in availability of some nutrients such as P (Haynes, 1983; Helyar and Porter, 1989; Ledgard and Steele, 1992). In the king grass sub-system, apparently K is being depleted and needs to be restored. This process has been extensively documented (Herrera, 1990) and maintenance of a favourable soil K-status in high-yielding forage areas should be a goal in any MFS.

The overall picture arising from these data is that as a result of nutrient exports from the farm in the form of products, and the redistribution of nutrients via organic transfers, nutrients accumulate in some of the arable fields, while some other fields (particularly pastoral) are 'mined' (Hiernaux et al., 1998; Archard and Banoin, 2003). This is especially true for P and K. The information on carbon dynamics is inconclusive, as there is doubt about the quality of the analytical data. However, accumulation seems to take place in the arable sub-systems, especially the annual crops and the sugar cane. Medium-term rotation (5–7 years) of the crop and livestock sub-systems might be a solution to this problem. However, longer-term research is necessary to establish the long-term effects of rotations and in general of agro-ecological management on soil fertility at farming system level.

4. Conclusions

More intensive use of the available natural resources at the farming system level, through diversified MFS in terms of both crop and milk production, contributes to food self-sufficiency and to efficient production of marketable products that contribute to household incomes without degrading the resource base.

Despite the small scale of the current experiment, its potential impact is large. More than two million hectares of land in Cuba are used in specialized milk or meat production systems, managed essentially according to the same principles used prior to 1990, while the institutional environment, in terms of infrastructure and availability of inputs, has changed drastically. Moreover, current livestock developments take place on small- and medium-scale family farms (in both individual and cooperative forms of production), to which the results of this study are potentially applicable.

The lack of capital to maintain conventional high-input systems, the necessity of increasing the level of national food self-sufficiency and the need to restrict negative impacts on the environment are not only issues for Cuba, but also for other developing and developed countries.

Chapter 4

Agro-Ecological Indicators (AEIs) for dairy and mixed farming systems classification: Identifying alternatives for the Cuban livestock sector

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Abstract

Attainment of acceptable levels of land and labour productivity and low external input use are not incompatible goals. This study examines characteristics of a range of current specialized Dairy Farming Systems (DFS) and Mixed (crop-livestock) Farming Systems (MFS) in Cuba to determine their efficiency in the process of food and feed production. The central question was whether the favourable results of MFS realized in a small-scale experimental system were also attainable in larger, commercial farms. To this end, we collected data on 93 farms from around the country for a period of one year. The farms were classified according to four predictor variables: farm type, years since conversion from DFS to MFS, proportion of land allocated to crops in rotation and farm size. Farms were compared based on 12 pre-selected Agro-Ecological Indicators (AEIs) by using analysis of variance and Tukey's HSD tests. The twelve AEIs were also subjected to a principal components analysis and related to the four predictor variables by reduced-rank regression, also known as redundancy analysis. Three farm types were distinguished: mixed farming experimental (MFe), mixed farming commercial (MFc) and specialized dairy farming (DFS). Total energy output per unit farm area was on average four to six times higher on the mixed farms than on the specialized dairy farms and protein output three to four times. Milk yield per unit of forage area was highest on MFe (2.4 Mg ha^{-1} yr^{-1}), followed by MFc (1.7), while it was much lower (0.7) on DFS. The redundancy analysis revealed that MFe did only slightly better than MFc and was most opposite to DFS in terms of AEIs. In conclusion, the previous experimental findings were confirmed nationwide, thus demonstrating the benefits of MFS in terms of agro-ecological performance for the Cuban situation.

Keywords: Agro-ecology; crop-livestock integration; dairy farming systems; energy efficiency; farming systems; multivariate analysis

1. Introduction

Over the past 50 years, considerable increases in crop yields and animal production have been achieved worldwide in conventional, specialized agricultural systems. Their negative biological and environmental consequences are now widely recognized (Grigg, 1993; Matson et al., 1997). Furthermore, to sustain increases in food production in these specialized systems, increasingly higher levels of inputs, such as chemicals, machinery and fossil energy have been necessary (Rosset, 1999; Funes et al., 2002; Tilman et al., 2002). This implies both, greater dependence on external energy and lower energy use efficiency in highly specialized agricultural systems (Pimentel, 1997; 2004). To address these problems, mixed farming systems (MFS), based on agricultural diversification at farm level, being less dependent on external inputs, have emerged as a promising alternative for more sustainable land and natural resource use (NRC, 1989; Van Keulen et al., 1998). MFS allow conservation of natural resources, while maintaining or even increasing yields (Sumberg, 1998; Uphoff, 2002; Pretty et al., 2006). Heterogeneity and diversity characterize such mixed farming systems, which have been developed especially in less favoured areas in response to the prevailing climatic, socio-economic and financial constraints (Ruben and Pender, 2004; Van Keulen, 2005). However, scientific interpretation, analysis and assessment of the dynamic, variable and site-specific interactions within MFS in developing countries are still fraught with uncertainty (Van Keulen and Schiere, 2004). There is a need therefore, for implementation of frameworks capable of integrating existent specialized knowledge, and manage it across disciplines, in order to deal with agricultural complexities in developing countries (Funes-Monzote et al., 2002; López-Ridaura et al., 2005; Herrero et al., 2007).

In Cuba, agricultural diversification is being recognized since the early 1990s as one alternative development, following the collapse of the agricultural sector. However, only small farmers from the private sector, capable of decentralized decision-making, have adopted these practices to a significant extent (Funes-Monzote et al., 2008). These smallholders, managing a relatively small proportion (about 20-25%) of the available agricultural land, have achieved substantial increases in land and labour productivity following the transition to mixed farms. They significantly contribute to national food security, producing 65% of the marketed agricultural output (Granma, 2006). Such small farms are characterized by efficient use of land and external inputs, careful management of locally available natural resources, and low dependence on external inputs, but they have been unable to realize their full potential due to limited capital availability and poor infrastructure.

There are now major opportunities for adoption of mixed farming technologies nationwide, especially in the livestock sector. The lack of capital for monoculture-based infrastructure, following the disintegration of the communist block (González et al., 2004; Nova, 2006), the inefficiency of the centralized-conventional, industrial model of agriculture (ANPP, 1991; Monzote et al., 2002), and its negative environmental impacts (CITMA, 1997) make application of agro-ecological approaches, based on environmentally-friendly use of natural resources, an imperative. Farmers and researchers have made considerable efforts in search of solutions to the problems characteristic of the specialized low-input farming systems such as low productivity, under-exploitation of available natural resources, low degree of diversification, and few economic incentives for farmers. However, most projects in this field have been limited in scope, lacking a coherent policy at national level.

This study builds on a previous study on small-scale prototype experimental farms that has demonstrated the potential of MFS to contribute to ecological, productivity, and financial objectives for cattle production in Cuba. Performance of the prototype farms was analysed on the basis of twelve Agro-Ecological Indicators (AEIs), representing attributes of sustainable natural resource management (Funes-Monzote et al., 2008). In scaling-up the analysis from prototype experimental farms to commercial farms, this study examines whether the results from the small-scale experiment are also attainable under commercial conditions, and for a greater number of farms. In addition, it seeks a better understanding of the underlying role played by each AEI, in close interaction with four pre-selected predictor variables (farm type, years since conversion, crop proportion, and farm size), for their characterization.

2. Materials and methods

2.1 Area description

The research took place in five provinces traditionally known for their milk and meat production, representing the main agro-ecological zones of the island. Sites were located in Eastern, Central and Western Cuba. Climatic conditions in the Eastern provinces are less favourable for agriculture, with longer drought periods, higher temperatures and lower annual rainfall (Table 1). However, all farms were located in areas suitable for agriculture, at altitudes between 20 and 100 meters above sea level.

2.2 Farm selection

Farms were selected in consultation with members of local research teams participating in the study, based on four criteria: (i) they should be managed under a ‘Low External Input’ regime; (ii) the sample should include specialized dairy and mixed farms of different sizes, at different stages of conversion, and with different crop-livestock ratios; (iii) farmers should be willing to collaborate in the study; and

Table 1. Soil types and climatic conditions at surveyed sites.

Region	Province	No. of farms	Soil type*	Mean temperature Max. (°C)	Mean temperature Min. (°C)	Rainfall distribution** Dry season (%)	Rainfall distribution** Wet season (%)	Rainfall distribution** Annual mean (mm)
West	Havana	48	Ferrasols, Cambisols	29.4	19.4	20.3	79.7	1547
Centre	Sancti Spíritus	11	Cambisols	30.6	20.7	18.5	81.5	1698
	Camagüey	6		30.4	21.5	22.6	77.4	1153
East	Las Tunas	26	Luvisols,	31.7	21.7	28.0	72.0	945
	Granma	2	Cambisols, Vertisols	32.7	20.7	23.8	76.2	1099

* Classification according to IUSS Working Group (WRB, 2006).

** Source for climatic data: ONE, 2004. The dry season, from November to April, is characterized by the lowest temperatures and lowest rainfall.

(iv) farms should be representative, in terms of practices and methods. In total, 93 farms were selected in the three regions (Table 1), most of which were already involved in research and development projects led by the Pasture and Forage Research Institute (IIPF) of the Ministry of Agriculture. This implied existing good working relationships between researchers and farmers, which facilitated the monitoring process from financial and practical points of view (i.e. interaction at low costs and limited time investments).

2.3 Characteristics of farms

The 93 farms selected were classified into three farm types (TY): experimental mixed farming (MFe), commercial mixed farming (MFc), and commercial specialized dairy farming (DFS), with the following characteristics:

MFe: Located at research stations within the agro-ecological network of IIPF, under ‘controlled’ conditions, designed and managed by researchers and technicians. These farms are relatively insulated from the influence of the prevailing socio-economic environment and served as research and demonstration prototypes for crop-livestock integration. Converted from pure pasture areas, MFe are characterized by high agro-diversity and intensive (re-)use of internal resources.

MFc: Either market-oriented or oriented at household food self-sufficiency, these farms are typically small to medium-sized, with private or cooperative land ownership. They integrate crops and livestock at high degrees of diversity, based on innovative technologies, traditional knowledge, and intensive recycling of nutrients and energy.

DFS: All farms of this type belong to State Enterprises or Basic Units of Cooperative Production (UBPC) and are managed mostly by hired labourers. DFS are characterized in general by limited use of local natural resources and mainly produce milk and/or meat. Sometimes a small cropping area is maintained for home consumption.

2.4 Selection of classification criteria

Results obtained in previous research on experimental farms (Funes-Monzote et al., 2008) guided the selection of classification criteria. In those investigations, the values of the Agro-Ecological Indicators of the two prototype mixed farms that were monitored, changed with time since their conversion to mixed farming systems. Therefore, we selected length of the period since conversion to mixed farming started (years since conversion, YC) as the first classification criterion. We also found differences between the two converted farms, characterized by 25% and 50% of the farm area under cropping, respectively; thus, we selected the proportion of the total farm area under arable cropping (crop proportion, CP) as another criterion. Finally, as in the development of farming systems, economies of scale play an important role, we selected total farm area, farm size (FS) as an additional criterion (Table 2). Hence, for the purpose of the present study, each farm type (TY) was combined with the three variables, YC, CP and FS (Table 3).

Factor analysis showed that neither region, nor agro-ecological conditions (soil type and climatic conditions) showed a differentiating effect in farming system classification; hence, we did not consider them in the study. Because of strong spatial and temporal fluctuations in prices for products and inputs, and unreliable financial records for all farms, financial indicators were excluded.

2.5 Sampling procedure and calculation method for Agro-Ecological Indicators

The basic data were collected for a one-year period (2002), following a structured questionnaire. Each farm was visited several times in the course of the year. Researchers and farmers/farm managers jointly completed forms during the field visits, which allowed them to build-up mutual trust and gave researchers the chance to acquire in-depth knowledge about farming system management, and to collect reliable information.

Twelve AEIs were derived from four analytical criteria representing attributes of sustainable natural resource management: diversity, productivity, energy use, and nutrient management. The calculation procedures for the 12 AEIs are given in Table 4.

Table 2. Farm classification of the monitored farms (n=93), based on the four selected criteria.

Selection criterion	Class 1	No. of Farms	Class 2	No. of farms	Class 3	No. farms
Farm type (TY)	Mixed Farming experimental, MFe	33	Mixed Farming commercial, MFc	25	Dairy Farming System, DFS	35
Years since conversion (YC)	3 or more	28	1 or 2	30	not converted	35
Crop proportion (CP), %	> 45–75, high	11	> 3–45, medium	50	≤ 3, low	32
Farm size (FS), ha	≤ 10, small	39	> 10–50, medium	26	> 50–150, large	28

Table 3. Geometric means of variables YC, CP and FS according to the variable type of farming (n=93) and their common geometric standard deviation (st. dev.).

Variable	Type			Geometric* st. dev.
	Mixed Farming experimental, MFe	Mixed Farming commercial, MFc	Dairy Farming System, DFS	
Years since conversion (YC)	3.3^a	1.9^b	0^c	1.48
Crop proportion (CP), %	36.1^a	25.2^b	1.8^c	1.81
Farm size (FS), ha	1.9^c	17.5^b	59.0^a	1.93

* Geometric means with different letters in superscript differ significantly (P<0.01) between farm systems (Tukey's HSD). Approximate 95% tolerance interval of AEIs within types is: [geometric mean / (geometric st. dev.)^2, geometric mean × (geometric st. dev.)^2].

2.6 Statistical analyses

The experimental unit for analysis was the farm. Original data of AEIs were transformed by $\log_{10}$ (x) to obtain a more normal distribution. Zero values were replaced by half the minimum non-zero value per class of the variable. The transformed data were subjected to analysis of variance and Tukey's HSD as the multiple comparison test with $\alpha = 0.05$. Factor analysis allowed us to identify the variables useful for farm classification.

Performance of the AEIs was compared within classes of the four predictor variables: TY, YC, CP and FS (see Table 2). Geometric standard deviation (also called multiplicative standard deviation) was used to obtain an approximate 95% range of values within types (Limpert et al., 2001). To visualize the differences among farms and farming systems, AEIs were subjected to principal components analysis and related to the four predictor variables by reduced-rank regression (the quantitative values of the variables were used except for TY). Reduced-rank regression (Davies and Tso, 1982; Ter Braak, 1994; Ter Braak and Looman, 1994), also referred to as redundancy analysis, can be viewed as a combination of principal components analysis and multiple regression. Compared to principal components analysis, its components

Table 4. Definition of the applied agro-ecological indicators (AEIs).

Analysis criterion	Indicator	Unit	Calculation method
Agro-diversity			
	SR	Margalef index*	Included are total number of species of crops, trees and domestic animals; excluded are soil biota, spontaneous vegetation or other plants and animals
	DP	Shannon index*	Included are the yield of each separate farm output and that of the total system
	RDI	Shannon index*	Included are both the numbers of tree species and individuals of fruit trees, timber and living fences
Productivity			
	MY	Mg ha^{-1} yr^{-1}	Total milk production on the farm
	MYF	Mg ha^{-1} yr^{-1}	Milk production on farm area directly used for animal feeding (including grazing areas, grass-legume associations, cut forage areas and silvo-pastoral system)
	EO	GJ ha^{-1} yr^{-1}	Total energy in agricultural products
	PO	kg ha^{-1} yr^{-1}	Total protein in agricultural products
Energy use			
	TEI	GJ ha^{-1} yr^{-1}	Energy value of all inputs directly used for production purposes
	HLI	hours ha^{-1} d^{-1}	Time spent on farm activities
	ECP	MJ kg^{-1}	Total energy used for production divided by total protein output: TEI×1000 / PO
	EE	GJ output GJ^{-1} input	Ratio between energy outputs and inputs
Nutrient regime			
	OFU	Mg ha^{-1} yr^{-1}	Amounts of compost or worm humus applied to crop areas

SR species richness, *DP* diversity of production, *RDI* reforestation index, *MY* milk yield per unit farm area, *MYF* milk yield per unit forage area, *EO* energy output, *PO* protein output, *TEI* total energy inputs, *HLI* human labour intensity, *ECP* energy cost of protein, *EE* energy efficiency, *OFU* organic fertilizer use.

*For calculation procedures of Shannon and Margalef indexes, see Gliessman (2001).

maximize the variance explained by the four predictor variables. Results were graphically presented as a distance biplot (Gabriel, 1982; Ter Braak and Looman, 1994) that best displays: (1) the means of the AEIs with respect to TY; (2) the correlations of the AEIs with YC, CP and FS; and (3) the Euclidean distances among the farms and the farm types. The plotted farm scores are linear combinations of the AEIs to best display the AEIs of farms (Ter Braak, 1994).

Multiple comparison tests for all variables were carried out using SPSS for Windows (SPSS, 1999). Reduced-rank regression was carried out using Canoco for Windows 4.5 (Ter Braak and Šmilauer, 2002).

3. Results

3.1 Performance of Agro-Ecological Indicators

Classifications of farming systems on the basis of the four predictor variables TY, YC, CP and FS showed strong associations among them. In fact, the characteristics of mixed farms overlapped with those of small- and medium-scale farms, and with the ones with greater crop proportions. Mixed farms, with significantly greater bio-diversity, were also more productive, more energy-efficient and showed better nutrient management than the specialized DFS, which performed poorly in terms of the selected AEIs. Subsections 3.1.1 to 3.1.4 describe the comparative results of univariate analysis for the performance of each of the AEIs within the classes of predictor variables TY, YC, CP and FS (Tables 5a and 5b).

3.1.1 Farm type (TY)

Multi-functionality and bio-diversity appeared to be two primary features of the mixed farm types. In all mixed farms, the values for the three biodiversity indicators were higher, although with some differences between the two mixed farm types. For example, species richness in MFe exceeded that in MFc, while the diversity of production and the reforestation index were slightly higher, though not significantly, in MFc. At the same time, productivity indicators (milk yield, milk yield per unit forage area, energy output, and protein output) were significantly higher for the mixed farm types than for the specialized farms. Productivity of some DFS farms was extremely low, clearly indicating neglect, while some mixed farms achieved surprisingly high levels of productivity. Overall, the highest milk yield, both per unit farm area and per unit forage area was achieved in MFe (1.5 and 2.4 Mg ha^{-1} yr^{-1}), i.e. two and more than three times that in DFS, respectively. Mixed farms produced four to six times as much energy and three to four times as much protein in products as the specialized DFS. Energy inputs were lowest in the MFe farms, without significantly

Table 5a. Geometric means of Agro-Ecological Indicators (AEIs) according to type, years since conversion, crop proportion and farm size (n=93) and their common geometric standard deviation (st. dev.).

AEIs	Unit	Type				Years since conversion			
		Mixed Farming experimental n=33	Mixed Farming commercial n=25	Dairy Farming System n=35	Geometric st.dev.	3 or more n=28	1 or 2 n=30	Non converted n=35	Geometric st.dev.
Species richness	Margalef index	8.8^{a}	6.0^{b}	2.5^{c}	1.51	8.6^{a}	6.6^{a}	2.5^{b}	1.53
Diversity of production	Shannon index	1.8^{a}	2.0^{a}	0.3^{b}	1.23	1.9^{a}	1.9^{a}	0.3^{b}	1.23
Reforestation index	Shannon index	1.5^{a}	1.8^{a}	0.7^{b}	1.64	1.6^{a}	1.7^{a}	0.7^{b}	1.65
Milk yield (farm area)	Mg ha^{-1} yr^{-1}	1.5^{a}	1.2^{a}	0.7^{b}	1.79	1.6^{a}	1.1^{b}	0.7^{c}	1.77
Milk yield (forage area)	Mg ha^{-1} yr^{-1}	2.4^{a}	1.7^{b}	0.7^{c}	1.85	2.6^{a}	1.7^{b}	0.7^{c}	1.84
Energy output	GJ ha^{-1} yr^{-1}	16.0^{a}	11.7^{a}	2.5^{b}	1.71	16.6^{a}	11.9^{a}	2.5^{b}	1.71
Protein output	kg ha^{-1} yr^{-1}	118.8^{a}	106.3^{a}	29.5^{b}	1.73	128.9^{a}	100.4^{a}	29.5^{b}	1.72
Total energy input	GJ ha^{-1} yr^{-1}	2.6^{c}	3.8^{ab}	3.6^{bc}	1.78	2.8 NS	3.4 NS	3.6 NS	1.81
Human labour intensity	hr ha^{-1} d^{-1}	3.6^{a}	1.6^{b}	0.8^{c}	1.87	2.9^{a}	2.2^{a}	0.8^{b}	2.01
Energy cost of protein	MJ kg^{-1}	22.0^{c}	36.1^{b}	23.2^{a}	1.76	21.8^{c}	33.6^{b}	123.2^{a}	1.77
Energy efficiency	GJ output GJ^{-1} input	6.1^{a}	3.0^{b}	0.7^{c}	1.76	5.9^{a}	3.5^{b}	0.7^{c}	1.81
Organic fertilizer use	Mg ha^{-1}	3.5^{a}	3.8^{a}	0.4^{b}	1.99	3.9^{a}	3.4^{a}	0.4^{b}	2.00

Geometric means with different letters in superscript differ significantly ($P<0.01$) between farm systems (Tukey's HSD). Approximate 95% tolerance interval of AEIs within types is [geometric mean / (geometric st. dev.)^2, geometric mean × (geometric st. dev.)^2].

For calculation procedures of Shannon and Margalef indexes, see Gliessman (2001).

Table 5b. Geometric means of Agro-Ecological Indicators (AEIs) according to type, years since conversion, crop proportion and farm size (n=93) and their common geometric standard deviation (st. dev.).

AEIs	Unit	Crop proportion (%) > 45–75 n=11	> 3–45 n=50	≤ 3 n=32	Geometric st.dev.	Farm size (ha) ≤ 10 n=39	> 10–50 n=26	>50–150 n=28	Geometric st.dev.
Species richness	Margalef index	9.6^{a}	6.8^{b}	2.4^{c}	1.53	8.6^{a}	3.6^{b}	3.1^{b}	1.78
Diversity of production	Shannon index	2.1^{a}	1.7^{a}	0.3^{b}	1.53	2.0^{a}	0.7^{b}	0.4^{c}	1.64
Reforestation index	Shannon index	1.5^{a}	1.7^{a}	0.7^{b}	1.64	1.6^{a}	0.9^{b}	1.1^{b}	2.03
Milk yield (farm area)	$Mg\ ha^{-1}\ yr^{-1}$	1.5^{a}	1.2^{a}	0.7^{b}	1.85	1.4^{a}	1.2^{a}	0.6^{b}	1.83
Milk yield (forage area)	$Mg\ ha^{-1}\ yr^{-1}$	3.6^{a}	1.7^{b}	0.7^{c}	1.89	2.4^{a}	1.5^{b}	0.6^{c}	1.56
Energy output	$GJ\ ha^{-1}\ yr^{-1}$	21.3^{a}	11.5^{b}	2.6^{c}	1.84	17.8^{a}	6.7^{b}	2.3^{c}	2.88
Protein output	$kg\ ha^{-1}\ yr^{-1}$	141.5^{a}	99.1^{a}	29.6^{b}	1.81	138.7^{a}	68.1^{b}	25.4^{c}	1.72
Total energy input	$GJ\ ha^{-1}\ yr^{-1}$	3.3 NS	3.1 NS	3.7 NS	1.81	3.4 NS	3.3 NS	3.2 NS	1.80
Human labour intensity	$hr\ ha^{-1}\ d^{-1}$	5.6^{a}	1.9^{b}	0.8^{c}	1.98	3.8^{a}	1.4^{b}	0.6^{c}	1.66
Energy cost of protein	$MJ\ kg^{-1}$	23.1^{b}	30.8^{b}	124.3^{a}	1.81	24.2^{c}	48.7^{b}	123.9^{a}	1.59
Energy efficiency	GJ output GJ^{-1} input	6.5^{a}	4.2^{b}	0.7^{c}	1.85	5.3^{a}	2.0^{b}	0.7^{c}	1.92
Organic fertilizer use	$Mg\ ha^{-1}$	5.2^{a}	3.2^{b}	0.3^{c}	1.92	3.9^{a}	1.0^{b}	0.6^{b}	2.08

Geometric means with different letters in superscript differ significantly ($P<0.01$) between farm systems (Tukey's HSD). Approximate 95% tolerance interval of AEIs within types is [geometric mean / (geometric st. dev.)^2, geometric mean × (geometric st. dev.)^2].

For calculation procedures of Shannon and Margalef indexes, see Gliessman (2001).

differing from DFS, while MFc had the highest total energy input (Table 5a). Human labour spent in farming activities, accounting for 53% of the total energy input in MFe, was equivalent to 1.38 GJ ha^{-1} yr^{-1}, i.e., more than twice that in MFc (0.61 GJ ha^{-1} yr^{-1}) and almost five times that in DFS (0.30 GJ ha^{-1} yr^{-1}).

Energy use efficiency, the ratio of energy output and energy input, was highest in MFe farms, followed by MFc, and finally DFS. The energy cost per unit of protein production in MFe and MFc was about one-fifth and one-third, respectively of that in DFS. Finally, both mixed farm types applied significantly higher doses of organic fertilizers per unit area (3.5 to 3.8 Mg ha^{-1}) than DFS (0.4 Mg ha^{-1}) (Table 5a).

3.1.2 Years since conversion (YC)

Differences in AEIs were associated with the length of the period since conversion. The conversion process itself includes diversification measures, as witnessed by the greater biodiversity on converted farms. Length of the period since conversion did not affect the values of the biodiversity indicators. Mixed farms operating three years or more achieved significantly higher milk yields per unit total area and per unit forage area than those with shorter conversion periods or the dairy farms that relied exclusively on the use of grazing and cut forage systems. Total energy input was not significantly different among the three classes, however, it tended to decrease with increasing time since conversion. Labour intensity for all converted farms was similar, and significantly higher than for the non-converted farms. Converted farms, operating longer, achieved higher energy use efficiency and lower energy cost of protein production, and utilized larger quantities of organic fertilizers per unit area (Table 5a).

3.1.3 Crop proportion (CP)

Higher proportions of farmland dedicated to arable cropping (CP) resulted in higher values for the farm agro-diversity indicators, i.e. species richness, diversity of production and reforestation index, as expressed in the Shannon and Margalef indices. Moreover, a higher proportion of crops in total land use led to higher productivity and energy use efficiency, at comparable total energy inputs. With increasing CP, both milk yield indicators significantly improved, as did energy output and protein output. The farms with the highest CP (45–75%) achieved the highest values of productivity in terms of milk yield per unit forage area (3.6 Mg ha^{-1} yr^{-1}), energy output (21.3 GJ ha^{-1} yr^{-1}) and protein output (141.5 kg ha^{-1} yr^{-1}). Farms with high CP demanded a three times higher human labour intensity than those with medium CP, which in turn was more than twice that for farms with low CP. Higher CP was associated with lower energy cost of protein production, higher energy use efficiency, and higher organic fertilizer doses (Table 5b).

3.1.4 Farm size (FS)

Smaller farms (≤ 10 ha) were more diversified, more productive, more efficient and used larger quantities of organic fertilizers than the medium and large farms, at approximately the same input levels, though human labour intensity (hr ha^{-1} d^{-1}) was higher in the smaller ones. Furthermore, while the indicators species richness, diversity of production and reforestation index did not differ between medium and large farms, all three indicators were higher in the smallest FS. Small and medium farms did not differ in milk yield per unit farm area, but the small farms, with high crop proportions, realized significantly higher milk yields per unit forage area (2.4 Mg ha^{-1} yr^{-1}) than the medium-sized (1.5) and the large-sized farms (0.6). Smaller farms achieved a three times higher energy output per unit area than the medium-sized and eight times that of the large farms. The pattern was similar for protein output per unit area. Human labour intensity increased considerably with decreasing farm size. The smaller farms attained significantly higher energy use efficiency and lower energy cost per unit protein output than the medium and large farms. Finally, significantly larger quantities (four to six times, respectively) of organic fertilizers were applied per unit area in small farms than in the medium and large farms (Table 5b).

3.2 Redundancy analysis

The four predictor variables (TY, YC, CP and FS) explain 74% of the variance in the log (AEIs), which means that the predictor variables adequately explain farming system variability. Three components of the reduced-rank regression account for 88, 8 and 2% of this explained variance. The first two components explain 96% of the interactions and thus a two-dimensional figure (biplot) appears sufficient to visualize the relations (Figure 1A). A very similar figure would result if based on principal components analysis of the log (AEIs), and the four predictor variables would be projected onto the principal components plane.

The first component (Axis 1), explaining most of the variance, may be referred to as ‘biological efficiency’ axis, as it correlates positively to three of the indicators of energy efficiency (EE, –ECP, EO), nutrient management (OFU) and measures of diversity, notably DP (Figure 1). The second component (Axis 2) may be referred to as ‘natural resource management’ axis, as it correlates positively to the three components of diversity and OFU and negatively to labour intensity.

By splitting Figure 1 in two, we avoided cluttering and achieved a clear visual representation of the individual farm performance and the variation within farm types. Figures 1A and 1B can be seen as a visualized summary and integrative representation of the results in Tables 3 and 5. Figure 1A shows that mixed farms were characterized by high CP and YC and low FS; hence, these three variables were strongly correlated with TY. This is in agreement with the results in Table 3. In addition, Figure 1A shows that both mixed farm types performed very similarly and attained more favourable values for all AEIs than DFS.

Mixed experimental show higher values than the mixed commercial farms for the variables pointing downward and to the right hand side, i.e. variables related to productivity and energy use efficiency (human labour intensity, milk yield per unit farm area, milk yield per unit forage area, protein and energy output, and energy use efficiency). Both mixed farm types show similar values for the variables pointing upward to the right hand side, i.e. variables associated with diversity and nutrient regime (species richness, diversity of production, reforestation index and organic fertilizer use) which at the same time diverge most strongly from DFS. Moreover,

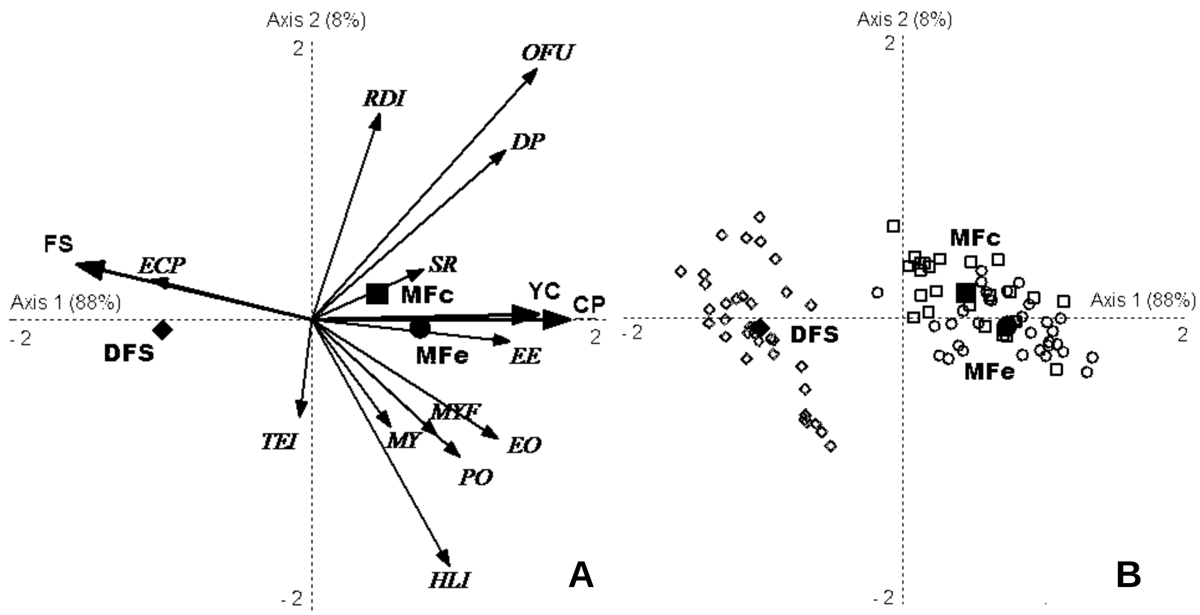

Figure 1. Distance biplot based on a redundancy analysis of the log Agro-Ecological Indicators (AEIs) on farm type (TY) (specialized farming commercial, i.e. DFS, mixed farming experimental, MFe, and mixed farming commercial, MFc), years since conversion (YC), crop proportion (CP) and farm size (FS) (A) with the farm scores (B) that best display the log (AEIs) accounting for 96% of the explained variance. (A) AEIs (thin arrows) and explanatory variables (fat arrows and TY class points). (B) The farms are indicated by TY (DFS, diamonds; MFc, squares; MFe, circles) and the centroids of TY by the corresponding filled symbols. For explanation of AEIs, see Table 3.

Nomenclature for AEIs: *SR* species richness, *DP* diversity of production, *RDI* reforestation index, *MY* milk yield, *MYF* milk yield per unit forage area, *EO* energy output, *PO* protein output, *TEI* total energy inputs, *HLI* human labour intensity, *ECP* energy cost of protein production, *EE* energy efficiency, *OFU* organic fertilizer use.

energy use efficiency and energy cost for protein production are the indicators most prominently differentiating among the three farm types, while total energy input is the indicator showing most similarities (Figure 1A).

Each of the four predictor variables and the twelve AEIs are interconnected and vary simultaneously. For example, Figure 1A shows that both indicators of energy efficiency (EE, ECP) are strongly (negatively or positively) correlated to FS, YC and CP. Apparently, the reforestation index, the use of organic fertilizers and the diversity of production are less influential factors for productivity and energy efficiency. As shown by their opposite positions on the graph, these indicators are inversely correlated to total energy input.

4. Discussion

Building on previous research findings on small-scale farms (Funes-Monzote et al., 2008), the results of the current investigation show the scope for increasing productivity and energy use efficiency by converting Cuban low input dairy farming systems (DFS) into mixed crop-livestock farming systems (MFS). However, what were the main reasons for this improved performance and what are the main measures to be taken for successful conversion?

To answer these questions, we first focus on the results of the univariate analysis of the four predictor variables (TY, YC, CP and FS) in terms of the 12 selected AEIs (Tables 5a and 5b). These results are discussed in relation to the four groups of criteria as distinguished in Table 4, i.e., (i) agro-diversity, (ii) productivity, (iii) energy use, and (iv) nutrient regime. Secondly, the results of the redundancy analysis, in which the AEIs and the predictor variables were cross-correlated, are discussed in an integrative way and related to the hypotheses.

4.1 Agro-diversity

The Convention on Biological Diversity (CBD) distinguishes three levels for agro-diversity, i.e. varietal and other genetic diversity, crop, animal and other species diversity and farming systems or agro-ecosystems diversity (UNEP, 1992). Brookfield and Padoch (1994) consider agro-diversity as ‘the many ways in which farmers use the natural diversity of the environment for production, including not only their choice of crops but also their management of land, water, and biota as a whole’. Brookfield and Stocking (1999) differentiated agro-diversity from agro-biodiversity, considering the second part of the first. In particular for agro-diverse and heterogeneous conditions such as those in less favoured areas of tropical countries, diversification of activities and genetic variability may play important roles in alleviating biophysical and/or socio-economic constraints (Ruben and Pender, 2004; Van Keulen, 2005). The current study focused on agro-ecosystem management aiming at improved food security (through increasing land and labour productivity) and conservation of the environment, based on efficient use of locally available resources instead of on external inputs. We aimed at evaluating to what extent the higher agro-diversity in terms of domestic crop, livestock and tree species, as part of integrated and multifunctional agricultural systems, contributed to realization of these objectives.

Greater agro-diversity, i.e. higher genetic resource availability as reflected in the indicators species richness, diversity of production and reforestation index, and, therefore, greater variation in time and space differentiated the mixed farms from the specialized farms. Under the conditions of low inputs and high uncertainty, in which these farms had to operate, this higher diversity greatly contributed to risk reduction and productivity increase. In fact, the degree of internal regulation in agro-ecosystems is largely dependent on the level of plant and animal diversity (Vandermeer et al., 1998; Altieri, 1999b), and furthermore, that variation (agro-diversity), resulting from the interaction between the environment, genetic resources and management, modifies the functioning of agro-ecosystems (Almekinders et al., 1995). Such variation may be part of the ecological principle that niche complementarities in mixed systems promote species abundance and internal resource use and, therefore, farm sustainability (Altieri, 2002; Kenmore, 2003; Van Keulen, 2005). Greater system efficiency in the use of locally available genetic resources may also positively affect productivity (Tilman et al., 2001), and allow sustainable agro-ecosystem intensification (Thrupp, 1998). Evidently, the industrial-specialized systems with lower agro-diversity have many difficulties in dealing with conditions of low inputs, and variations in climate and/or market conditions, have fewer possibilities to use local resources and, therefore, are more dependent on external inputs, contributing to their vulnerability under conditions of stress.

The sources for farm biodiversification were varied. Farmers obtained traditional landraces of plant and animal species from neighbouring farmers and new genetic material developed in research institutions. During the last five years, in Cuba, locally, innovative systems have been successfully developed, in which farmers could select their own stock of genetic diversity, matching the characteristics of their farming systems, biophysical conditions and socio-economic expectations (Ríos, 2004). In pursuit of realization of the objectives related to household food security and income generation, in the mixed farms, varying proportions of the farm area were dedicated to crop production for commercialization, in which conservation measures were implemented. In deciding on the proportion of the farm area to be used for crop cultivation, factors such as land availability, stocking rate and animal feed balance on the one hand and soil characteristics, productivity of forages and availability of crop residues were taken into account by farmers and researchers (in the case of experimental farms). Market constraints, sales contracts with the state, as well as other socio-economic factors also played a role in deciding to convert a specialized dairy farm into an agro-diverse and multifunctional enterprise. The diversified home gardens substantially contributed to production of the family food supply. High agro-diversity also required more dynamic decision-making and led to better allocation of feeds and labour throughout the year, contributing to improved resource use (Schiere et al., 2002; Tittonell et al., 2007b).

The high net photosynthetic rate of C_4 species in response to high light intensities, associated with the high temperatures (Ehleringer et al., 1997), constitute an advantage for pasture productivity in tropical environments ('t Mannetje, 2003). Incorporation of high-yielding C_4 forage species such as sugar cane (*Saccharum officinarum*, L.), king grass (*Pennisetum purpureum*, Schum.), Guatemala grass (*Tripsacum laxum*, Nash.), and guinea grass (*Panicum maximum*, Jacq.) guarantees high biomass production in mixed farms. Their strategic use in the course of the year was a powerful tool of sustainable intensification. In addition, leguminous herb, shrub and tree plants, and green manures were widely used to improve soil fertility (Lal, 2005) and to increase feed quality. Combining high biomass yielding species with leguminous species in mixed stands resulted in high N availability, stimulated humus formation and led to high CO_2 sequestration (Power et al., 2001; Christopher and Lal, 2007). Trees, introduced for various purposes (shade, fence, food and feed), played an important role in nutrient recycling, since they acted as a pump for nutrients from deep soil layers (Breman and Kessler, 1995) as stressed in Funes-Monzote et al. (2008) (Chapter 3). In general, trees were planted during the first year of conversion, but the products and environmental services, e.g. forage or fruit production, N and C fixation, were only attained in the medium term, i.e. from the third year onwards (Monzote et al., 1999).

4.2 Productivity

Productivity was conceptualized as the capacity of the system components, i.e. crops, animals and trees, to capture and convert the available natural resources (energy, water, nutrients and genetic diversity) into plant and animal biomass. Productivity indicators used were milk yield per unit farm area, milk yield per unit forage area, and protein and energy output per unit farm area, all of which were much higher in the mixed systems than in the specialized ones (Table 5a), at more or less similar availability of external resources. Milk production per unit farm area was higher following conversion to mixed systems, despite the assignment of 25–36% of the farmland to arable cropping (Table 3), confirming the earlier results in small-scale experimental farms (Chapter 3; Funes-Monzote et al., 2008). The temporal (years since conversion) and spatial (farm design) agro-diversity were major factors in realizing this higher land productivity (Tables 5a and 5b). The increase in energy and protein output per unit farm area was not significantly different between farms converted for 1–2 years and those converted longer, illustrating the almost immediate response of land productivity to farm diversification. This effect can be attributed to two factors: (i) the often high soil fertility stock in the previously grazed areas, that was released after ploughing-up and sowing to crops, and (ii) the greater use of internal resources combined with the inherent differences in conversion efficiency of sun energy into crop and animal products (Trenbath, 1986; Spedding, 1988).

The high 'initial' soil fertility is the result of at least two factors: (1) the original soil characteristics and the absence of tillage, and (2) the inputs with animal manure, shedded leaves and roots over a prolonged period of time. However, after establishment of the crop rotation, soil conservation measures should be immediately implemented to avoid rapid erosion with the associated loss of favourable characteristics (Lal, 2005). Inclusion of legumes in the rotation increases N availability and according to Carpenter-Boggs et al. (2000), net N mineralization is higher in plots that never received fertilizer N than in plots with a history of chemical N fertilization. Regular applications of animal manure and compost have positive effects on soil fertility, promote N mineralization and lead to an increase in SOM content, with positive effects on water retention, and, therefore, root growth (Pimentel et al., 2005; Richter et al., 2007).

The significantly higher milk yields per unit farm area and per unit forage area show that the internal and scarce external resources were utilized more intensively in the mixed farms than in the specialized ones. The higher conversion efficiencies for crop products not only explain the higher land productivity in terms of food energy and protein but they also resulted in availability of greater quantities and better quality animal feeds with a better spread throughout the year. In the specialized systems, solely relying on grasses with strong seasonal fluctuations in growth rate, animal production during the dry season was very low.

Overgrazing was another key factor constraining productivity in specialized dairy farms. Their grazing areas, dominated by native pastures of low productivity, were, as a result of poor management, in general strongly (40–50%) invaded by inaccessible thorny fast-growing, woody weeds such as 'marabú' (*Dichrostachys cinerea*) and 'aroma' (*Acacia farnesiana*). Retention of low-productive and/or old animals in the specialized farms also negatively impacted their milk yields.

Albeit milk yield per unit farm area was not statistically different between the medium-sized and small farms, all productivity indicators tended to increase with decreasing farm size. Attainment of the highest values of productivity in farms ≤ 10 ha indicates more intensive use and more efficient allocation of natural resources at this scale. On the contrary, the lowest levels of productivity on the larger, specialized farms indicate poor system management and extensive use of natural resources.

4.3 Energy use

Efficient energy use is a priority under the conditions of low inputs in Cuban agriculture (Funes-Monzote and Monzote, 2001; Monzote et al., 2002). The current study shows that mixed farming systems realized much higher energy use efficiencies and lower energy costs of protein production than the specialized dairy systems. This was strongly associated with their significantly higher energy outputs and, especially for the experimental farms, also lower total energy input (Table 5a). The more intensive use of internal resources in the mixed systems and the inherent differences in conversion efficiencies for crop and animal products were drivers for the higher energy use efficiency, similarly to the productivity indicators. The use of crop residues to feed animals, as well as intensive use of manure in crop and forage areas were two practices in the mixed farms that resulted in more efficient use of the energy inputs. Moreover, the more intensive use of farm fields in the crop rotations in the course of the year, judiciously adapted to seasonal variations, also contributed to higher energy use efficiencies. Only in the year of conversion were energy inputs different between the commercial and experimental mixed farms (Table 5a). This was due to the use of fossil energy during the period of establishment of the commercial farms, which were about ten times larger in size (Table 3). The significant increase in energy efficiency over time in the converted farms (Table 5a) was realized with a proportionally smaller increase in labour use.

4.4 Nutrient regime

Optimizing the use of animal manure is an important objective in nutrient management in crop-livestock farming systems, especially when no other sources of fertilizers are available (Rufino et al., 2007; Tittonell et al., 2007). Furthermore, if the manure is processed by (worm-)composting methods, its quality as fertilizer improves. Organic fertilizer use on the mixed farms was almost tenfold that on the specialized dairy farms (Table 5a). Apart from cow dung deposition during grazing, annual applications of animal manure in the specialized farms were very low (0.3 Mg ha^{-1}). At a stocking rate of one animal unit of 400 kg per hectare, about 5.5 Mg manure ha^{-1} yr^{-1} can be collected (Antonio Salinas, Cooperative '26 de Julio', Bacuranao, Havana, pers. comm.). While application of animal manure in mixed farms is common practice, in the specialized dairy farms it appeared problematic.

The lack of labour to perform all farm activities, low economic incentives, no immediate response to manure applications in terms of system productivity, other priorities in farm management and low awareness of soil care, were some of the factors responsible for this perception. The manure collected in the specialized farms was sometimes applied to the cut forage area of king grass or sugar cane, but the most common practice was to store it in heaps, susceptible to leaching losses with rain and run-off to fields close to the sheds. Demand for animal manure is high in urban farms and specialized arable farms, and the specialized dairy farms are eager to provide it, at the cost of mining their soils.

Animal manure application in mixed farms, mostly in the form of organic amendments (compost and worm humus), ranged from 3 to 5 Mg ha^{-1} yr^{-1} in varying doses, mostly to the cropping and cut forage areas. These rates recycle 49–73 kg N ha^{-1} yr^{-1}, 35–52 kg P and 56–83 kg K. Other practices promoting nutrient recycling included the use of green manures and cover crops, incorporation of crop residues and the use of plants and trees with extensive root systems (Tilman et al., 2002; Sanchez et al., 2004). Crop residues were commonly first fed to animals, using the refusals as mulch or incorporating them into the soil after composting. The use of organic fertilizers was significantly higher on farms with higher crop proportions. Cultivation of crops was in itself an incentive to utilize all the manure available, since there was pressure for farmers to return in the short term the nutrients removed. On smaller farms, greater amounts of organic fertilizers were applied per unit farm area, associated with the relatively easier handling of small amounts of manure and refusals.

4.5 Multivariate analysis

Due to the complexity and multi-factorial nature of mixed crop-livestock systems, innovative research methods are necessary to capture the effects of integrated practices. In particular, the analysis of the data for this purpose requires new or unusual statistical approaches (Tanaka et al., 2008). The results in Figure 1 show that multi-factorial hypotheses can be tested using reduced rank regression (redundancy analysis) as a comprehensive method of representation and analysis of multiple interactions. The biplots allowed us to identify and demonstrate the impact of complex interactions between indicators measured and predictor variables defined. Furthermore, by combining the results from linear associations between two factors, such as in Tables 5a and 5b, with the visual outcome of redundancy analysis (Figures 1A and 1B), we obtained more comprehensive explanations for farming systems performance. Such a combination of methods (uni-variate and multi-variate) enabled an integrative analysis and interpretation and appeared a powerful tool for analysis of agro-diverse environments in our study.

Multivariate methods have been applied in various fields of agricultural research, ranging from plant community studies (Schacht et al., 2000) to household assessment

(Ottaviani et al., 2003) and regional studies (Baudry and Thenail, 2004). In a recent study on weed ecology (Reberg-Horton et al., 2006), the univariate and multivariate statistics were combined for hypothesis testing (predictive) and data interpretation (descriptive) purposes. However, to our knowledge, these methods have up till now not been used for analysing farming systems.

In evaluating the performance of the agro-ecological indicators in terms of each predictor variable selected, i.e. farm type, years since conversion, crop proportion and farm size, our results indicate that the agro-diverse management strategies of the mixed farms, both experimental and commercial, positively affected farm productivity (Tables 5a and 5b). This association is shown in Figure 1A by the high cross-correlations between the variables years since conversion (YC), crop proportion (CP) and two of the three diversity indicators (SR, DP) on the one hand, and milk yield (MY, MYF), energy output (EO), energy use efficiency (EE) and protein output (PO) on the other. Meanwhile, the variable farm size (FS) and the indicator energy cost of protein production (ECP) were most strongly inversely correlated to all other indicators, which indicates the pertinence of developing mixed farming systems at small and medium scales (up to about 50 ha). Therefore, factors related to farm size should be carefully evaluated for technology adoption in accordance with site-specific conditions.

On the basis of the results of the multivariate analysis and the discussion in Sections 4.1 to 4.4, we may conclude that MFS are an attractive option for the development of Cuban agriculture. The combination of diversification strategies with a reduction in scale and the long-term establishment of strong interactions at the level of the farming system increases productivity and energy use efficiency.

Finally, Figure 1B clearly shows the similarities between both mixed farm types in terms of the performance of the 12 evaluated Agro-Ecological Indicators and their divergence from the specialized dairy farms. This strongly confirms the hypothesis of the current study that experiences from small-scale experimental farms can be translated to larger-scale farms and to commercial conditions.

5. Conclusions

Any technological change in agriculture at the farm level should be accompanied by adaptive changes in the overall economy at higher levels (i.e. national scale). Our research leads us to argue that in Cuba, under present conditions, agro-ecological mixed farming strategies will contribute proportionally more to increasing land productivity, food self-sufficiency and household income and improving the environment than specialized farming. Reductions in farm size of the still predominating large collective farms accompanied with an increase in crop-livestock integration were effective measures on both experimental and commercial farms, to increase energy and nutrient use efficiencies, without increasing the dependence of the farming system on external inputs. The short period (~2 years) needed for a successful conversion to mixed farming makes it a manageable and cost-effective operation.

The use of multivariate methods of analysis was a key to obtaining new insights in the different variables influencing performance of selected Agro-Ecological Indicators. In testing our hypotheses and interpreting the results in an integrated way, the use of a distance biplot based on redundancy analysis supported scaling-up of the results achieved previously at prototype experimental farms, indicating the agro-ecological potential of small- and medium-scale MFS for the future of Cuban agriculture.

Chapter 5

Identifying sustainable mixed farming strategies for local conditions in San Antonio de Los Baños, Havana, Cuba

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Abstract

Three major trends affecting Cuban agriculture over the past 15 years are decentralization, diversification and promotion of local food self-sufficiency. After 30 years of a centrally planned and export-oriented agricultural sector (1960–1990), there is increasing recognition of the need for design and implementation of site-specific, decentralized and self-sufficient alternatives. However, these activities proceed in an ad-hoc fashion, without a clear strategy in an environment with limited possibilities and many uncertainties. An integrated perspective in the research and extension system would help in guiding the transition toward greater autonomy at farm enterprise level in the agrarian sector. In order to support the transition to an integrated, sustainable agriculture in Cuba, there is an urgent need to develop operational methodologies that stimulate consistent implementation of environmentally non-degradable and socio-economically viable strategies. This should include systematic integrated assessment of location-specific small farm approaches, taking into account technological, environmental and socioeconomic factors. In this study, we identified multi-stakeholder-supported local visions of 'best practice' strategies to guide the process of conversion towards more integrated and sustainable land use. Building on previous research at experimental and national scales, this study took place at regional scale over a four-year period (2000–2004) on one specialized dairy farm 'Vaquería 10' (33.7 ha), and two mixed farms, 'Remedio' (9.4 ha) and 'La Sarita' (47 ha). All three farms are located in San Antonio de Los Baños municipality, Havana, Cuba. This study illustrates the scaling-down (application) phase of the ECOFAS methodology, an Ecological Framework for the Assessment of Sustainability. ECOFAS consists of a cyclical structure of six steps, aimed at guiding the process of introduction of innovative mixed (crop-livestock) farming strategies. Local stakeholders (farmers, researchers, extension officers and representatives of the ministry of agriculture in the municipality) defined alternative strategies for agriculture in the region, based on identification of critical technological, environmental and socio-economic factors constraining the current performance of farming systems. Results of the study show that implementation of 'best practice' mixed farming systems management strategies in the region potentially can lead to strong positive impacts on land productivity, food self-sufficiency, as well as socio-economic performance.

Keywords: Mixed farming systems; crop-livestock integration; dairy production; agro-ecology; local innovation; participatory action research; sustainability indicators

1. Introduction

In contrast to Cuba's centralized, monoculture and export-oriented agricultural paradigm that prevailed from 1960 to 1990, the model emerging since 1990 is increasingly based on decentralization, diversification and local food self-sufficiency. In response to these changing foci, farmers and technicians, supported by scientific research, follow innovative approaches in developing alternative sustainable farming systems, adapted to local conditions (Funes et al., 2002; Funes-Monzote, 2004; Ríos, 2006; ACTAF, 2006; Iglesias et al., 2007). Principles of agro-ecology and organic agriculture are guiding the development of agricultural systems, characterized by multi-species farming systems (agro-diversity) and diverse farm systems (heterogeneity) managed by farmers with different wishes, expectations and traditions (cultural diversity), and with various opinions about desirable agricultural developments (political diversity) (Funes et al., 2002; González et al., 2004; Wright, 2005; Nova, 2006).

Agricultural scientists have indicated great potential for innovation and sustainable development when local knowledge is combined with scientific research (Reijntjes et al., 1992; Pretty, 1995; Sumberg and Okali, 1997; Chambers et al., 1998; Uphoff, 2002; Sumberg et al., 2003). Effective implementation of such an integrated approach should lead to identification of both, site-specific agricultural practices that are not sustainable and sustainable practices (Lefroy et al., 2000; Holt-Giménez, 2002). The remaining question then is: How can sustainable farming methods be implemented in efficient and viable ways, taking into account the needs of all stakeholders.

In most of the developing world, peasant farmers have to earn a living in marginal circumstances. They work with less productive lands, fewer natural and capital resources, and little access to new technologies (Ruben and Pender, 2004; Van Keulen, 2005; Devendra, 2007; Tittonell, 2008). However, marginalized farmers are numerous, contribute substantially to local and global food security, and develop more environmentally-friendly farming systems (Altieri, 1999a; Pretty et al., 2006; Devendra, 2007). For example, in Cuba, small mixed farmers cultivate about half of the total land in use by agriculture in low external input systems, which produce 65% of its total domestic food sales (Granma, 2006a). Hence, land productivity in peasant small mixed farming systems (MFS) is substantially higher than in the specialized crop and livestock systems that are centrally managed. This is an indication of the absolute importance of the small-scale sector in Cuban food security.

The potential of MFS to achieve relatively high productivity and energy use efficiency at low external input levels was identified by researchers in the early 1990s (Muñoz et al., 1993; García Trujillo and Monzote, 1995). For more than a decade, innovative farmers and researchers have reported on successful introduction and implementation of low external input mixed farming systems in Cuba (ACAO, 1993, 1995, 1997; Monzote et al., 1999). However, despite these positive experiences, MFS are still faced with many technological and socio-economic constraints. Among the first are: (i) lack of detailed information on the internal functioning of mixed farming systems, (ii) limited knowledge on the role of functional agro-diversity, and (iii) absence of context-specific guidelines for 'best practices' in mixed systems. Socio-economic constraints range from resistance of farmers to convert their farms to the economic conditions that do not provide incentives for realizing the full potential of mixed farming. Another important limitation is the lack of a methodical and systematic structure for implementing and adapting existent knowledge.

Technologically, integration of crop and livestock production offers ways to cope with the environmental and socio-economic challenges facing agriculture. MFS have been associated with such objectives as food self-sufficiency, optimal use of land, multifunctionality, optimization of nutrient and energy flows, and high agro-diversity (Altieri, 2002; Schiere et al., 2002; Lantinga et al., 2004; Pimentel et al., 2005). In addition, MFS tend to diversify farmers' sources of income, to contribute to food security and to empower poor farmers living in marginal conditions (Sumberg, 1998; Pretty et al., 2003; Devendra, 2007; Herrero et al., 2007).

Therefore, this study aimed at identification of alternative local MFS strategies to guide the process of conversion towards more integrated and sustainable land use. As the third stage of the ECOFAS methodology, an Ecological Framework for the Assessment of Sustainability (Funes-Monzote et al., 2002), the study focuses on site-specific conditions, rather than on technology generalization. In previous stages, the performance of MFS in Cuba was examined under experimental conditions at small-scale farming (stage 1, Chapter 3), and in a study that combined both, experimental and commercial farming at national scale (stage 2, Chapter 4).

2. Background information on the study area

The study took place in San Antonio de Los Baños, one of 19 municipalities in Havana province, south-west of Havana city (Figure 1). In total, it covers a mostly flat topography of 126 km^2, characterized by predominantly fertile, deep (about three metres) and highly productive red clay soils formed from hard limestone rock, occasionally slightly stony, with abundant groundwater availability.

Soils are slightly acid to acid, typically ranging in soil organic matter (SOM) from 1 to 3% and often compacted due to intensive cash crop cultivation with use of heavy machinery. Climate is tropical savannah (Aw; Köppen, 1907) with annual average temperature of 25.2 °C, ranging from 20 to 30 °C. Relative humidity is about 78%.

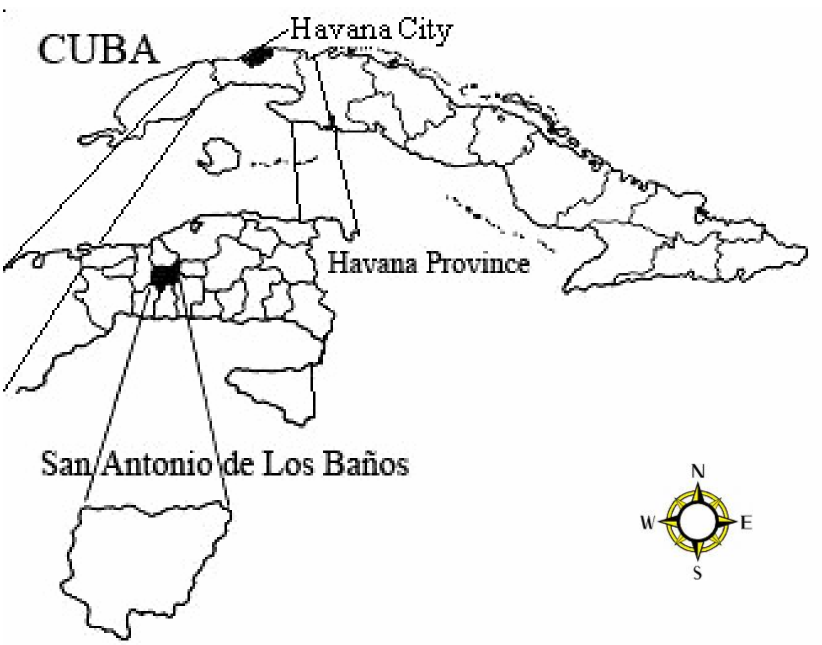

Figure 1. Location of San Antonio de Los Baños municipality.

From the average annual rainfall of 1872 mm, 84% occurs during the rainy season (from May to October) (Table 1) (MINAG, 2005).

3. Brief historical overview

History is fundamental to understanding the current agricultural processes from the perspective of the past interrelationships between humans and the environment. Environmental history, a relatively new field of science, deals with the assessment of longer-term effects of agriculture on society (Funes-Monzote, 2008). This study shows that the revival of agricultural practices used in San Antonio de Los Baños in the past, could be useful in developing strategies to solve present problems in farming systems, as suggested by Van Keulen and Schiere (2004). Historically, San Antonio de Los Baños is known for the cultivation of tobacco, still economically important for local farmers. French immigrants from Haiti introduced coffee to the region in the late 18th and early 19th centuries, which is still cultivated, as well as sugar cane, though in small areas. During the 19th and 20th century, tobacco cultivation, cattle ranching and citrus production were dominant. However, due to its favourable climate, soils and water availability, as well as its proximity to the market of the capital, the agricultural sector was diverse and intensive.

Mixed crop-livestock farming was successful in achieving high levels of productivity and efficiency in the use of natural resources at small- and medium-sized farms. In 1946, with twice the area of today, about 90% of the approximately 900

Table 1. Selected climate variables for San Antonio de Los Baños municipality (2002–2005).

Month	Mean temperature (°C)	Maximum Temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)
January	20.9	26.0	15.9	76.8	46.9
February	22.5	27.6	17.6	76.5	65.2
March	24.0	29.2	19.3	76.0	56.4
April	24.7	30.1	19.2	73.0	59.3
May	27.1	31.7	22.0	75.8	157.2
June	27.4	31.7	22.8	80.0	328.3
July	27.9	32.6	22.8	78.5	276.1
August	28.1	32.8	22.5	78.3	334.9
September	27.3	31.8	22.6	81.8	302.4
October	26.4	30.8	21.7	80.5	175.8
November	24.5	28.8	19.5	78.8	29.6
December	22.1	26.5	17.2	77.5	40.2
Cumulative or average	25.2	30.0	20.2	77.8	1,872.2

Source: Estación Meteorológica, Instituto de Investigaciones del Tabaco, MINAG.

farms in San Antonio de Los Baños were between 5 and 75 ha, with an average of 20 ha. Overall, crops occupied 41% of the cultivated area, and permanent pastures the remainder (Table 2). Of the cultivated area, cereals and beans accounted for 13.3%, tobacco for 8.4%, root and tuber crops for 7.4%, and vegetables, sugar cane and fruits for 5.9%. The non-cultivated area comprised only 0.6% (CAN, 1951). The major economic activities were tobacco cultivation, generating 33.7% of the income, and livestock with 32.6%; in addition, root and tuber crops generated 15.4%, cereals and beans 11.4%, and vegetables, sugar cane, coffee, fruits, forestry products 6.9%. Livestock production in particular was highly diverse in terms of both, feed crops and animals. The farms that reported livestock as their principal activity generated on average 65% of their income from animal products, and 35% from crops under rotational systems. Cattle were kept to provide traction, but also for home consumptiom of meat and for commercialization. Oxen constituted on average about 15% of the cattle herd.

In the second half of the 20th century, especially from 1960 until 1990, in conjunction with the nation-wide implementation of intensive specialized agriculture, land use patterns radically shifted in San Antonio de Los Baños towards monocultures and high external input use. Extensive areas, previously devoted to mixed crop-

Table 2. Fifty-five years' (1946–2001) historical evolution of population, land use and milk production in San Antonio de Los Baños.

	Characteristic	Unit	1946		2001	
A	Total area*	ha	24,200		12,600	
B	Population	#	27,000		44,000	
C	Population density (B/A)	# ha^{-1}	1.1	110 km^{-2}	3.5	350 km^{-2}
D	Agricultural land area	ha	20,878	86% of A	9,100	72% of A
E	Cultivated land area	ha	18,516	89% of D	7,159	79% of D
	E_1 Crops		7,627	41% of E	6,297	88% of E
	E_2 Permanent pasture		10,889	59% of E	862	12% of E
F	Forest	ha	1,062	5.1% of D	575	6.3% of D
G	Other uses or abandoned	ha	1,300	6.2% of D	1,366	15% of D
H	Cattle herd size	head	18,553	1.7 ha^{-1} of E_2	7,500	8.7 ha^{-1} of E_2
				1.0 ha^{-1} of E		0.8 ha^{-1} of E
I	Other animals	#				
	Swine		9,377		7,800	
	Sheep and goats		838		6,000	
	Horses		1,874		430	
	Poultry		15,1793		300,000	
	Rabbits		n/a		5,000	
	Bees (beehives)		1,838		n/a	
J	Annual milk production	l cow^{-1}	773**		411	(1,300)***

Sources: CAN, 1951; CENCOP, 2003; ONE, 2004; MINAG, 2005.

* Half of the territory of San Antonio de Los Baños (some 12,000 ha) was transferred in the beginning of the 1960s to the neighbouring municipality of 'Caimito' to establish the state enterprise 'Los Naranjos', the icon of the industrial livestock model developed in Cuba during the period 1960–1990.

** Calculated on the basis of the overall milk production of the municipality at that time (5 129,000 litres) divided by the total number of cows (6,630).

*** As no data were available on milk production for the different production systems, we present typical values for the specialized and, between brackets, the mixed farming systems.

livestock farming, were transformed into specialized dairy, tobacco, citrus, and other cash crops on large state or cooperative farms. As this 'modernization' progressed, traditional farming practices were considered old-fashioned and were replaced by green revolution technologies that relied on high external inputs. These new technologies resulted in higher production, however, their high energy costs, high infrastructural investments and negative impacts on bio-diversity and the natural environment implied low sustainability (Anonymous, 1984). Following the new administrative-political division in 1976, San Antonio de Los Baños was left with half its original area, whereas the population doubled over a period of 55 years, thus increasing pressure on the natural resources (Table 2).

During the 55-year period of analysis, the proportion of permanent pasture in the cultivated area substantially declined (to 12% in 2001) in favour of the crop area. This was also the trend in the country as a whole as a consequence of the change in production purpose from beef to milk since the beginning of the 1960s. The intensive milk production system, based on large amounts of imported concentrates, did not put such a large claim on land resources as the beef production system. The national area under permanent pasture was roughly 4 million hectares in 1959, and gradually declined to half (González et al., 2004). The reduction in permanent pasture area in San Antonio de Los Baños resulted in a strong increase in pressure on the forage resources; however, the cattle stocking rate in terms of the total cultivated land area, was the same in the year 2001 as in 1946. This is a clear indication for the current high level of crop-livestock integration in the non-specialized sector (Table 2).

In the beginning of the 1990s, following the collapse of the Soviet Union and the withdrawal of support to the Cuban agricultural sector, the intensive, input-dependent model was confronted with its high vulnerability, leading to searches for new pathways towards agricultural sustainability. Interesting farming systems approaches developed by local farmers enabled increases in efficiency in the use of resources to produce food with minimum external inputs.

4. Methodology

The study to identify local alternatives for farming system improvement, carried out over a four-year period (2000–2004), consisted of six cyclical steps (Figure 2). The cycle started with identification of critical points (unsustainable practices, major constraints), the objectives (sustainable pathways) for livestock production in the region as well as the selection and diagnosis of a group of farms, typical of livestock production in the region and used as ‘reference’ set (step 1). As part of a more detailed diagnosis, bio-resource and farm infrastructure maps were constructed (step 2). Following complete diagnosis, farm characterizations were performed and indicators selected based on the critical points identified (step 3). In step 4, the indicators were monitored and information collected for a one-year period, followed by assessment of the performance of each individual indicator (step 5). Finally, an integrated analysis was performed, and improvements in the farming systems were formulated in a participatory process (step 6). Another cycle was then started with identification of new critical points and new objectives in the never-ending problem-solving cycle. Bio-resource and farm mapping and farm characterization now represent the modified situation. New indicators may be selected for monitoring and performance assessment in the continuous farming system improvement process.

On-farm action research methods (Pretty et al., 1995; Checkland and Holwell, 1998), such as the scaling-down phase (application) of ECOFAS, described in Chapter 1 (Funes-Monzote et al., 2002), were applied within the cyclical process to guarantee participation of all local stakeholders, including researchers. Particularly the recognition of local farmers' knowledge, their capacity for agro-ecosystem analysis and innovation skills (Conway, 1985; Sumberg and Okali, 1997; Chambers et al., 1998; Sumberg et al., 2003) were critical in the study. This combination of tools facilitated concerted efforts of farmers, researchers and policy makers to identify 'best practices' to optimize the performance of the mixed farming land use under local conditions.

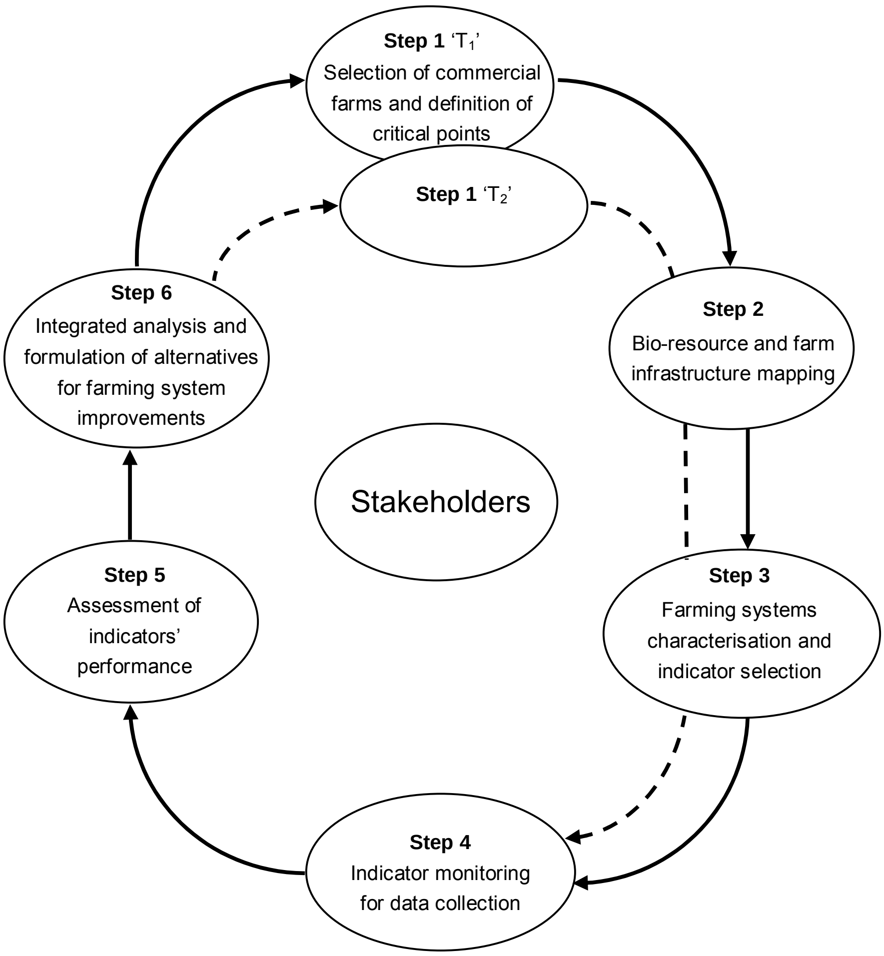

Figure 2. Farming systems evaluation-reflection and design cycle for farming system improvement. Adapted from: Vereijken, 1999; Van Ittersum et al., 2004; López-Ridaura et al., 2005.

Three workshops were organized in the course of the study. In the first workshop, the preliminary results of the diagnosis (step 1) and the bio-resource diagrams (step 2) were discussed. The primary constraints for development of MFS, according to the different stakeholders involved, were identified. This process resulted in joint identification of critical points for farming systems development and of 'best practices' at farm and regional levels. In the second workshop, participants jointly made a transect walk, during which they exchanged mixed farming field experiences and strategies developed at farm level. Finally, in the third workshop, results of the indicator assessments were presented and guidelines for farming systems development were defined for improving production and natural resource management systems. Although focused at farming system level, the methodology also took into account land use objectives at higher scales (such as the municipality); therefore, information from different scales (farm, cooperative, and municipality) was collected.

4.1 Farm selection and description

Historical information was important in identification of farm selection criteria. In fact, the historical evolution of the San Antonio de Los Baños region, and the strong renaissance of many traditional farming practices following the crisis of 1990, were major reasons for its selection as region for study (see Section 3 of this chapter). Another reason was the presence of a large cattle herd, maintained on a relatively small pasture area, indicating the intensive use of crop residues and other sources for animal feeding. The data in Table 2 (8.7 head per ha of permanent pasture land) reveal that in fact most of the crop residues and the available organic resources on fallow fields are used for cattle feeding.

The farms selected within the region were representative according to the empirical criteria of the local stakeholders, i.e. farm endowments, farm productivity and strategies in the use of natural resources. Key informants (extension officers and representatives of the livestock sector at municipal level) proposed several farms and farmers on the basis of the purposes of the study, from which, following farm visits, three farms were selected: a specialized dairy farm 'Vaquería 10' (33.7 ha), and two mixed farms namely 'Remedio' (9.4 ha) and 'La Sarita' (47 ha). Both mixed farms had been managed for at least 70 years under a private land tenure system, using traditional agricultural methods. The specialized farm represented the average dairy operation in the region of the last 35 years. All three farms were managed as low external input systems.

The three farms differed in size, land tenure arrangement, farm management, agro-diversity, labour intensity and farm infrastructure. The farm managers, who agreed to participate in the study, were active innovators, open to discussing alternatives and freely providing information. Although other stakeholders participated in the study, the main sources of ideas and information were the farm managers of the selected farms.

To classify the farms, the typology developed in a nationwide study on mixed and specialized dairy farming systems was adopted (Chapter 4). Farm A classified as a mixed farm, of small size with a medium proportion of the land area devoted to crops. Farm B classified as a mixed farm, of medium size and medium crop proportion. Both mixed farms belong to a Credit and Services Cooperative (CCS)[4]. Farm C classified as a specialized dairy farm, of medium size. It belongs to a Basic Unit of Cooperative Production (UBPC)[5]. Figure 3 shows the layout of the three farms, including land use at sub-system level.

4.2 Participatory diagnosis and identification of critical points

For farming systems diagnosis and identification of critical points for sustainable mixed farming system development, elements from different participatory research approaches were applied, such as rapid rural appraisal, functional and interactive research methods and participatory action research (McCracken et al., 1988; Chambers, 1994; Pretty et al., 1995; Bellon, 2001). This combination provided versatility to the diagnosis phase from a multi-stakeholder perspective. Various tools were used, such as field walks, informal discussions, participatory workshops, conversations and semi-structured interviews with the farm managers and household members (Appendix 1), reviews of accounting records, as well as direct field measurements.

4.3 Bio-resource and farm infrastructure mapping

Bio-resource and farm infrastructure diagrams, adapted from Lightfoot et al. (1994; 1998) and Dalsgaard and Official (1997), aimed at simplifying complex information, provided a comprehensive overview of the natural and physical resources available at each farm. They served as references for analysis of critical points at farm level (Conway, 1985; McCracken et al., 1988). The diagrams, created jointly with the farm managers, cover the system, sub-systems and farm bio-physical component levels. They provide information on field size, farming system infrastructure and its boundaries, agro-diversity components and production levels. All information compiled in the diagrams aimed at improving communication among researchers and all other stakeholders involved in the study.

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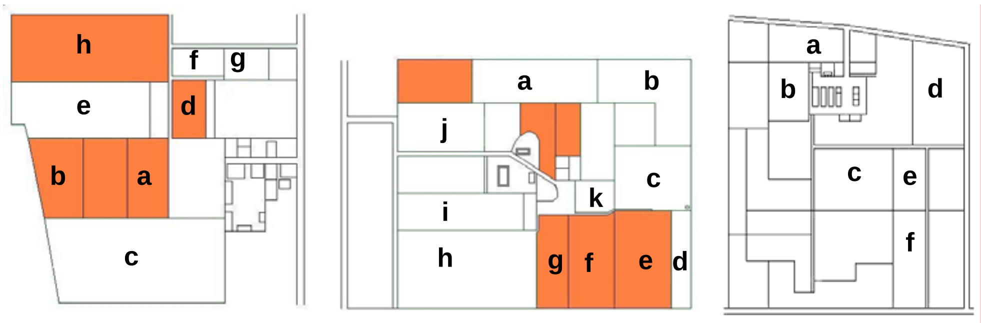
[4] The Agriculture Cooperative Law defines a CCS as a voluntary association of independent small farm households, for mutual economic support. Members own their individual assets (property, equipment), and cultivate their own land (Álvarez, 2002).

[5] The UBPC are production units with a cooperative structure that farm state land that was given free of charge in permanent usufruct (the average size is substantially smaller that the former state farms, that were partitioned to form the UBPC) (Martin, 2002).

Farming system



Crop-livestock ratio*	A – Remedio (9.4 ha) 27/73		B – La Sarita (47 ha) 35/65		C – Vaquería 10 (33.7 ha) 0/100	
Field identifier	Sub-system/ Land use type		Sub-system/ Land use type		Sub-system/ Land use type	
	Previous**	Diagnosis	Previous	Diagnosis	Actual	Diagnosis
a	C	C	C	G	F	F
b	C	C	G	G	G	G
c	C	G	C	G	G	G
d	C	C	G	G	G	G
e	G	F	G	C	Gr	Gr
f	C	F	G	C	G	G
g	G	F	G	C	-	-
h	F	C	C	G	-	-
i	-	-	C	G	-	-
j	-	-	C	G	-	-
k	-	-	F	F	-	-

Figure 3. General description of land use of the three farming systems under study.

* The crop-livestock ratio is defined as the ratio of land area directly used for each sub-sector.

** 2–4 years before the study started. The filled areas in the farm layouts represent the crop lands. Each field identified by a letter a, b, c, … k was sampled for soil physical-chemical analyses (0–20 cm). C (arable crop), F (forage), G (grass), Gr (grove).

4.4 Farming system characterization

Comprehensive farming system characterization was based on information obtained during participatory diagnosis, including participatory workshops, field days and rich picture building, and from bio-resource and farm infrastructure diagrams. Characterization included agro-ecological, financial and socio-economic aspects of farming systems development, as suggested for integrated hard and soft system analyses (Checkland, 1999).

4.5 Indicator monitoring

ECOFAS indicators, previously tested in Chapters 3 and 4, were adopted for this study, since they correspond to most of the critical points identified; however, additional indicators may be defined in relation to specific objectives. Monthly farm visits, transect walks, semi-structured interviews, descriptions of daily routines and activity profiles were the main methods used for monitoring and data collection. The research team and the collaborating farm managers jointly performed annual analyses of results.

Data required for energy balance calculations were obtained from accounting records, and farm managers' estimates of energy inputs in production activities (e.g. human labour, animal labour, diesel, feeds, etc.) and energy outputs in the form of agricultural products. The energy balances were calculated using the ENERGIA computerized system (Sosa and Funes-Monzote, 1998). For calculation of the total consumable energy produced on-farm, product energetic values were applied as given by Ensminger et al. (1994); Garcia-Trujillo (1996) and Gebhardt et al. (2007). For calculation of the capacity of the system to provide energy and protein requirements for human consumption, information supplied by FAO/WHO/UNU (1985) and Porrata et al. (1996) was applied (Appendices 3-6).

4.6 Assessment of indicator performance

4.6.1 Soil analysis

Soil analyses were carried out by the laboratory of soils at the National Institute for Agricultural Sciences (INCA), San José de Las Lajas, Cuba. The top soil (0–20 cm) of each farm was sampled at sub-system level (see Figure 3) and nutrient contents determined following the Methodology for Detailed Cartography and Integral Evaluation of Soils (Hernández et al., 1995). At least five individual samples, taken at random, were mixed, and a sub-sample taken for chemical analysis according to Paneque et al. (2002): soil pH (H_2O) was determined by potentiometry in a soil-water suspension (1:2.5); soil organic matter (SOM) by the Walkley and Black method, based on oxidation by potassium dichromate in a sulphur solution; available P by the Oniani method and exchangeable cations (K^+, Ca^{2+}, Mg^{2+} and Na^+) by the ammonium acetate method. Carbon stocks were calculated assuming a C-content in SOM of 0.58 kg kg^{-1} and multiplication by bulk density and thickness of the corresponding horizon.

Soil particle size distribution was determined by the method of Bouyoucos (modified), using sodium pyrophosphate for removing the micro-aggregates and NaOH as dispersant. Micro-aggregate content was determined by the same method, without dispersant. Particle size distribution and micro-aggregate content were used to calculate the dispersion factor for each sample. For interpretation of the soil fertility characteristics, the classification of the manual for soil interpretation of the Ministry of Agriculture of Cuba (DNSF, 1982) was used. For soil classification and profile descriptions the Cuban methodologies proposed by Hernández et al. (1995, 1999) and those of WRB (2006) were adopted.

4.6.2 Agro-ecological, financial and socio-economic analysis

Agro-ecological, financial and socio-economic indicators were analysed at the end of each year. Averaged results of the four-year period (2000–2004) were represented in amoeba graphs (Ten Brink et al., 1991), which improved interaction with farmers in terms of defining objectives and strategies for farming system improvements. Target values for each AE&FI were derived from 'best performing' farming systems, in association with specific critical points according to explicit agro-ecological objectives. These methods are in line with the proposed by Vereijken (1997) for prototyping Integrated and Ecological Arable Farming Systems (I/EAFS) and by Bockstaller et al. (1997) and López-Ridaura (2005) for assessment of farming system sustainability.

As suggested by López-Ridaura (2005), data were 'standardized' by expressing the values as percentages of the optimum (best) value for each indicator[6]. Socio-economic indicators were evaluated based on a 1–5 scale, with 1 very low and 5 very high.

For financial analysis, the method developed in Chapter 3 was used. Due to the current economic situation in Cuba, any financial analysis is characterized by a high degree of uncertainty. Potential constraints and opportunities at the political level for adoption of MFS were also examined. Information from annual semi-structured interviews and informal talks at monthly intervals with the farmers allowed capturing of spatio-temporal interactions among agro-ecological, financial and socio-economic factors.

4.7 Identification of alternatives for farming system improvements

Information collected in the participatory action research process was analysed as the basis for designing alternatives aimed at improving local farming systems. MFS 'best practice' strategies were identified based on three main sources of information: (i) critical points identified for livestock production in the region; (ii) farm characteristics summarized in the bio-resource and infrastructure diagrams; and (iii) results of the assessment and analysis of farming systems performance as expressed in agro-

[6] If the indicator is to be maximized (e.g. protein output), the value of the indicator is expressed as percentage of the maximum value (% = Value/Max × 100). If the indicator is to be minimized (e.g. energy cost of protein), the value of the indicator is expressed as the inverse of the percentage of the minimum value (% = 1/(Value/Min) × 100).

ecological, financial and socio-economic indicators. Agro-ecological performance of the study farms, historical data and socio-political aspects in the context of current Cuban agriculture were combined in five main areas of impact as suggested in the ECOFAS methodology: (1) Farming System Agro-Diversity, (2) Farm Productivity and Energy Use Efficiency, (3) Nutrient (re-)Cycling and Nutrient Balance, (4) Economic Feasibility and (5) Farmers' Empowerment and Decision Making.

5. Results and discussion

5.1 Participatory diagnosis and identification of critical points

As the first step in the evaluation, reflection and design cycle (Figure 2), diagnosis at farm and regional levels aimed at identification of critical points, i.e. explicit issues of unsustainability in livestock farming systems (De Wit et al., 1995) for their conversion into mixed crop-livestock systems (Table 3). Environmental problems identified by the Cuban Ministry of Environment, Science and Technology at the national level were also considered important (CITMA, 1997). A participatory workshop, joint discussions of local stakeholders and the research team involved in the study and informal discussions-talks with key informants supported the identification of critical points. Similarly to Masera et al. (1999) and López-Ridaura (2005) in their sustainability evaluation of natural resources management systems, each critical point, referring to a specific dimension and attribute of farming systems, was translated into a specific aim for each spatial scale (Table 3).

5.1.1 Identification of critical points at regional level

Climate conditions: Temperature and humidity conditions in San Antonio de Los Baños are favourable for agriculture. The major climatic constraints identified by local stakeholders were rainfall variability and the destructive effects of hurricanes (Table 3). Of the total annual rainfall of 1650–1870 mm, only about 16% falls in the so-called dry season, November–April, leading to pronounced seasonality in quality and quantity of pasture, forage and crop production, which is a limitation for cattle production based mainly on these feed resources. Hurricane damage was not only associated with the direct impact of heavy rains and winds, but also with the after-effects that constrain production for longer periods.

Biodiversity, productivity and efficiency: Highly specialized crop systems, low tree cover (about 6%), low land productivity and poor management of natural resources characterized the specialized agricultural sector in San Antonio de Los Baños. The critical situation of the national livestock sector (González et al., 2004) was the consequence of de-capitalization, the sudden scarcity of external inputs and low use of

Table 3. Critical points identified by stakeholders and objectives to be addressed for the development of MFS in San Antonio de Los Baños at farm (FL) and regional (RL) scales.

Dimension/ attribute		Critical point	Aim	FL	RL
AGRO-ECOLOGICAL	Bio-diversity	Few forage sources Low agro-diversity	Diversification of forage sources through introduction of legumes, high quality forage species and forage trees and use of crop residues for animal feeding	x	
		Small number of trees	Establish agro-silvo-pastoral systems	x	x
		Few crop and animal species managed	Increase crop and animal bio-diversity	x	x
	Productivity	Low animal production and crop yields	Increase crop yields and animal production	x	x
		Low production of forage crops	Increase forage production	x	
		Limited possibilities for irrigation	Establish low-cost irrigation systems		x
	Efficiency	Improper use of available natural resources, i.e. light, land, water, biodiversity	Design of more integrated land use systems that make better use of natural resources	x	
		High dependence on external energy inputs	Reduce dependence on external energy inputs	x	x
		Negative nutrient balances	Avoid nutrient export through manure sales*	x	
		Low energy use efficiency	Introduce crops into livestock systems and 'best practice' mixed farming methods for better use of biomass as renewable source of energy	x	
	Stability	Poor cattle manure utilization	Composting all manure to increase quality	x	
		Fluctuation in climate (rainfall) and destructive effects of hurricanes	Adapt farming systems to climatic variability		x
		Unstable provision of inputs	Create a stable market of inputs		x
		Low and erratic labour supply	Create incentives for labourers		x
FINANCIAL	Self-reliance	Low food and feed self-sufficiency	Increase food and feed production	x	x
		Scarcity of external inputs	Create ways to access indispensable inputs		x
	Feasibility	Highly specialized production systems	Diversify sources of income	x	
		Low added value of production	Create facilities for processing of agricultural products and improve marketing opportunities		x
		Low milk market prices	Reduce dependence on milk as income source	x	
	Profitability	Low profitability	Improve economic feasibility	x	
		Lack of credit to establish mixed systems	Create a (municipal) credit system		x

Table 3. (Continued)

Dimension/ attribute		Critical point	Aim	FL	RL
SOCIAL	Acceptability	Lack of interest in livestock activities by farmers	Make livestock production economically attractive		x
		Limited innovation capacities	Promote farmer's innovative behaviour	x	x
		Loss of many farming traditions	Revitalize traditional knowledge	x	x
	Equity	Poor domestic services	Improve housing conditions		x
		Poor working conditions	Improve working conditions and salaries	x	x
		No attention for gender issues	Focus on gender issues	x	x
		Skewed within-household income distribution	Aim at fair distribution of income	x	x
	Empowerment	Legal limitations on decision making within the UBPC**	Focus on decision making at farm level	x	
		Lack of skilled labour	Organize extension and training activities for farmers		x
		Difficulties in product collection and commercialization, and veterinary services	Stimulate the empowerment of farmers and farmers' associations	x	x

FL – Farm level, RL – Regional level.

* Specialized livestock farms used to sell manure to tobacco farms, urban and other arable farms, leading to soil nutrient and organic matter mining in livestock farms.

** In the UBPC, the Board of the cooperative collectively takes decisions related to the production process, but decision-making is limited to certain topics.

internal resources. With few other sources of animal feed than the degraded and poorly managed pastures and forages, specialized dairy farming systems showed high vulnerability to seasonal fluctuations in climate and to the unstable situation with respect to provision of external inputs.

Almost 40% of the land in the municipality was dedicated to production of export crops such as tobacco (*Nicotiana tabacum,* L.) and oranges (*Citrus sinensis,* L.). Some 20% was used to cultivate various vegetables and 15% for grains, mainly maize (*Zea mays,* L.) and beans (*Phaseolus vulgaris,* L.). Root and tuber crops such as potato (*Solanum tuberosum,* Sw.), cassava (*Manihot esculenta*, Crantz.), sweet potato (*Ipomea batatas,* L.) and taro (*Xantosoma* spp.) occupied another 10%, and banana (*Musa* spp.) and flowers about 5%. The remaining area (about 10%) was reported as pastures in specialized livestock farms, managed as low external input systems, with low diversity. However, the majority of the herd was kept in mixed crop-livestock systems. Hence, agriculture in San Antonio de Los Baños was characterized by a mosaic of mixed-diversified and specialized-monoculture farming systems. Many different types of multi-cropping arrangements such as corn/beans, corn/squash, beans/cassava and corn/sweet potato were popular among small and medium-scale farmers, pursuing increasing land equivalent ratios, because of their limited farm size (Figure 4). At municipal level, agriculture was highly heterogeneous in terms of land use types, but such heterogeneity at higher spatial scale hardly influenced natural resource management at farm level.

Nutrient management: The soils of San Antonio de Los Baños, part of the Havana-Matanzas plains, belong to the most fertile soils of the world. However, following long periods of intensive cultivation, these soils clearly show signs of fertility decline and deterioration of physical properties (MINAG, 2005; Hernández et al., 2006). In the livestock farms, comprising mostly pure pasture systems, not ploughed for a period of about 15 years, nutrient export has been low. Critical points regarding soil fertility in livestock farms were related to inappropriate nutrient management in specific sub-systems such as cut forage areas. In these systems, relatively large quantities of soil nutrients (nitrogen, phosphorus and potassium) were extracted, negatively affecting soil fertility High demands for manure as fertilizer from cash crops such as tobacco and from urban agriculture were satisfied by supply from the specialized dairy farms, with the consequence of declining soil organic matter contents in these farms. Composting of manure and/or crop residues or other practices aiming at soil fertility restoration were not common.

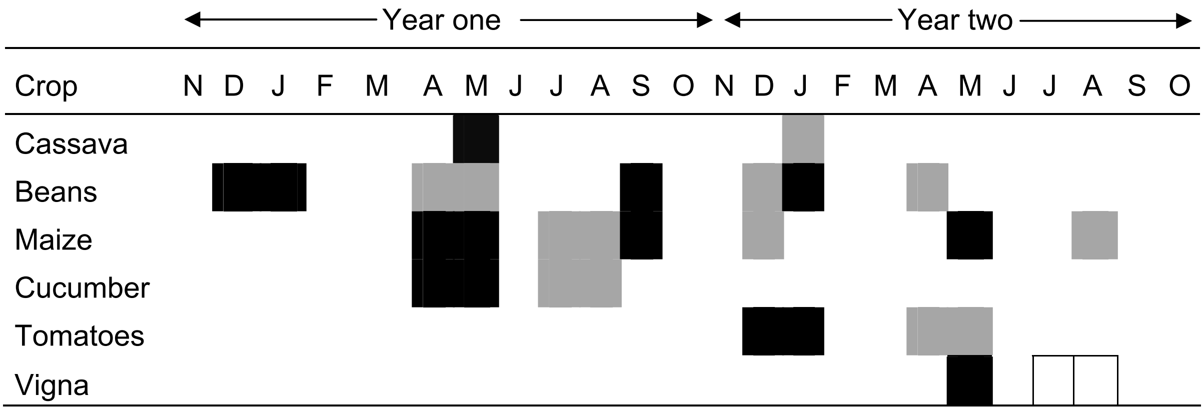


Figure 4. Typical multiple cropping and relay cropping sequences of rain-fed crops for 2 years for San Antonio de Los Baños. Crop substitutes: beans/groundnuts/ soybean; maize/sorghum/sunflower; cucumber/squash/watermelon; vigna/sesame/ mucuna/canavalia. The agricultural year starts at the end of the rainy season (May–October) and the beginning of the dry season (November–April).

Symbols: Sowing Harvesting Incorporation into the soil

Natural resources management and input dependence: Inappropriate allocation and under-utilization of available natural resources, combined with scarcity of external inputs were identified as major critical points limiting the transition process towards more integrated agriculture, and development of more economically feasible and more energy-efficient farming systems in the region (Table 3). Environmental protection and well-being of the rural and urban populations were also threatened by lack of inputs and inadequate infrastructure to adopt environmentally acceptable agriculture practices. At regional scale, inputs were mostly allocated to the 'protected' specialized crop production systems such as potatoes, tobacco and citrus, and a small part to vegetables and seed production and monogastric livestock enterprises such as egg and pork production. These commodities were heavily subsidized centrally, based on their perceived 'higher profitability, higher productivity and higher biological efficiency'. On the other hand, the diversified, small-scale farming sector had limited access to such resources and was marginalized due to its perceived 'lower profitability, lower productivity and higher labour demands'.

Self-reliance, feasibility and profitability: Monocropping and low input availability were critical points threatening self-reliance and feasibility of specialized dairy farming systems (Table 3). In addition, even with all the necessary inputs available, land productivity was low due to poor management, and the associated low efficiency in the use of energy and natural resources was diagnosed as a major financial constraint for specialized dairy farming. Resistance to a change of strategy towards self-reliance at farm, regional and national levels has actually been a greater constraint for the development of mixed farming systems than the collapse of the industrial model itself. State-controlled markets for products and inputs were also identified as components of the technological, socio-economic and financial unsustainability of specialized milk production systems. Low added value of the products, due to limited possibilities for local processing, high post-harvest losses and inefficient commercialization chains, further constrained farming system profitability.

Acceptability, equity and empowerment: The social and political attributes of farming systems were among the most problematic and influential ones during diagnosis and identification of critical points. Low acceptability of the specialized dairy farming model was associated with the serious deterioration of the farm infrastructure, dismantling of the technical support service and lack of resources, major factors undermining its viability. Low salaries and poor living and working conditions for cattle farmers and their families negatively affected their well-being and social equity. To make an acceptable living, farmers were forced to look for alternative remunerative activities, distracting from improving or even maintaining productivity of their enterprises. Lack of training due to weak extension services, low access to technology, limited decision-making capabilities, top-down pressures to realize production plans, and marketing restrictions for milk and meat products, were other key factors negatively affecting farming systems performance.

Finally, there has been progressive loss of traditions and a declining interest in livestock farming in the specialized dairy sector in San Antonio de Los Baños. A statement by Héctor, one of the farmers participating in the study, was typical: 'I saw people acting as they were packing up to leave'. Many farmers tended not to innovate, but were satisfied in performing their duties, as any additional efforts did not improve their daily lives.

5.1.2 Farm diagramming and characterizations of farm types

Diagnosis included detailed characterization of the three selected 'typical' farms. The use of farm-diagramming methods resulted in increased understanding of the holistic structure of agricultural systems as a prerequisite for sound participatory analysis of their performance (Giampietro and Pastore, 2001) and as a basis for strategy definition (Conway, 1998). Figures 5, 6 and 7 show the spatial pattern of biotic resources (agro-diversity) and physical farm components, complemented with land use and production data. Following Lightfoot et al. (1994) and Dalsgaard and Official (1997), these farm-based bio-resource and infrastructure diagrams do not detail the energy or nutrient flows, but contain information required for productivity analysis and energy balance calculations at farm scale. A summary of farm charachteristics for the three farms is presented in Table 4. The general layout of these farms was similar to those of the three experimental farms (two mixed and one specialized) evaluated for six years at the research station (Chapter 3). Therefore, further analysis is based on these similarities.

Mixed farms

Diversity: Farms A and B, classified as a small-scale and a medium-scale mixed farm, respectively, both with a medium proportion of arable cropping, were highly agro-diverse (expressed in number of species managed), heterogeneous (in terms of number of farm components) and complex (in terms of exchange of energy and nutrients, as well as in socio-economic interrelations). At the diagnosis stage, farm A produced 26 marketable products (from 8 livestock and 18 crop species), while farm B produced 24 products (5 and 19, respectively), including seven flower species (Figures 5 and 6). Adding the species of pastures and forage crops, fruit trees, timber trees and living fences, except for spontaneous vegetation and wild plants and animals, 38 different

Table 3. Summary of farm characteristics.

Characteristic	Farm type		
	A 'Remedio' (9.4 ha)	B 'La Sarita' (47 ha)	C 'Vaquería 10' (33.7 ha)
Type*	Mixed small-scale	Mixed medium-scale	Dairy medium-scale
Land**	Limited	Adequate	Adequate
Household members	12	8	6
Labour intensity/stability	High (Family-hired labour) – fairly stable	Low (Family-hired labour) – fairly stable	Low (cooperative members) – unstable
Agro-diversity (crops-animals-trees)	High	High	Low
Productivity***	High	High	Low
Sources of water	Aquaduct/underground water, little for irrigation	Aquaduct/underground water, abundant for irrigation	Aquaduct/big reservoir
Capital	Medium	Medium	Low
Economic feasibility	High	High	Low
Infrastructure	Makeshift timber/steel barn, low cost, functional	Makeshift timber/steel barn, low cost, functional	Concrete structures, expensive, poorly maintained
Machinery/equipment	Complete set of machinery and implements, old but well-maintained	Complete set of machinery and implements, old not as well-maintained as at farm A	Few machines, belonging to the cooperative, difficult to access
Input use	Animal feeds (concentrates, molasses and crop by-products); diesel, fertilizers, pesticides, electricity, veterinary medicines, human and animal labour		
Farm output (production)	High (high diversity of products)	High (few marketable products)	Low
Nutrient recycling	High	Medium	Low
Access to social services****	Good	Good	Good
Family housing conditions*****	Good	Good	Fair

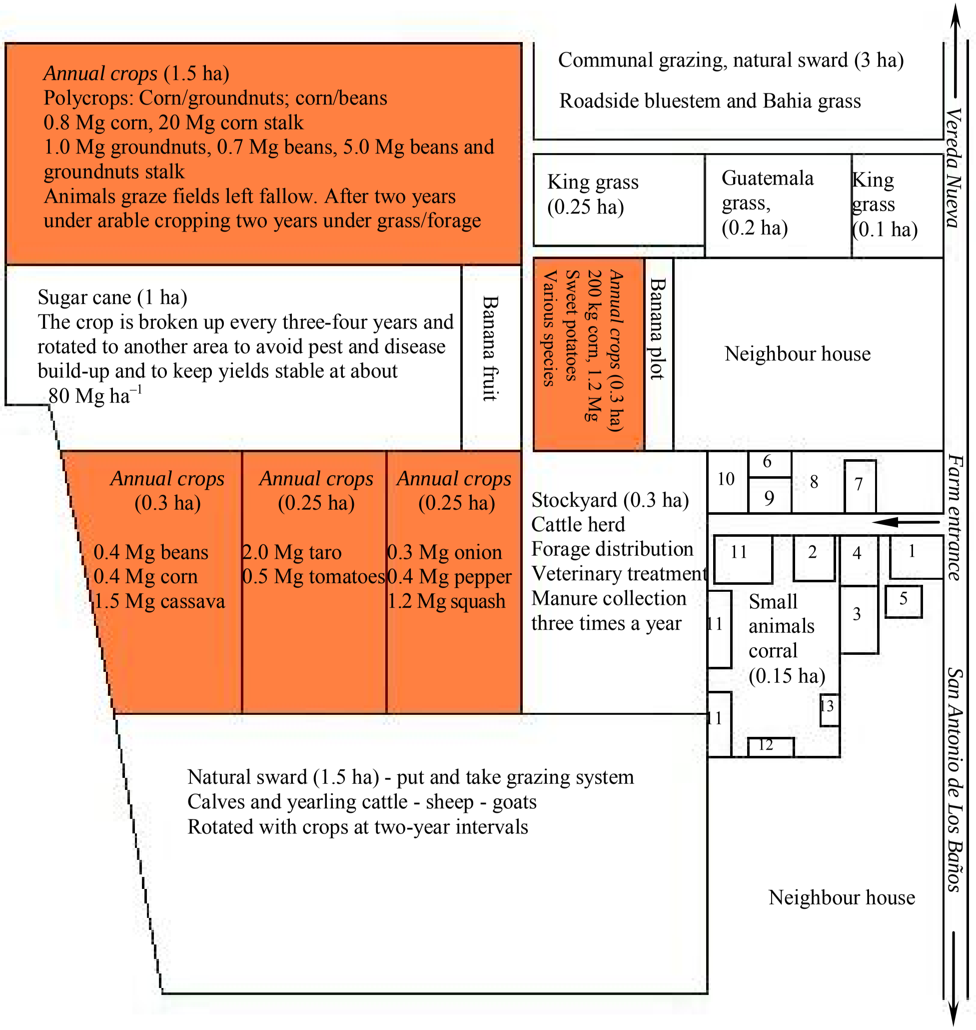
* All farms can be characterized as low external input agricultural (LEIA) systems;

** In terms of the estimated land area necessary for a family livelihood;

*** Energy and protein production per unit land area;

**** Social services include education and health care, roads, water supply and electricity;

***** Housing conditions were rated good, when the rooms were adequately ventilated and with acceptable comfort.



Infrastructure

Family houses (1,2,3); Warehouse for seeds and product storage, garage (4); Warehouse and repair shop (5,6,7) Machinery parking (8); Crop by-products and forage processing, chopper, water pump for house supply and irrigation and other machines (9); Dairy stable (10), Pig shed (11), Rabbit cages (12), Goat stable (13).

Animal production (Mg)*	
Cow milk	15.000
Goat milk	1.825
Beef	3.150
Pork	2.150
Mutton	0.650
Rabbit meat	0.440
Chicken meat	0.050
Eggs (units)	1650

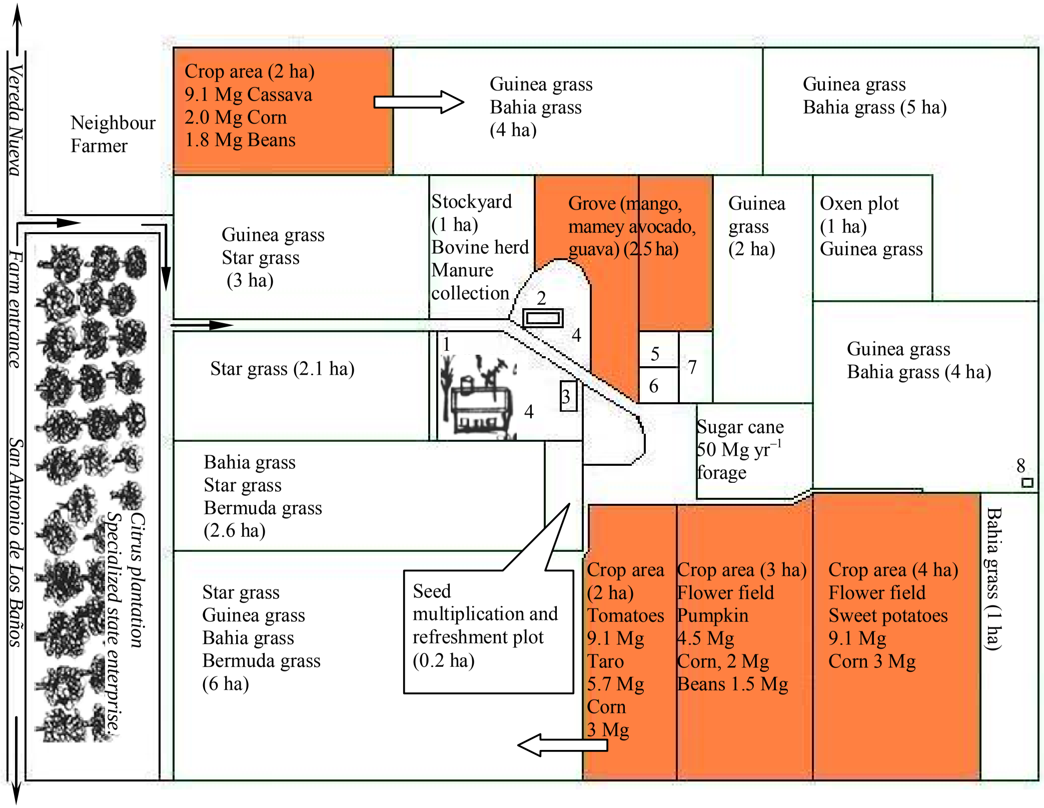
Fruit production (Mg)*	
Mango	2.500
Mamey	0.600
Orange	0.400
Guava	0.160
Lemon	0.160
Cherimola	0.120
Coffee	0.050

Fruit trees are spread out through the fields

Animal herd	
Cattle (22.8 AU) **	41
Pigs	12
Sheep	17
Goats	19
Chickens	41
Rabbits	120
Horses	2

Cattle herd	
Cows	11
Heifers	8
Female yearlings	5
Female calves	6
Oxen	2
Bulls	2
Male yearlings	2
Male calves	5

Figure 5. Bio-resource and farm infrastructure diagram of farm A, 'Remedio' (9.4 ha). * Annual animal and crop production given in fresh weight. Yields of animal products correspond to the total farm area. ** AU = animal unit of 400 kg live weight.



Infrastructure

Family house (1,2); Warehouse for seeds, harvest storage and repair shop (3,5); Machinery parking (4); Dairy stable, horse stable, forage chopper, crop by-products processing place (6); Calves corrals (7); Water pump (8).

Animal production (Mg)*		***Fruit production (Mg)****	
Cow milk	50.760	Mango	2.000
Beef	5.818	Avocado	2.000
Pork	0.909	Guava	0.800
Mutton	0.455	Anonna	0.400
Eggs	1300	Soursop	0.400
		Cofee	0.100

Animal herd		***Bovine herd***	
Cattle (78.3 AU)**	158	Cows	40
Pigs	10	Heifers	15
Goats	12	Female yearlings	11
Chickens	50	Female calves	51
Horses	4	Oxen	4
		Bulls	8
		Male yearlings	11
		Male calves	18

Figure 6. Bio-resource and farm infrastructure diagram of farm B 'La Sarita' (47 ha). * Annual animal and crop production given in fresh weight. Yields of animal products correspond to the total farm area. ** AU = animal unit of 400 kg live weight. The white arrows indicate the direction of livestock-crop rotation within a complete cycle of about 12 years.

species were identified in farm A and 49 in farm B. Despite their similarities in terms of biodiversity and farm components (Figures 5 and 6), farm size and land use intensity characterized the two mixed farms as different types. In both farms, part of the production was marketed.

Spatial and temporal attunement of agro-diversity resulted in agro-ecological and financial benefits. While cattle and/or other animal species guaranteed a daily monetary income via milk, meat or egg production, they simultaneously played a role in nutrient and energy recycling via consumption of straw and other crop residues not suitable for human nutrition, and production of manure and traction. Multiple cropping practices (Figure 4) resulted in land equivalent ratios exceeding 1, i.e. higher yields of the mixed crops than the sum of the yields of each species as a single crop. Additional benefits of agro-diversity were pest control, protection against soil erosion, and generation of extra income that helped to 'finance' milk and beef production. Furthermore, trees, dispersed throughout the farm area, and complementing crop and animal production, produced considerable quantities of fruits and forage, and provided other environmental services (e.g. refuge for birds, shade and nutrient recycling). Trees also address global concerns such as carbon sequestration and energy efficiency. Recent experiments in Cuba (Sánchez, 2007) with agro-forestry systems consisting of associations of *Leucaena leucocephala* (Lam.) De Wit. and guinea grass, *Panicum maximum* Jacq., over a 10-year period, have shown an increase in SOM from 3.16 to 4.12% in the 0–20 cm soil depth. This was attributed mainly to shedding of dead leaves and manure additions during grazing with stocking rates fluctuating from 1.5 to 2.0 animal units (AU[7]) ha^{-1}. Earlier research had demonstrated that guinea grass, tolerant to shade, in association with leucaena in silvopastoral systems produced more biomass of higher quality than in pure stands (Alonso, 2003). In adition, leucaena trees can fix from 200 to 600 kg atmospheric N ha^{-1} yr^{-1}, which allows intensification of livestock production.

Animal feeding strategies: The overall cattle stocking rates in farm A (2.4 AU ha^{-1}) and farm B (1.7 AU ha^{-1}) were high for tropical agro-ecosystems. Despite the limited area in grass and forage crops, i.e. 73% and 65% of the total area, respectively (Figures 5 and 6), stocking rates expressed in terms of those areas were 3.2 AU ha^{-1} for farm A and 2.6 for farm B, not including the other animal species, of which in farm A, the number was high (Figure 5).

Overall, about 75% of the total feed consumed by animals was on-farm or locally produced, while small quantities of concentrates were purchased, and mainly fed to young stock and monogastric animals. The most important species in the *grazed*

[7] An animal unit (AU), in this study, is defined as 400 kg animal live weight.

pastures were Bahia grass (*Paspalum notatum*, Fluegge), Bermuda grass (*Cynodon dactylon*, L.), Guinea grass (*Panicum maximum*, Jacq.) and star grass (*Cynodon nlemfuensis,* Vanderyst), and the legumes glycine (*Neonotonia wightii,* Wight & Arn), dolichos lab-lab (*Lablab purpureus,* L.) and canavalia (*Canavalia ensiformis,* L.). Rations, based on the combination of high yielding *cut* forages such as sugar cane (*Saccharum officinarum,* L.), king grass (*Pennisetum purpureum,* Schum.) and Guatemala grass (*Tripsacum laxum*, Nash.), and crop by-products such as corn and sorghum (*Sorghum vulgare*, Pers.) stover, cassava haulms, sweet potato leaves, bean and groundnut (*Arachis hypogaea* L.) haulms, whose availability and quality varied throughout the year, constituted a diverse and adequate diet for animals. Complementary strategies such as the use of communal grazing land and feed imports from other local sources (i.e. molasses, by-products from the citrus processing industry, and occasionally residues from neighbouring farmers) provided mixed farmers with a flexible animal feeding scheme throughout the year, including the dry season. Expertise in animal husbandry, pasture management, cropping system management and crop by-product utilization contributed to successful farm performance.

Labour: The complex farm structure and the highly dynamic set of system interactions in the mixed farms resulted in a large number of activities. Among the most important activities were feeding animals, sowing, weeding, dung collection, ploughing, fencing, harvesting, milking cows, slaughtering animals and repairing machines. Night guards were required to protect animals. Animal feeding was the most labour-intensive activity, occupying about 20% of the total time expenditure. External labour was contracted to cut forages, herd animals and milk cows, and for ploughing with oxen in cooperation with family members. Work planning was based mainly on short-term decisions in response to farm demands. Women actively participated in certain activities such as feeding small animals, harvesting, particularly products such as spices, and preparing meals for family and hired labour. They were also responsible for childcare and housekeeping.

A major constraint was the limited availability of qualified labour, for example, with skills to plough with oxen. Moreover, hiring labour was in general not remunerative. On farm B, due to its larger size, more labourers were hired permanently and for casual labour. A typical working day was about 8 hours for a wage of 20 to 30 Cuban Pesos (CUP), i.e. less than two US$ per day, which, however, is higher than the 15 CUP a day salary for administrative functions in the city. Permanent labourers also received salary in kind for their families (e.g. milk, roots and tubers, vegetables, grains and even some meat).

Input sources and their strategic use: Strategic use of scarce resources was part of continuous innovation and problem-solving processes. Both mixed farms received limited quantities of inputs through formal channels such as credit and services cooperatives. Other necessary materials and inputs such as spare parts, tools, fertilizers, diesel and veterinary medicines, bags, cords, fences, boxes, glasses, etc. were mostly acquired in the informal market, because they were unavailable or very difficult to find, due to absence of or inefficiency in formal channels. Scarcity of these materials constrained efficient work of farmers under difficult conditions and development of additional activities such as food processing or forced them to look for alternatives.

Machinery and infrastructural conditions: Although infrastructure and equipment were old, both mixed farms owned a complete set of machinery and implements for soil preparation and farm operations in general, i.e. a tractor with trailers, horse carts, cisterns for molasse conservation, diesel or electric engines for pumping water and warehouses for proper product and input storage (Figures 5 and 6). The low-cost dairy stables, facilities for counting, treating or selling animals, and corrals for housing of small animals were sufficient for adequate animal management. Both farms owned sprinkler irrigation systems and tillage equipment such as a plough, furrower and slasher, as well as forage cutters. In addition, farm A owned other equipment such as a rice mill, a corncob strip machine and a grass harvester. These could be rented to other farmers, generating extra income. Recycling of spare parts and operation of on-farm repair shops supported smooth operation of the machinery. Fencing was an important element of infrastructure in the mixed farms to avoid damage to crops. However, the fences were inadequately maintained, leading to frequent escape of animals and damage to crops. A warehouse in good condition for storage of local seeds takes away the need of buying seeds for the next season.

Animal-crop interactions: Farmers did not adhere to fixed crop rotations, but adapted their cropping systems to weather conditions, market demands and input availability. At the diagnosis stage, farm B consisted of 12 fields, each field being used for about three years under arable cropping and about five years under grazing (Figure 6). High doses of organic manure were applied in the arable cropping phase and in the forage areas after the second harvest following their establishment. Due to the smaller area of farm A (Figure 5), rotation and land use were even more dynamic and decisions even more complex, due to the larger number of components.

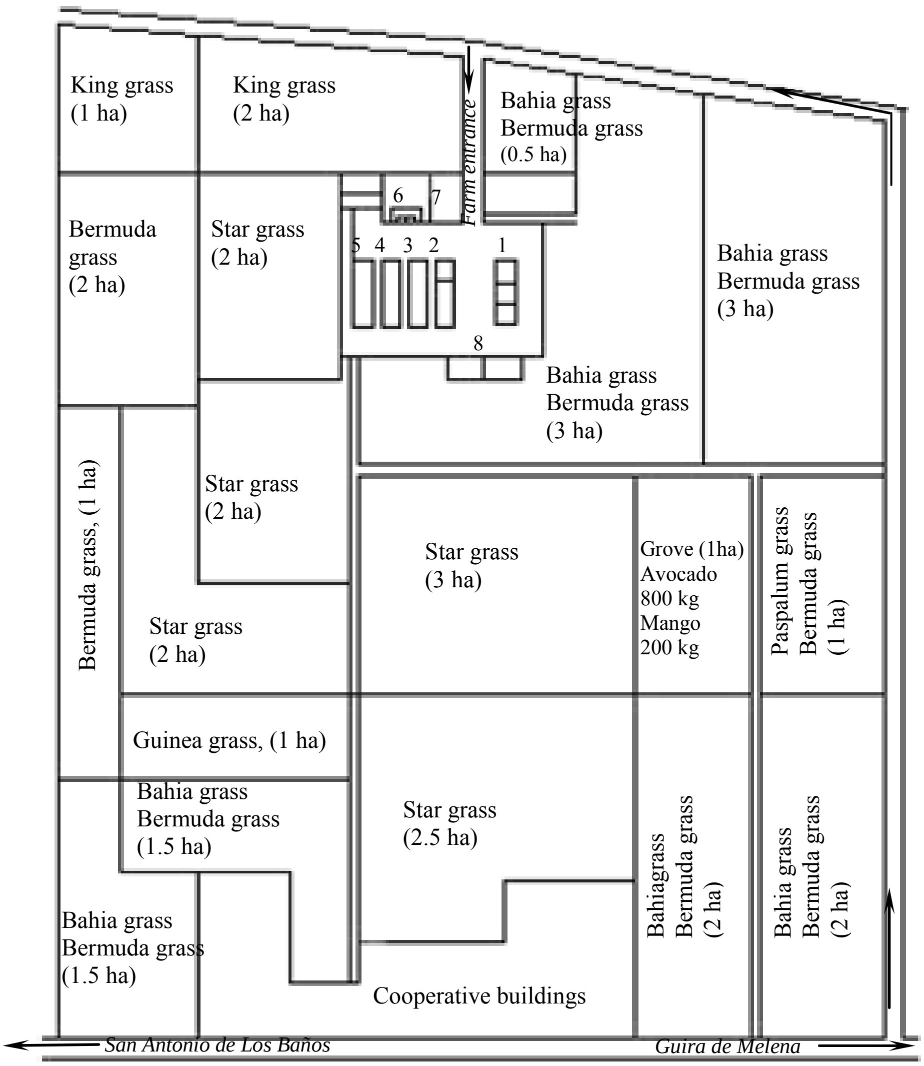
Nutrient management: Both mixed farms applied similar practices in nutrient management. Cattle, sheep, goats and horses recycled nutrients directly into the fields via manure and urine deposition while grazing. All manure collected in the cattle stables and from the small animal corrals (pigs, rabbits and chickens) was composted for about three months and subsequently applied to the forage and crop fields just before the rains. Imported animal feeds (i.e. residues from a citrus processing centre, crop residued from other farms, and by-products from the sugar cane industry such as molasses, enriched bagasse and concentrate feeds), represented external sources of nutrients. These inputs, together with nutrients recycled by animals, plants and trees, appear sufficient to compensate for the substantial nutrient exports in products, since there were no obvious signs of nutrient depletion.

Specialized dairy farm (C)

Farm C, based on pastures and forages, was managed in a rotational grazing system with the aim of producing milk. Pasture deterioration, low farm productivity, and poor animal health were major critical points identified. An avocado and mango grove, existent before the dairy farm was established some 30 years ago, where the house of the previous landowner had been located, was the only place with trees. It served as reservoir for diversity and as refuge for cows in the hottest hours of the day when grazing the nearby paddocks (Figure 7). As milk production was the main economic activity for farm C, the best cows from other units of the cooperative were taken to this farm and calves were sold at four months of age. As a typical specialized dairy operation, it consisted of a grazing area with a mixture of natural and cultivated grasses such as Bahia grass, roadside bluestem (*Dichantium caricosum*), star grass and Guinea grass and three hectares of king grass managed under a cut and carry system, used mostly during the dry season (Figure 7). Sugar cane, used as animal feed during the dry season, was grown outside the farm on cooperative fields. Due to lack of labour, the dry season forage sources received little attention and were often not utilized due to their poor quality. Without any other on-farm feed sources than these low-productive pastures and forages, and a stocking rate of 2.5 AU ha^{-1} (Figure 7), the farm was highly dependent on imports of forages and other feedstuffs, especially during the dry season.

The cattle herd of crossbreed Holstein × Zebu, was old and poorly maintained, with cows 8 years old on average and with 3.5 lactation per cow, i.e. low reproductive efficiency. Originally, farm C was designed for a herd of 120 milking cows. The expensive concrete infrastructure included cattle sheds, a dairy stable with mechanical milking system with eight positions, an elevated water reservoir, warehouses for input storage, and a spraying bath for tick control (Figure 7).

Four labourers were in charge of running the farm, one acting as administrator and another as night guard to protect animals. The other two were in charge of all farm



Infrastructure

Family house and warehouse buildings (1); Dairy stable with mechanized milking system (2); Stable for calves (3); Stable for cows (4,5); Water tank elevated 15 m above ground (6); Oxen plot (7); Spraying bath (for tick control) (8).

Bovine herd

Cows	72
Heifers	4
Female calves	14
Oxen	3
Male calves	2
Total herd (83.3 AU)**	95

Animal production (Mg)*

Cow milk	29,596
Beef	1,260

Figure 7. Bio-resource and farm infrastructure diagram of farm C 'Vaquería 10' (33.7 ha).

* Annual animal production given in fresh weight. Animal production refers to the total farm area;

** AU = animal unit of 400 kg live weight.

operations. Low wages and the associated lack of motivation resulted in very highlabour turnover, so that many of the daily tasks were not (satisfactorily) performed, contributing to the deterioration of the dairy operation. Although these problems were mostly attributed to the lack of resources and the low level of technological know-how, they were also related to the lack of autonomy in decision-making, low profitability and difficulties associated with the organization at the cooperative level. Due to the inappropriate functioning of the cooperative, farmers were not truly committed to results. An integrated assessment, including agro-ecological, financial and socio-economic aspects is required to identify bottlenecks in specialized dairy farming systems. This would provide a basis for the design of more sustainable dairy farming systems, based on consistent 'best practice' strategies.

5.2 Farming system analysis, indicator monitoring and assessment

5.2.1 Soil characterization

Topography of the three case study farms is essentially flat, with slight slopes of 1 to 2%. The common parent material is Miocene hard limestone. In evaluating the farm soil characteristics, we looked for non-disturbed or well-conserved soils in the farms that could serve as reference for the 'original' soil conditions. Rotations of arable crops and forages, regular application of animal manure to crops and forages, incorporating all crop residues and refusals from animal feeding into the soil and combined use of oxen and tractors, were the main characteristics of the integrated soil management strategy in the mixed farms (A and B). The pasture soils in the specialized dairy farm (C), not disturbed for about 20 years, showed the best structure and the most favourable values for the soil fertility indicators among the three farms (Tables 5, 6 and 10). An in-depth study of the soil profile was made on farm A, on which an intensive mixed crop-livestock system had been practiced for about 70 years. Such a study contributes to increased understanding of the dynamics of soil organic matter and physico-chemical characteristics (Table 7) in different layers (Table 8), under low external input soil fertility management, supported by the use of many different complementary strategies to optimize nutrient recycling at farm level.

The lack of differentiation in nutrient contents among land use types for the mixed farms could be the result of the long-term rotation of arable crops and forages that tends to lead to convergence of soil characteristics. This does not happen in the specalized farm, in which soil characteristics for the land uses defined (grass, forage and grove) showed 'logical' patterns. In this section, we analyse patterns that may reflect, at plot level, the effect of a certain land use and/or a specific crop or livestock management practice.

Farm A 'Remedio'

The dominant soil on this farm was classified as Red Fersialitic mollic with carbonates according to the new version of the Cuban genetic soil classification system (Hernández et al., 1999). This corresponds to the sub-unit Haplic Cambisols (humic,

Table 5. Soil profile descriptions of 'typical' soils in the three farms according to the Cuban classification (Hernández et al., 1999) and the WRB classification (WRB, 2006).

Farm	Horizon	Depth (cm)	Description
A 'Remedio'	Agr	0–24	Brown reddish dark (5 YR 3/4), with peds red very dull (2.5 YR 2.5/2), 3–5% gravels of hard limestone, clayey texture, angular blocks of 5-7 cm, compacted, few pores of medium size, fresh, medium quantity of fine roots, weak reaction to HCl, net transition.
	B_{11}	24–50	Red (10 R 4/8), clayey texture, sub-angular blocks of 5 cm and polyhedric structure, slightly compacted, with gravels of dark colour and some peds, medium porosity, slightly moist, few fine roots, some internal channels of dark colour, without reaction to HCl, net transition.
	B_{12pd}	50–67	Red (10 R 4/8), clayey texture, not defined structure, more than 50% hard limestone, without reaction to HCl, net transition.
	B_2	67–85	Red (10 R 4/6), clayey texture, small angular blocks of 1–3 cm, friable, medium and fine porous, moist, without roots, without reaction to HCl.
Soil classification: Cuba: Red Fersialitic mollic with carbonates; WRB: Haplic Cambisol (humic, eutric, clayic, rhodic)			
B 'La Sarita'	A_1	0–18	Brown reddish (2.5 YR 3/4), clayey texture, sub-angular blocks of 5 cm that crumbled into granular nutty structure, compacted, slightly moist, medium porosity, many fine roots, presence of peds, without reaction to HCl, gradual transition.
	B_1	18–38	Dark red (2.5 YR 3/6), clayey texture, polyhedric structure that crumbled into nutty structure, slightly compacted, more porous with worm galleries, moist, few roots, with cutans, without reaction to HC gradual transition.
	B_2	38–80	Dark red (2.5 YR 3/6), clayey texture, polyhedric thinner structure, friable quite plastic, porous, less roots, with cutans, worm galleries, slightly moist, without reaction to HCl.
Soil classification: Cuba: Red Lixiviated Ferralitic typic eutric; WRB: Ferralic Nitisol (eutric, clayic, rhodic)			
C 'Vaquería 10'	A_{11}	0–10	Brown red (2.5 YR 4/4), clayey texture, sub-angular blocks of 5 cm that transit to granular nuciform, slightly compacted, porous, dry, wi limestone gravels and stones, small roots in decomposition and presence of ants, without reaction to HCl, gradual transition.
	A_{12}	10–20	Similar to previous layer, but with smaller angular blocks, equal porosity, more evident transition.
	B_{11}	20–34	Red (2.5 YR 4/6), more clayey texture, sub-angular to polyhedric blocks, compacted, abundant fine pores, more humid, scarce roots, with cutans, without reaction to HCl, gradual transition.
	B_{12}	34–48	Brown reddish (2.5 YR 4/8), smaller sub-angular blocks, equal porosity, more humid, less cutans, without reaction to HCl, notable transition.
	B_2	48–70	Brown reddish (2.5 YR 4/8), clayey texture, sub-angular to polyhedric blocks, many fine porous and less cutans.
Soil classification: Cuba: Red Fersialitic mollic with carbonates; WRB: Haplic Cambisol (humic, eutric, clayic, rhodic)			

Table 6. Particle size distribution (%) of 'typical' soil profile for the three study farms.

Farm	Horizon	Depth (cm)	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Clay in micro-aggregates	DF*
A	Agr	0–24	25.4	4.0	12.0	16.0	42.6	7.5	17.6
	B_{11}	24–50	26.6	1.0	2.0	2.0	68.4	13.0	19.0
	B_{12pd}	50–67	–	–	–	–	–	–	–
	B_2	67–85	13.6	4.0	3.0	2.0	77.4	14.0	18.1
B	A_1	0–18	26.7	4.0	6.0	10.0	53.3	n/a	n/a
	B_1	18–38	10.7	2.0	4.0	4.0	79.3	n/a	n/a
	B_2	38–80	12.7	3.0	1.0	2.0	81.3	n/a	n/a
C	A_{11}	0–10	16.7	4.0	4.0	2.0	65.3	n/a	n/a
	A_{12}	10–20	17.6	2.0	6.0	6.0	68.4	n/a	n/a
	B_{11}	20–34	7.8	5.0	5.0	4.0	78.2	n/a	n/a
	B_{12}	34–48	11.7	6.0	4.0	4.0	74.3	n/a	n/a
	B_2	48–70	25.6	2.0	2.0	2.0	68.4	n/a	n/a

Clay soil texture for all farms at all depths. n/a: not applicable

* DF (dispersion factor) = clay percentage in micro-aggregates ×100/clay percentage in mechanical composition. Farm A (Remedio), Farm B (La Sarita) and Farm C (Vaquería 10).

Table 7. Soil organic matter content and physico-chemical characteristics (profile farm A).

Depth (cm)	pH (H_2O)	SOM (%)	P (ppm)	K^+	Ca^{2+}	Mg^{2+}	Na^+	SEC*
				$(cmol_{(+)}\ kg^{-1})$				
0–24	7.3	4.2	44.8	0.86	26.3	5.7	0.09	32.95
24–50	7.5	1.6	32.1	0.79	25.4	5.8	0.08	32.07
50–67	7.6	1.3	8.5	0.55	26.8	6.0	0.10	33.45
67–85	7.7	0.6	8.2	0.60	27.2	6.2	0.13	34.13

* SEC (Sum of Exchangeable Cations)

Table 8. Carbon (C) stocks (profile farm A).

Depth (cm)	C (%)	Apparent density ($kg\ dm^{-3}$)	C content ($Mg\ ha^{-1}$)
0–24	2.44	1.05	61.5
24–50	0.95	1.10	27.2
50–67	0.75	1.12	14.3
67–100	0.32	1.15	12.1

eutric, clayic, rhodic) according to the World Reference Base classification (WRB, 2006). Soil texture in the A horizon is predominantly clay. Small calcium carbonate kernels are formed by fractionation of the mother rock (Table 5). There is strong micro-aggregate formation, especially in the coarse sand fraction (second order aggregates), as a result of long-term application of organic matter and the permanent crop cover without ploughing, resulting in a low dispersion factors (Table 6), partly responsible for the excellent soil structure in the first 20 cm. Soil pH is high, due to the presence of carbonates (eutric). The sum of exchangeable cations (SEC) is high in these clay soils with values of 30–36 $cmol_{(+)}$ kg^{-1}. Cation ratios (Ca^{2+}/Mg^{2+}; K^+/Mg^{2+} and $Ca^{2+}/(Mg^{2+}+K^+)$) are favourable, except in field *h*, where Mg^{2+} is slightly lower, due to continuous crop cultivation. These results are in agreement with the soil profile characteristics (Table 7).

Carbon stocks in the soil profile were 89 Mg ha^{-1} in the top 50 cm and an additional 26 Mg ha^{-1} in the layer 50–100 cm (Table 8). SOM content exceeded 5% in all sub-systems, except in *d* (crops), continuously cropped for about 70 years, which was 4.8% (medium), still high for these soils (Table 9) and the sample analysed from field a (4.2%; Table 7) that was apparently not representative (Table 9). These values suggest a reduction of 30–40% compared to the expected stocks under natural conditions (Hernández et al., 2006), representing the minimum carbon losses following cultivation, according to the criteria of Lal et al. (2007), who estimated losses from 30 to 75% in agro-ecosystems under different levels of intensification.

While the physical soil structure deteriorates as a result of SOM mineralization, leading to destruction of micro-aggregates, DF increases (Table 6). According to the hypothesis of Morales et al. (2008), the dispersed clay in these soils can follow three pathways: lateral transport, vertical transport, or filling the pores of the aggregates in the upper part of the B horizon, forming a plough pan. The latter leads to formation of coarser aggregates and thus to higher values of DF. According to Hernández and Morell (2005), DF for these soils should be less than 20. Only in field *a*, following intensive crop cultivation without rotation with pastures for many years, DF > 20 (Table 10).

High contents of SOM and, therefore, high C-stocks, as in the soils of farm A, are rare in the plain of Havana-Matanzas, since these soils have been continuously cultivated with cash crops such as coffee, sugar cane, and tobacco from the beginning of the 20th century (Crawley, 1916). Depletion of organic C in these soils accelerated during the second half of the century, as a result of changes in crop management in the continuing intensive cultivation of sugar cane and other cash crops: Restricted root growth due to soil compaction as a result of the use of heavy machinery and removal or burning of crop residues, with the associated exposure of the soil to the prevailing

Table 9. Soil fertility characteristics (0–20 cm) for the different fields of the three study farms.

Farm Sub-system (Field)	pH (H_2O)	SOM (%)	P (ppm)	K^+	Ca^{2+}	Mg^{2+}	Na^+	SEC*	TSS (ppm)
				$cmol_{(+)}\ kg^{-1}$					
A 'Remedio'									
a	8.2	5.6	11.6	1.30	27.0	6.8	0.13	35.23	661
b	8.2	5.1	34.5	1.13	27.0	6.5	0.08	35.71	569
c	8.2	6.3	12.3	1.08	29.2	5.2	0.17	35.65	620
d	8.2	4.8	15.2	1.00	26.7	4.1	0.11	31.91	535
e	8.2	6.1	41.6	0.76	26.4	5.6	0.06	32.82	661
f	7.9	5.6	8.1	0.51	26.0	4.9	0.11	31.52	603
g	8.2	5.9	8.1	0.51	24.3	5.5	0.08	30.39	603
h	8.2	5.4	10.2	0.51	27.2	3.4	0.08	31.19	566
B 'La Sarita'									
a	6.7	4.4	3.6	0.62	13.6	4.4	0.04	18.66	235
b	7.5	3.4	26.5	0.29	15.2	5.2	0.06	20.75	328
c	6.5	2.4	14.3	0.51	14.3	4.3	0.06	19.17	235
d	6.8	2.7	9.2	0.23	16.9	5.6	0.06	22.79	235
e	6.6	3.5	8.8	0.18	14.8	4.2	0.06	19.24	235
f	7.4	3.5	5.3	0.06	14.6	4.8	0.11	19.57	281
g	6.8	3.4	7.9	0.43	11.5	4.2	0.06	16.19	281
h	6.2	3.3	2.6	0.25	13.0	4.8	0.04	18.09	235
i	6.0	4.8	1.8	0.77	11.2	4.6	0.06	16.63	235
j	6.0	4.2	1.7	0.47	9.7	4.2	0.06	14.43	235
k	7.5	3.9	13.6	0.70	10.4	4.2	0.04	15.34	375
C 'Vaquería 10'									
a	7.3	5.6	3.6	0.31	26.0	7.0	0.09	33.4	405
b	7.9	6.1	6.8	1.02	32.0	4.0	0.09	36.1	506
c	7.8	5.6	5.3	0.59	31.5	7.5	0.09	39.7	456
d	7.3	5.9	16.5	0.82	24.0	5.5	0.06	30.4	557
e	7.4	6.8	8.6	1.03	33.5	5.5	0.09	40.1	456
f	6.5	4.8	1.3	0.22	23.5	6.5	0.09	30.3	183

* SEC (Sum of Exchangeable Cations).

** TSS (Total Soluble Salts). Letters identifying farm sub-systems are shown in Figure 3. In the encircled fields soil profiles were described.

Table 10. Soil particle size distribution, texture class and dispersion factor (0–20 cm) (Farm A).

Farm Sub-system	Coarse sand (%)	Fine sand (%)	Coarse silt (%)	Fine silt (%)	Clay (%)	Texture class	DF*
a	33.4 (69.0)**	19 (14)	5 (5)	8 (3)	34.6 (8.0)	Clay loam	23.1
b	30.4 (69.0)	15 (16)	7 (5)	1 (4)	46.6 (6.0)	Clay	12.9
c	33.4 (74.0)	16 (12)	10 (5)	3 (4)	37.6 (5.0)	Clay loam	13.3
d	29.4 (72.0)	14 (13)	9 (5)	7 (5)	40.6 (5.0)	Clay	12.3
e	29.7 (70.7)	23 (14)	2 (6)	5 (2)	40.3 (7.3)	Sandy clay	18.2
f	20.7 (72.7)	12 (9)	4 (5)	8 (5)	55.3 (8.3)	Clay	13.2
g	33.7 (73.7)	13 (11)	9 (7)	6 (2)	38.3 (6.3)	Sandy clay	16.5
h	24.7 (76.7)	16 (12)	6 (3)	8 (4)	45.3 (4.3)	Clay	9.5

* DF (dispersion factor) = clay percentage in micro-aggregates ×100/clay percentage in particle size distribution. Letters identifying farm sub-system are shown in Figure 5.

** Between parenthesis the composition in terms of soil micro-aggregates.

high temperatures and heavy rains during summer. Less than 1% SOM, and the presence of a plough pan are typical characteristics for the soils in this region (Hernández and Morell, 2005; Hernández et al., 2006). The high SOM contents in farm A are attributed to the continuous use of animal manure, incorporation of crop residues into the soil and the incorporation in the rotation of high-yielding (20 and 30 Mg above-ground DM ha^{-1} yr^{-1}) forages such as sugar cane, king grass, and Guatemala grass. Consequently, the favourable soil physical structure has been conserved in these soils, despite the high level of land use intensification (Tables 5 and 10).

Available soil P content is high in all sub-systems, with the highest values in fields *b* (arable crops) and *e* (forage), while high exchangeable K^+ contents were recorded in fields *a, b, d* (arable crops) and *c* (grass) and medium values in fields *e, f, g* (forage) and *h* (arable crops).

In general, the physico-chemical characteristics of the soils in farm A were qualified as ‘outstanding’, despite their intensive use and the considerable export of nutrients via products (milk, meat and crop products) over a long period.

Farm B ‘La Sarita’

The dominant soil in this farm was classified as Red Lixiviate Ferralitic typic, eutric according to Hernández et al. (1999), corresponding to Ferralic Nitisol (eutric, clayic, rhodic) according to WRB (2006). The grass sub-systems *h, i, j* were slightly acidic, while pH of all other sub-systems was close to neutral. Acidification is typical for ferralic soils formed from schists in high rainfall areas in the western part of the island, specifically in the La Palma and Viñales regions of Pinar del Río province. Moreover, as DNRE (1999) indicates, acidification is aggravated by continuous cultivation of grasses or the continuous extraction of biomass through crop cultivation or hay production. However, the soils in this farm, formed from hard limestone, are characterized by higher SEC and are less susceptible to acidification.

Values of SEC in this farm are half those in farm A, probably related to the characteristics of the Ferralic Nitisols soil type, but also to the lower organic matter content. SEC is somewhat higher in the sub-systems with higher pH (18.9 $cmol_{(+)}$ kg^{-1}) than in those with lower pH (16.4 $cmol_{(+)}$ kg^{-1}) (Table 9). Ca^{2+} dominates the exchange complex (9.7–16.9 $cmol_{(+)}$ kg^{-1}) followed by Mg^{2+} (4.2–5.6 $cmol_{(+)}$ kg^{-1}). Exchangeable Na^{+} is very low (< 0.1 $cmol_{(+)}$ kg^{-1}) and exchangeable K^{+} is low, varying from 0.06–0.77 $cmol_{(+)}$ kg^{-1}, with the lower values in sub-systems *e, f* (arable crops) and *b, d* and *h* (grass) and the higher values (0.43–0.77 $cmol_{(+)}$ kg^{-1}) in *a, c, i, j* (grass) and *g* (arable crops, recently converted from grass). Exchangeable K^{+} was generally lowest in soils with the highest intensity of crop production. The (Ca^{2+}/Mg^{2+}) ratio is adequate, i.e. 2/1 to 6/1, albeit in the lower range, associated with relatively low contents of Ca^{2+}. The K^{+}/Mg^{2+} ratio is low (< 0.1) in the majority of the sub-systems, but adequate (0.1–0.6) in *a, c, j* (grass) and *k* (forage). The $Ca^{2+}/(Mg^{2+}+K^{+})$ ratio is adequate (2–6), but in the low range (between 2 and 3), and in sub-system *j* it is very low (< 2). TSS values below 375 ppm do not indicate salinization.

SOM varies from 2.4 to 4.8%, averageing 3.4% (medium) (Table 9). In sub-systems *c* and *d* (grass-outfields) SOM is low (2.4 and 2.7), while it is high in grass sub-systems following crops in which high doses of manure were regularly applied, i.e. *a, i, j* (> 4.0%). Similarly, the high value of SOM in the permanent sugar cane forage area *k* (3.9%) was also attributed to the high manure application and re-incorporation of dead leaves into the soil. In both, crop and forage areas, high doses (above 20 Mg ha^{-1} yr^{-1}) of fresh manure were applied. Available P-values are medium in the sub-systems *d* (grass), *e* and *g* (crops), low in *a* (grass) and *f* (crops), very low in *h, i, j* (grass) and high in the other sub-systems, with the highest content in *b* (grass) (26.6 ppm P), previously dedicated to flowers and cash crop cultivation with high fertilizer doses for about four years. In general in farm B, exchangeable bases and nutrients in the soil are lower than in farm A, probably associated with inherent soil characteristics and lower rates of manure application.

Farm C 'Vaquería 10'

The dominant soil on this farm, as on farm A, was classified as Red Fersialitic mollic with carbonates according to the new version of the Cuban genetic soil classification system (Hernández et al., 1999), corresponding to Haplic Cambisol (humic, eutric, clayic, rhodic) according to the World Reference Base classification (WRB, 2006). Overall, soil pH was slightly alkaline, except in sub-system *f* (grass) where it was slightly acidic. SEC values varied between 30.3 and 40.1 $cmol_{(+)}\ kg^{-1}$, similar to those in farm A (Tables 5 and 9).

Ca^{2+} was the dominant exchangeable cation, with values between 23.5 and 33.5 $cmol_{(+)}\ kg^{-1}$, followed by Mg^{2+} (4.0–7.0 $cmol_{(+)}\ kg^{-1}$). Exchangeable K^{+} was low in sub-systems *a* (forage) and *f*, medium in *c* and *d* (grass) and high in *b* (grass) and *e* (grove). Exchangeable cation ratios were adequate for Ca^{2+}/Mg^{2+}, $Ca^{2+}/(Mg^{2+} + K^{+})$ and K^{+}/Mg^{2+}, except for low K^{+}/Mg^{2+} in sub-systems *a, c* and *f,* due to the low K^{+} contents.

Available-P content varies, being lowest in *f* (Bahia grass and Bermuda grass) which is an outfield, grazed at low frequency, low in *a* (forage) and *c*, with high nutrient extraction, medium in *b* and *e* (mid-fields) and high in *d*, the grazing area close to the stables, receiving runon.

SOM content was high in all sub-systems (> 4%), with the highest values (6.75%) in the grove sub-system *e* (Table 9). This SOM content can be considered the equilibrium level associated with relatively high annual inputs. The high SOM contents in *b* and *d* (grass), close to the stables are explained by OM input through runon to those grazing areas. The lowest SOM content in sub-system *f*, located far from the stables, could be associated with a lower grazing frequency. These SOM contents are equivalent to organic C stocks in the layer 0–20 cm ranging from 58 to 78 $Mg\ ha^{-1}$.

The high SOM contents in farm C, the high natural fertility and 'excellent structure' can be attributed to a number of factors: (1) the original soil characteristics. This was confirmed by the analysis of the reference sample in the 'non disturbed' grove sub-system (*e*) (Table 8); (2) the high annual inputs in shedded leaves and roots in the 20-year old permanent pastures, and (3) the low nutrient exports in products. The favourable soil conditions in long-term non-disturbed pasture-based systems have also been identified by García-Trujillo and Monzote (1995), Monzote and Funes-Monzote (1997) and Funes-Monzote et al. (2008) in their studies on establishment of mixed farming systems.

5.2.2 Agro-ecological and financial analyses

Performance of the AE&FIs for the three case study farms is evaluated based on four-year average data. Partial data on annual agro-ecological and financial performance for each farm are given in Table 11. These data on agro-diversity, productivity, energy efficiency and financial indicators complemented the comprehensive information from the diagnosis process. Critical points identified at regional and farm scales, and the soil

Table 11. Agro-Ecological and Financial Indicators (AE&FIs) according to farm type (four-year period).

AE&FIs	Unit	Farm A 'Remedio'					Farm B 'La Sarita'					Farm C 'Vaquería 10'				
		1	2	3	4	Mean SD	1	2	3	4	Mean SD	1	2	3	4	Mean SD
Agro-ecological indicators																
Species richness	Margalef index	6.3	6.3	6.6	6.8	0.24	7.4	7.5	7.5	6.3	0.59	2.5	2.5	2.8	3.1	0.29
Diversity of production	Shannon index	2.5	2.2	2.5	2.6	0.17	2.4	2.3	2.2	1.9	0.22	0.3	0.3	0.3	0.3	0.03
Reforestation index	Shannon index	1.8	1.9	1.8	1.8	0.09	1.6	1.7	1.6	1.8	0.06	1.5	1.4	1.3	1.2	0.14
Milk yield	Mg ha^{-1} yr^{-1}	1.8	1.9	1.7	1.3	0.26	1.1	1.7	1.1	1.3	0.28	0.9	1.1	1.4	2.1	0.53
Milk yield/unit of forage area	Mg ha^{-1} yr^{-1}	2.4	2.5	2.3	1.7	0.36	1.7	2.7	1.7	2	0.47	0.9	1.1	1.4	2.1	0.53
Energy output	GJ ha^{-1} yr^{-1}	23.5	19	23.5	25.2	2.66	10.3	14.9	11	13.2	2.10	2.9	3.4	4.3	6.7	1.69
Protein output	kg ha^{-1} yr^{-1}	290	210	292	301	42.44	89	128	90	107	18.30	36	41	52	80	19.67
Total energy input	GJ ha^{-1} yr^{-1}	11.0	11.2	10.9	10.1	0.48	7.2	5.6	5.6	10.1	2.12	7.1	6.9	4.6	13.5	3.82
Human labour intensity	hr ha^{-1} d^{-1}	2.6	2.6	3.4	3.2	0.41	1.1	1.2	1.1	1.1	0.05	1.2	1.4	1.3	1.3	0.08
Energy cost of protein	MJ kg^{-1}	38	53	37	34	8.50	81	43	62	94	22.29	198	168	89	168	46.69
Energy efficiency	output $input^{-1}$	2.1	1.7	2.1	2.5	0.33	1.4	2.7	2	1.3	0.65	0.4	0.5	0.9	0.5	0.22
Organic fertilizer use	Mg ha^{-1}	5.2	4.4	4.8	3.7	0.64	1.9	3.1	2.5	1.3	0.77	–	–	–	–	0.00
Financial indicators																
Total value of production	Thousands CUP * ha^{-1} yr^{-1}	25.8	14.8	25.3	30.8	6.73	6.4	9.7	8.5	7.5	1.41	1.0	1.2	1.8	2.5	0.68
Value of crop production		6.7	5.9	6.5	7.3	0.58	3.5	5.5	4.9	3.9	0.91	0.1	0.1	0.1	0.3	0.10
Value of livestock production		19.1	8.9	18.8	23.5	6.17	2.9	4.3	3.6	3.6	0.57	1.0	1.1	1.7	2.2	0.56
Net production value		16.3	9.5	16	19.1	4.06	4.3	6.6	5.6	5.0	0.97	0.9	1.1	1.6	2.3	0.62
Total costs of production		5.1	4.8	5.9	5.9	0.56	1.7	1.7	1.7	1.9	0.10	0.9	0.8	1.0	1.2	0.17
Gross margin		11.1	4.8	10.1	13.2	3.57	2.6	4.8	3.9	3.1	0.96	0.04	0.3	0.6	1.1	0.46
Benefit-cost ratio		3.2	2.0	2.7	3.2	0.57	2.5	3.8	3.2	2.7	0.58	1.0	1.3	1.6	2.0	0.43

* CUP= Cuban Pesos; (24 CUP = 1CUC). CUC= Cuban Convertible Pesos (1CUC is equal to about 1€).

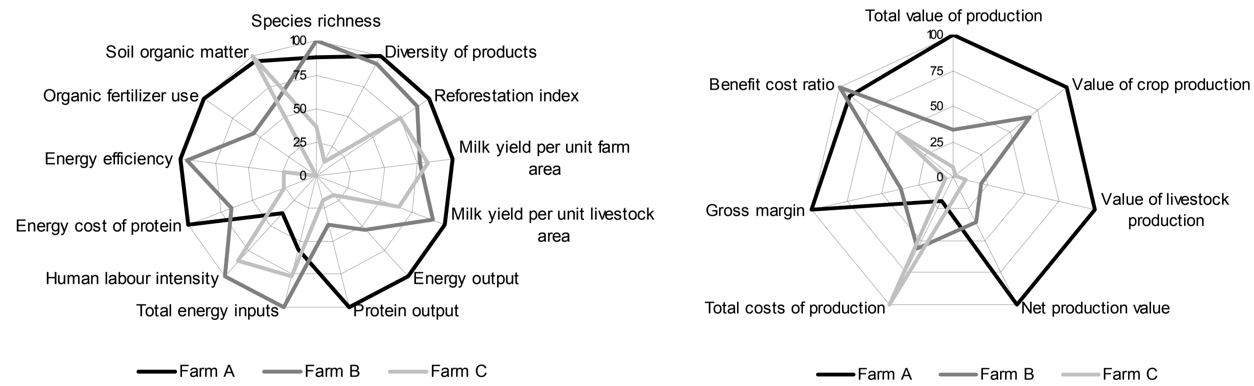
characterization for the three farms provide a multi-faceted framework for consistent multi-stakeholder decision-making on the 'best practices' that should be adopted to enhance productivity and to achieve sustainability of local farming systems.

Comparative analysis of the performance of the farming systems was presented in the form of amoeba diagrams for the AE&FIs (Figure 8), which increased understanding and facilitated interactive analysis, as they triggered joint discussions among the research team, the farmers and other stakeholders involved in the study. Each farm, with its own characteristics, attained each year a specific value for each AE&FI (Table 11), which allowed critical assessment of its performance for that specific year, as well as of the strategies for improving farm performance in the short and long(er) term (Figure 8).

Agro-diversity

The farm agro-diversity indicators were expressed as Shannon and Margalef indices (Gliessman, 2001; Figure 8), that take into account the contribution of each component of diversity and its distribution and/or its relative weight within the farming system's overall diversity. Similar to the results at experimental scale (Chapter 3), the degree of diversification was much higher in the two mixed farms than in the specialized farm, especially with respect to species richness and diversity of production. However, in the specialized farm, the indicator of species richness slightly increased across the years, although diversity of production and reforestation index did not show improvements (Table 11). In fact, in the course of the study, new species were introduced to this farm in order to improve animal feeding. Agro-diversity appears to positively correlate with the other AE&FIs as demonstrated in Chapter 4. Trees covered only 5 to 6% of the farm area in all farms. The large number of tree species in the mixed farms compared to the specialized farm (Figures 5 and 6), did not lead to substantially higher reforestation indices (Table 11), because the number of individuals for each species was not large enough (Figure 8). Changing the distribution of trees among the different species could substantially increase the reforestation index for all farms. Introduction of forage tree species in silvopastoral systems could increase the livestock production potential through improved feed availability and quality.

From diagnosis results, presentations during workshops and interactions with farmers and other stakeholders, it became clear that higher agro-diversity was strongly advantageous to farmers in the situation of scarcity of external inputs; however, these advantages in 'system quality' such as environmental conservation and biological regulation could not be explicitly quantified. Higher agro-diversity and greater functionality of its components (i.e. crop-livestock interactions) were mostly associated with higher yields, a higher degree of household food self-sufficiency, and higher



Agro-ecological indicator	Unit	Best value*	Financial indicator** (in kCUP ha^{-1} yr^{-1})	Best value*
Species richness	Margalef index***	7.5	Total value of production	24.17
Diversity of production	Shannon index***	2.4	Value of crop production	6.59
Reforestation index	Shannon index***	1.8	Value of livestock production	17.58
Milk yield per unit farm area	Mg ha^{-1} yr^{-1}	1.7	Net production value	15.23
Milk yield per unit forage area	Mg ha^{-1} yr^{-1}	2.2	Total costs of production	0.98
Energy output	GJ ha^{-1} yr^{-1}	22.8	Gross margin	9.79
Protein output	kg ha^{-1} yr^{-1}	273.0	Benefit-cost ratio	3.04
Labour intensity	hr ha^{-1} d^{-1}	1.1		
Total energy input	GJ ha^{-1} yr^{-1}	6.1		
Energy cost of protein	MJ kg^{-1}	40.0		
Energy use efficiency	GJ output GJ^{-1} input	2.1		
Organic fertilizer use	Mg ha^{-1} yr^{-1}	4.5		
Soil organic matter (SOM)	%	5.8		

Figure 8. Performance of agro-ecological and financial indicators (averaged over the four-year period 2002–2006) for the three case study farms. * The best values (100%) achieved by any of the three farms under study, averaged over the four year period. ** 1 € is about 1 CUC (Cuban Convertible Peso); 1 CUC = 24 CUP (Cuban Pesos). *** For calculation procedures of Shannon and Margalef indices see Gliessman (2001).

animal feed production. Highest four-year average values of agro-diversity achieved in the mixed farms, coincided with the highest values of land and labour productivity and energy use efficiency as well as with better financial results.

A primary constraint for cattle production in tropical countries such as Cuba is the variability in availability and quality of pastures and forages (Minson, 1971; Skerman and Riveros, 1992), as a result of fluctuations in climate (Funes, 1979). The most successful strategies in alleviating this constraint applied by local farmers have been those that optimally combined the various feed resources, based on species and varieties adapted to the local conditions. Mixed crop-livestock systems have been and are the backbone of agriculture in many regions of the world (Sumberg, 1998; Preston and Murgueitio, 1994; Devendra, 2007; Herrero et al., 2007). In addition to grazing resources, substantial quantities of crop by-products (residues), available throughout the year, can potentially be used as animal feeds (Renard, 1997). The results of this study confirm the potential of agro-diverse mixed crop-livestock systems to provide a wide range of opportunities to alleviate the feed constraint for animal production in the tropics.

Appropriate allocation of energy and nutrient resources at farm level, such as animal manure, crop residues, grazing resources, external inputs and labour, contributed to increases in productivity and efficiency (Schiere et al., 2002; Herrero et al., 2007; Tittonell, 2008). For example, composting all residues from crop and animal production transformed wastes into a fertilizer for crop production. Continuous experimentation, innovation and technology adaptation in diversified crop-livestock systems are needed to safeguard profitability, while maintaining or improving their resource base (Ewing and Flugge, 2004). The mixed farms in our study were designed in such a way that most available resources were used strategically, considering their availability throughout the year and their functionality.

Productivity and efficiency

Agricultural productivity is expressed here as the production of milk, energy and protein per unit of land area, while energy use efficiency is expressed as energy output per unit energy input, and as energy requirements per unit protein production. To bring agricultural products of very different nature under a common denominator, they are often expressed in monetary terms; however, other units can be used as a common denominator, such as nutrient (protein) or energy content. Farm productivity in terms of energy and protein output per unit area and the efficiency of conversion of energy inputs in these two components of human nutrition, are therefore measures of farm sustainability.

As in the previous studies at experimental and national scale (Chapters 3 and 4), in this study, inclusion of crops in a pasture-based livestock farm did not negatively affect milk production. Synergies within the complex farming system have resulted in more efficient use of on-farm resources. Higher farm production, associated with more efficient use of natural resources, biodiversity maintenance, and soil conservation as well as higher income-generation capacity and food self-sufficiency (Figure 8), are closely related to the technological change that has taken place in the conversion from a specialized farming system into a MFS.

High land productivity in terms of food production and energy output, low energy cost of protein production, and low input use per unit area were key factors in attaining high energy use efficiencies and low energy-protein ratios in the mixed farms. All indicators of productivity and efficiency, including energy and protein production per unit land area, were highest in the small-scale mixed farm A, despite the higher labour intensity and the higher energy input per unit of farmland (Figure 8). Moreover, energy cost per unit protein production (40 MJ per kg) was lowest in farm A, while two units of consumable energy were produced per unit energy input in production, similar to that in farm B. Although it was not our objective to analyse the time trends in AE&FIs, performance of farm C improved in the course of the four years (Table 11). Small changes in farm management, i.e. culling of old cows and structuring the herd in groups, as well as more efficient use of feed resources resulted in farm improvements. Milk yields more than doubled over the four-year period, with associated impacts on energy and protein output. In the 4th year, by decision of the Ministry of Agriculture, the farm started receiving concentrate feeds which doubled total energy input. The consequence was a deterioration in energy use efficiency in terms of energy cost of protein production and the ratio energy output/energy input and creation of a disincentive for any effort toward animal feed self-sufficiency.

In the specialized farm, the energy cost per kg of protein produced was about 160 MJ. The energy cost of protein production, in the form of meat and milk, in input-intensive specialized livestock systems in Cuba in the 1980s was typically over 100 MJ per kg. Funes-Monzote (1998) reported on the low energy use efficiency in these industrial systems (about 6 MJ invested per MJ output). In the United States, fossil energy input was 14 units per unit output for animal protein in the form of milk and 40 for beef (Pimentel, 2004). Combining productivity and energy use efficiency analyses provides added value to evaluation of sustainable development.

Labour

Labour intensity was by far highest in the small-scale mixed farm A, followed by C (medium-scale specialized) and B (medium-scale mixed) (Figure 8). Therefore, it appears that labour intensity is not only differentiated between mixed and specialized farming systems, but also contains a scale effect. Of course, labour intensity is also related to the productivity indicators. Land productivity was higher in mixed farms A and B, integrating crop and livestock production, than in the specialized farm. Hence, higher land productivity and energy use efficiency are not only the result of higher labour input, but also of the ability to exert effective control over key resources, defined by Sumberg et al. (2003) as farming system precision.

Hired labourers on the mixed farms were paid better than those on the specialized farm, thus farm work on a mixed enterprise is economically more attractive, though 'more complex and difficult'. In addition to their salaries, the workers received benefits in different forms. A frequent answer to the question of how difficult work on a mixed farm was for labourers was that they found it more interesting and motivating. They took part in more diverse activities, earned more, and participated in decision-making.

Finances

As a result of more diversified production, higher labour intensity and more intensive and efficient use of natural resources, farm A achieved higher land and labour productivity in monetary terms. However, farm B (five times larger in area) showed a slightly higher benefit-cost ratio due to the effects of the economies of scale (Figure 8). In general, financial indicators were more favourable for the mixed farms except for total costs of production. The low inputs in the specialized farm C, combined with the low expenses in salaries, resulted in production costs half of those in farm B and one fourth those in farm A (Figure 8). Financial indicators improved in the course of the study in farm C as a result of the higher income due to milk production increases associated with high concentrate inputs and other management measures; however, they were still far from the values achieved on the mixed farms (Table 11). Both mixed farms benefitted more from local sources of inputs; however, their operations were not subsidized as farm C was, and in many cases, inputs had to be purchased in the informal market at higher prices. High gross margins and elevated benefit-cost ratios in mixed farming make it much more profitable than specialized farming.

In previous studies (Chapters 3 and 4), the favourable financial results of mixed farms were influenced by the high prices received for agricultural products. Here we see that in farm A the value of animal production (17.6 kCUP ha^{-1} yr^{-1}) exceeded that of crops (6.6 kCUP ha^{-1} yr^{-1}) (Figure 8). This is the result of the high prices for pork (30–50 CUP kg^{-1}) and mutton (20–40 CUP kg^{-1}), due to the restriction to sell beef. In farm B, the value of crop production constitutes a larger share of total production (Table 11).

A recent increase in the price paid to farmers for milk and beef still does not bring those prices in line with those for crop products or non-restricted animal protein products. At the end of the year 2007, the producer price was increased from 1.00 to about 3.00 CUP (i.e. about 0.10–0.15 €) per liter of milk, but a price for pork of about 40 CUP kg^{-1} completely distorts any financial analysis. Change of production purpose (e.g. pork instead of milk) is not a possibility, since on the one hand dairy farmers are obliged to sell milk to the state and on the other hand such change would imply high costs (infrastructure, inputs, technical know-how, etc.) that are neither affordable, nor logical. However, inclusion of pork production as a sub-system within a mixed farming design, as in farm A, can greatly improve the financial situation of dairy farming systems, since feasible non-conventional systems for pork production are available (Preston and Murgueitio, 1994; Pérez, 1997; Domínguez, 2003). Financial analysis of a farming system in which 50 pigs in a conventional fattening system were combined with dairy production, following an agro-ecological farming system approach, showed high profitability (Funes-Monzote and Del Río, 2002). That system was characterized by dynamic use of local resources, combining crops, trees and livestock production. Biogas, organic manure (compost and worm humus) and animal feeds were some of the by-products of this mixed crop-livestock system.

5.2.3 Socio-economic analysis

Various studies have indicated the importance of social issues in the transition to sustainable agricultural production in Cuba (i.e. the role of farmers and researchers in innovation and institutional change and farmers' organizations) (Pérez Rojas et al., 1999; Sinclair and Thompson, 2001; Martin, 2002; Wright, 2005; Ríos, 2006). Since the socio-economic organization in Cuba is different from that in most other countries, analysis and interpretation of the organizational processes is difficult, and their possible application to other contexts is fraught with uncertainties. Recent work by Wright (2005) may help in understanding such socio-economic complexity. Most analyses tend to acknowledge the failure of the specialized, high-input model of agriculture in Cuba, and it is also generally agreed that in no other country has the collapse been so evident and dramatic (Chapter 2). Cattle husbandry in particular faces severe socio-economic constraints that have been thoroughly analysed by González et al. (2004) and Nova (2006). Although in Section 5.1 critical points were linked to socio-economic factors, it was not the aim of this study to elaborate on their analyses. However, a brief socio-economic analysis is performed as a basis for defining 'best practice' strategies for local conditions.

From a socio-economic perspective, livestock production is one of the more complex branches of the economy. Some specialists have argued that livestock production, due to its long cycles, was less suitable to adapt in the short term to changes at national scale, and therefore needs more time to recover from the collapse. However, after about 17 years, it is clear that new approaches for restoration of the sector are urgently needed, to replace the industrial, specialized, high external input model. Due to the centralized (state, formal) distribution of milk and meat, a large part of the population has difficulties accessing these products. One liter of milk per day is sold to all children up to seven years old and to sick people at a subsidized price of 0.25 CUP l^{-1}, while in the free market it is 2.00 CUC. With one CUC equal to 24.00 CUP, milk is about 200 times more expensive in the non-subsidized market. Therefore, it is hardly affordable for a large part of the urban population, earning about 15.00 CUP per day. Meat is also sold to the sick at a price of 1.50 CUP per kg and is priced at about 12.00 CUC per kg in the free market. Such imbalances completely distort any socio-economic analysis about the impact of the market on production. De-regulation of milk and meat marketing would help in improving farming systems, in creating incentives for increased production, as well as in achieving more affordable prices of these products, more in accordance with the purchasing power of the 'non-protected' part of the population. Increases in the price of milk powder in the international market to values exceeding 6 k\$US Mg^{-1} makes imports of about 60 M\$US, hardly covering the national demand, irrational. Policies that really provide incentives for production increases should be based on free market economic relationships. Guaranteeing provision of these products to the vulnerable sector of the population does not need to be threatened.

The social side of this study is as complex as it is impossible to capture in its full implications. Mixed farming could be an attractive solution for the difficult financial situation of the dairy sector, and although the strongest motivation for mixed farmers or contracted labourers was the high income compared to that in the specialized farms, performance of the study farms is not only influenced by technological and/or financial factors. Three main additional elements were identified as determining factors for success of mixed farms: (1) the capacity of farmers to take farming system decisions, (2) the involvement in innovation and experimentation, and (3) generation of sufficient income for a comfortable living (Figure 9).

Mixed farmers were active innovators and experts in agricultural and environmental interactions, and all stakeholders felt respect and curiosity for the knowledge of and the concepts managed by mixed farmers. In contrast, specialized farmers with less knowledge of traditional agricultural practices, were not as aware of innovation and experimentation as a means of agricultural improvement. As yield increases in low input systems in small- to medium-sized farms have been associated with innovative natural resource management, specialized farmers could benefit from education in traditional mixed systems. However, another factor to consider may be the need to break down the monotonous specialized farm infrastructure that generates little incentive to innovate.

In the amoeba diagram, based on the opinions of all stakeholders participating in the study, the relative importance is illustrated of different social indicators, identified in the diagnostic phase, affecting farming system performance for the three farm types (Figure 9). The high stability of labour in mixed farms A and B compared to farm C is directly associated with their 'high' wages. Moreover, farm labourers derive additional benefits from being involved in mixed farming (they often bring home food, saving money). Stronger participation, greater self-esteem, better housing and working conditions (Figure 9) all contribute to the increasing interest in diversified production. Access to training and farmers' associations (cooperatives) play only minor roles in promoting mixed farming. However, farmers having greater traditional knowledge are able to generate endogenous innovations, which are hardly influenced by access to 'formal' training, extension services or scientific knowledge.

Type of land tenancy is another important factor. In the mixed farms A and B under private land tenure, farmers were able to make decisions independently. However, economic and legal limitations such as low availability of capital, regulations for private land use and for commercialization of products and the lack of a decentralized market for inputs, strongly constrained the production possibilities. Combination of the benefits of the mixed farming approach with a more open agricultural policy would greatly help in the successful implementation of integrated strategies. Access to training and extension service activities is limited for all farm types. In the two organizations to which farms belong, the UBPC 'Factor Rojo' and the CCS 'Vicente

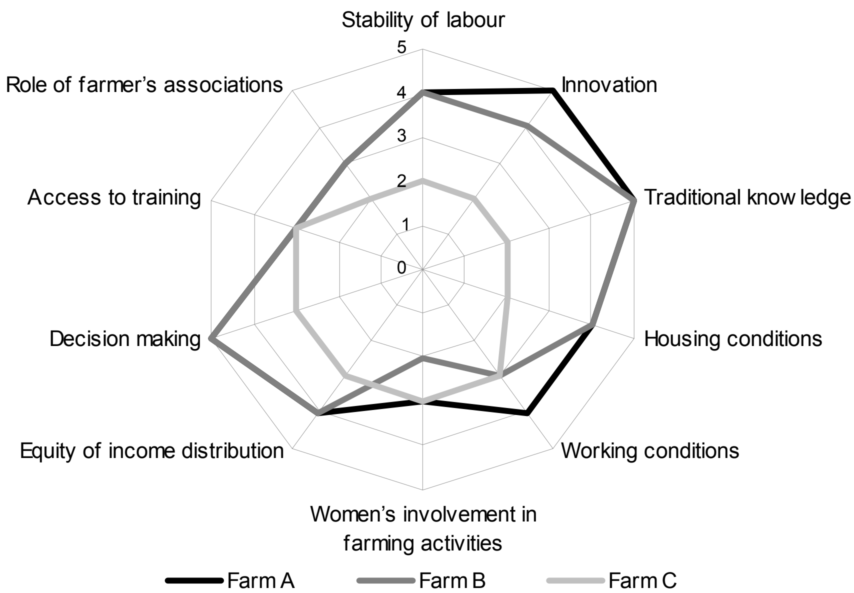


Figure 9. Identified social indicators for the three study farms.

Pérez Noa', meetings are organized to discuss administrative issues, but they rarely provide training or technical assistance. Training mostly takes the form of farmer to farmer exchange. This method has great potential, but it should be better organized by local institutions in charge of agricultural development activities (Holt-Giménez, 2002).

5.3 Identifying sustainable MFS strategies for local conditions

Identification of most suitable farming strategies for the local conditions of San Antonio de Los Baños was based on contributions from all stakeholders participating in the study. Proposed strategies target pre-defined aims of solving critical problems for farming systems in the region (see Table 3). Diagnosing the conditions under which dairy farming is being developed, understanding the reasons for moving towards more integrated crop-livestock production systems, and analysing their performance in a participatory way, should lead to identification of suitable MFS strategies for the local conditions. These strategies then will have to be translated into policies at municipal and national levels. Strategies were aggregated into five main areas of impact: (1) Farming System Agro-diversity, (2) Farm Productivity and Energy Use Efficiency, (3) Nutrient (re-)Cycling and Nutrient Balance, (4) Economic Feasibility and (5) Farmers' Empowerment and Decision-Making.

Farming System Agro-diversity

- Provide access to a diversity of crops, trees and forage species and to integrated crop-livestock technologies.
- Allocate 10–15% of the specialized dairy farm area to establishment of crops (cereals and pulses, vegetables, root and tuber crops). Expand the crop area, to the point where milk production starts to be negatively affected (weed-infested lands are available, first use these areas).
- Include a second farm animal component, such as chickens, swine and/or goats.
- Establish diverse feed sources (i.e. grass-legume associations, pure grass swards, forage trees) and use crop residues to cope with seasonal fluctuations in feed availability/quality.
- Adjust animal stocking rate to cover at least 75% of their feed requirements by on-farm production.
- Establish living fences and fruit trees.
- Establish a monitoring program for regular analysis of biodiversity indicators

Farm Productivity and Energy Use Efficiency

- Implement a mixed crop-livestock-tree farm design.
- Establish multi-cropping systems to increase the land equivalent ratio.

- Optimize energy use efficiency.
- Minimize the use of petrol and other non-renewable energy sources.
- Install forage choppers and grain mills to increase digestibility of fibrous animal feeds and to produce feedstuffs for small animals.
- Establish a monitoring program for regular analysis of energy use efficiency and productivity indicators.

Nutrient (re-)Cycling and Nutrient Balance

- Establish a crop rotation system aimed at maintaining high levels of SOM.
- Introduce an efficient nutrient management strategy based on effective nutrient recycling.
- Introduce leguminous N-fixing species (annual and perennial).
- Eliminate export of manure and avoid mining of soil fertility.
- Compost all manure combined with animal feed refusals and crop residues.
- Use green manure species within the multi-cropping systems.
- Establish a monitoring program for regular analysis of soil fertility indicators.

Economic Feasibility

- Focus on the use of locally available natural resources and minimize use of external inputs.
- Diversify farm production to increase income (i.e. increase diversity and quality of marketable products).
- Develop income-generating activities in addition to crop and livestock production.
- Organize at municipal level the necessary infrastructure to sell inputs directly to farmers.
- Increase added value through food and feed storage, transformation and packing.
- Use low-risk technologies and promote family farm labour by providing credit associated to family farming activities and create public funds for contract labour in peak labour periods.
- Adjust farm labour demands as much as possible to labour availability.
- Develop and adapt machinery and equipment for the conditions of diversified small-scale farming.
- Establish a monitoring program for regular analysis of financial indicators.

Farmers' Empowerment and Decision-Making

- Strengthen interaction among all stakeholders to promote farmer-to-farmer learning on crop-livestock integration (farmer field schools).

- Involve research institutions in farming system development projects.
- Encourage innovation towards system diversification (promote 'best practice' technologies adapted to small-scale farming).
- Improve farmers' well-being and increase farmers' income by subsidizing agricultural activities.
- Protect indigenous knowledge at risk of being lost.
- Improve decision-making capacity of farmers.
- Establish a monitoring program for regular analysis of socio-economic indicators.

These strategies should be implemented based on adaptive resource management approaches, where farm management, aimed at satisfying the needs in each stage of the conversion, is adapted in response to the values of the various indicators (Aarts, 2000). The new situation then represents the baseline for a new cycle of analysis that should be defined according to diagnoses for farms in the process of conversion to MFS.

6. Final remarks

Locally adapted mixed farming system alternatives were identified to guide the process of conversion towards more integrated and sustainable land use. The methodological framework developed allowed identification, in consultation with all local stakeholders, of the critical points constraining and the objectives to pursue in developing mixed farming systems in the region. Strategies aimed at realizing these objectives at farm and regional levels were also defined in a participatory process.

The physico-chemical properties of soils on the Havana-Matanzas plain have deteriorated in the course of the last one hundred years. One reason is the loss of soil organic matter in specialized crop farms (Hernández et al., 2006) and the decrease in biological activity (Rodríguez, 1998) due to intensive agricultural use, with insufficient attention for soil conservation. The anthropogenic influence was very intense in the period 1970–1990, when high-external input agriculture was practiced, characterized by intensive use of fertilizers, pesticides and heavy machinery. Furthermore, this agricultural model, highly dependent on external sources of inputs, did not focus on the locally available natural resources and thus, was inefficient from economic and energetic perspectives. As socio-economic conditions dramatically changed, there is a need for design of alternative farming (or land use) systems that are aiming at realization of a new set of objectives.

Results of this study show that in the Cuban context, in integrated crop-livestock systems locally available resources can be managed efficiently, so that reasonably high yields can be realized, while maintaining their quality, using low external input levels. In addition, the study confirmed that organic matter contents are generally high in soils that have been in grass for a long time, which, thus, form an excellent starting point for the development of mixed farming systems. Inclusion of the animal component, combined with judicious manure management, and planting of grasses, contributes to improvement of organic matter- and nutrient-depleted agricultural soils. Research that looks at longer-term developments in mixed crop-livestock systems in different spatio-temporal combinations is needed to identify the most appropriate technology alternatives for farmers in different agro-ecological and socio-economic environments. Strategies and technologies developed by innovative farmers in one region could serve as a model to identify appropriate solutions in other regions, at local and/or national scale.

Decentralization of decision-making in agriculture from large-scale cooperatives to small-scale family farms, diversification of production systems and improvements in food self-sufficiency cannot be achieved without changes in agricultural policies. Although the Cuban government has recently increased its efforts to promote these new developments, conceptual and methodological barriers still impede the technological, financial and socio-economic transition. In this context, the methodology developed in this study could serve as a model to support introduction of more sustainable farming systems. Four basic principles must guide the process: (1) decision-making at local level, with a high degree of autonomy, (2) establishing agro-diversity to increase revenues from livestock farming and reduce reliance on external inputs, (3) achieve food self-sufficiency, while guaranteeing efficient use of natural resources, and (4) improving rural livelihoods as a main impact of the transformation. Adoption of these four principles at local scale should positively impact at the national level.

Due to the reduced population in rural areas, the deteriorated infrastructure, and the lack of inputs and capital, many of the practices recommended for expanding small-scale integrated farming systems must be adopted judiciously. It will certainly need patience, dedication, and a good deal of time and effort to establish mixed crop-livestock farming at national scale. The infrastructure that still supports specialized farming, depending on external inputs, should be re-designed and adapted to new objectives that include increased land and labour productivity, also in economic terms, and environmental conservation. Many concepts and practices of integrated production could be introduced progressively into the conventional management systems, since mixed farming systems are increasingly associated with farming system intensification. Finally, new strategies, emerging from science and practice should be adapted in a participatory way (Vereijken, 1997).

Chapter 6

General discussion

In this chapter, we focus on emergent properties of and opportunities and constraints for the development of mixed crop-livestock farming systems (MFS) as a leading component in the transition towards sustainability in Cuban agriculture. By moving across scales of analysis, from experimental farms at small-scale via local conditions to country level, we will discuss environmental, economic and societal priorities in this transitional process. Feasibility and implications are discussed, as well as ways for adoption at a broader, nation-wide scale by focusing on local adaptation instead of technology generalization.

1. The context

In the period 1960–1990, the mainstream of the Cuban agricultural sector was characterized by industrial, intensive production technologies, dependent on external inputs, which ended abruptly at the beginning of the 1990s, as a consequence of the economic crisis associated with the collapse of the Soviet Union. Despite the acknowledged successes in the transition towards sustainable agriculture in Cuba since then (Rosset and Benjamin, 1994; Funes et al., 2002; Wright, 2005), it appears that the impact in terms of national food self-sufficiency is still limited. Notwithstanding the advances in the implementation of low-input technologies, including their socio-economic achievements, sustainable agriculture in Cuba is far from achieving its potential impact. In fact, the country at the moment imports about 50% of its food needs and only half of the suitable land is cultivated, thus dependence on external food sources is high and food security is permanently threatened. Responding to that situation, diversification, decentralization and the movement towards food self-sufficiency are major trends in Cuban agriculture. However, these developments must be systematically supported by science and policy to ensure a reliable outcome in terms of agriculture’s contribution to a viable economy. The Cuban economy has grown over the three year period 2004–2007 at an average rate of 10%, but if economic recovery is used as an argument to return to intensive, industrialized agriculture, sustainability and resource conservation will be threatened. Changes in Cuban agriculture, once driven by the dire necessity for input substitution, must now be guided by more conscientious and scientifically-driven policies that aim at development of an agricultural sector that combines production and conservation objectives.

The soaring world market oil and food prices of the last years emphasize the need for a new impulse to agricultural re-orientation by re-focusing the national priority on the substitution of food imports by home-grown food products (Castro, 2008; MINAG, 2008). In such scenario, mixed crop-livestock farming systems have much to contribute to the development of a Cuban sustainable agricultural model. In the period since the early 1990s, multi-stakeholder platforms of farmers, scientists and policy makers have been involved, at various locations in the country, in their design and implementation: Rural development strategies are being identified at the local level, technologies adapted to location-specific conditions and traditional indigenous and scientific knowledge are being integrated to arrive at more sustainable agricultural practices and best use of available resources.

Three main societal groups are involved in the design and implementation of such strategies:

- 'New' farmers (urban and rural) that emerged during the years of economic difficulties. Most of these farmers do not own the land, but have usufruct rights. Well-educated, these farmers had been qualified in other sectors of the economy; many as professionals, however with idealistic biases with respect to agriculture and a strong environmental conscience. They are innate innovators, able and willing to acquire, interpret and manage information in implementing and freely adapting highly diversified farming systems, characterized by complex interactions. They also have in many cases organizational skills, which is an important asset in implementing the transition process.
- Small traditional mixed farmers and their families who inherited and own the land, and preserved a significant body of traditional knowledge on the management of locally adapted-diversified farming systems. This peasant production model has been for the last 15 years, the example in the transition of Cuban agriculture.
- A growing number of members of UBPC[8] that implement diversified agricultural systems under decentralized management schemes. These members of cooperatives have gained experience in practicing low input methods of agriculture by imitating the small traditional farmers and bring with them knowledge on cooperative functioning.

The recent national policy statement, identifying agriculture as a priority and strategic sector for the future of the country (Castro, 2008), favours farming system diversification, decentralization of decision-making and a strong focus on food self-sufficiency. While writing these lines in the middle of 2008, new decisions are being taken towards continued decentralization of decision-making and modified land tenure regulations. The Ministry of Agriculture announced the dismantling of more than 100 'inefficient state enterprises', along with support for the creation of 2,600

[8] UBPC are production units with a cooperative structure, that farm state lands that were given, free of charge, to the cooperative in permanent usufruct (their average size is substantially smaller than that of the former state farms, that have been broken up to form the UBPC) (Martin, 2002).

new urban or peri-urban small farms and the distribution in usufruct of most non-utilized state lands, i.e. about 3 million hectares. Under these new regulations, decisions on the use of resources and local food production and commercialization strategies will be taken at municipal level, while the central government and the state enterprises will support farmers by providing the necessary inputs and services (MINAG, 2008).

2. Prototyping mixed farming systems

Mixed farming systems, mostly developed where external pressures and lack of land or inputs forced farmers in less favoured areas to adopt strategies based on a more rational use of natural resources (Altieri, 2002; Pretty et al., 2003; Ruben and Pender, 2004; Van Keulen, 2005), offer major opportunities for tropical regions in terms of sustainable farming system intensification and efficiency in resource use (Pretty et al., 2006; Giller et al., 2006; Herrero et al., 2007). Integrated crop-livestock systems could potentially become central components in addressing urgent environmental, economic and social limitations for sustainable agricultural development. Water and air pollution, extensive deforestation and depletion of soil nutrients through erosion and soil mining are some of the environmental threats associated with efforts to overcome hunger in developing countries. The challenge to agricultural research is to demonstrate that agro-ecosystem intensification and nature conservation are not mutually exclusive. Increases in agro-diversity may result in provision of important environmental services (Vandermeer et al., 1998; Tilman et al., 2001) and at the same time may lead to increases in system productivity (Tilman et al., 2002).

To operationalize the technological and environmental advantages of MFS for sustainable development, this thesis embraced the prototyping methodology (Vereijken, 1997; 1999). This methodology allowed us to assess the performance of specialized dairy farming systems (DFS) and MFS and identify feasible agricultural strategies, based on specific regional biophysical and socioeconomic conditions. An activity in Cuba, aiming at realizing objectives similar to those of prototyping, was the United Nations Development Program (UNDP) project, Sustainable Agriculture Networking and Extension (SANE), through the implementation of the so-called ‘agroecological lighthouses’. Carried out since 1995, the project combined various agro-ecological innovations in prototype farms as examples for the transition of Cuban agriculture to more sustainable practices (Treto et al., 1997; Altieri et al., 1998).

2.1 From small-scale experimental farms to countrywide validation

Although the development of model farms in experimental stations, without interaction with the socio-economic environment, has been criticized (Vietor and

Cralle, 1992), in this study it was considered as a useful procedure for ‘learning by doing’ how to study integrated farming systems. Many of the technologies applied in the mixed farm experimental prototypes had been successfully tested before in specialized trials, assessing agronomic performance. The whole farm analysis through agro-ecological and financial indicators was a prototyping effort to evaluate the relative role played by each technology component in farm level performance and to assess the consequences of conversion from DFS towards mixed farming (Funes-Monzote et al., 2008). Field days and educational activities, as well as discussions on specific themes were organized at the prototype experimental farms, where farmers and researchers interacted.

This model of experimentation and development of farming system ‘prototypes’ has not been exclusive to developing countries, aiming at efficient use of scarce resources. It has many similarities with the ‘De Marke’ project on dairy farming, initiated in 1992 in The Netherlands, with the aim to maintain land productivity, while reducing environmental problems by identifying best practices for nutrient management (Aarts et al., 1992; Aarts, 2000; Van Keulen et al., 2000). This approach has been also applied at the experimental farm of Wageningen University, Ir. A.P. Minderhoudhoeve at Swifterbant in Oostelijk Flevoland, The Netherlands (Oomen et al., 1998; Lantinga et al., 2004), in looking for desirable environmental effects of mixed farming systems.

The experimental farm prototypes presented in this thesis, that were part of the SANE project, address major environmental problems in Cuban agriculture identified by the Ministry of the Environment, i.e. loss of biodiversity, soil erosion and deforestation (CITMA, 1997). Moreover, other constraints of the specialized dairy sector were tackled, such as the low land and labour productivity, low economic returns, inefficient use of internal resources and low energy use efficiency. Indicators expressed at farming system level integrated the results of each technology applied to every single crop or livestock production activity. For example, the prototypes with 25 and 50% of the area allocated to arable cropping, evaluated during a six-year period, achieved protein outputs of 133 and 191 kg ha^{-1} yr^{-1} and energy outputs of 16.4 and 27.1 GJ ha^{-1} yr^{-1}, respectively. Energy cost of protein production was 2.3 times lower in both MFS prototypes than in the original specialized system, while energy use efficiency (output input^{-1}) was four-fold in the mixed prototypes.

The small scale at which this first stage of the research took place was not a limitation for generation, for the first time in Cuba, of relevant insights in agro-ecological and financial indicator performance for MFS systems that served as a starting point and reference for their further development (Monzote et al., 1999; Funes-Monzote et al., 2008).

After six years of monitoring small-scale prototype MFS, the most important question was whether their achievements could also be attained at a greater number of farms, varying in terms of size, stage of conversion to mixed farming and proportions of farm area allocated to arable cropping. Other emergent topics were how well farmers could manage such complex, multifunctional systems, whether the need for expertise would limit their implementation and to what extent the need for greater labour intensity would affect their performance.

The seven research teams that, in different parts of the country, participated in the study aiming at answering these questions, observed that the performance of the small-scale experimental mixed farms was repeated under commercial conditions, in diverse environments and in farms with diverse endowments (Monzote et al., 1999). On the basis of this sample of farms at national scale, we were able to analyse and compare the actual performance of three farm types, i.e. experimental mixed (MFe), commercial mixed (MFc) and specialized (DFS) under the different biophysical and socio-economic conditions of the country. Total energy output per unit farm area was on average four to six times higher on the mixed farms than on the specialized dairy farms and protein output three to four times. Milk yield per unit of forage land area was highest on MFe (2.4 Mg ha^{-1} yr^{-1}), followed by MFc (1.7), while it was much lower (0.7) on DFS. This study provided evidence for the advantages and disadvantages of converting specialized dairy farming systems into mixed farming systems and built consensus among a range of stakeholders. These results are relevant for policy makers having to deal with the formulation of rural development policies in setting priorities for attainment of specific objectives. However, methodologically, it was even more important that the prototypes appeared to be adapted to location-specific conditions, explicitly expressed in critical points identified by local stakeholders and aiming at goals achievable under the local biophysical and socio-economic conditions.

2.2 Local MFS strategies to guide the process of conversion towards more integrated and sustainable land use

In the San Antonio de Los Baños case study at local (municipal) scale, in addition to the objective of increasing farm productivity, other aims related to the environment, the efficient use of available resources and the adaptation of farming systems to local climatic conditions were targeted. The participatory action research process that was followed in the development of location-specific sustainable farming systems was characterized by a strong commitment to realizing the expectations of all stakeholders. The case study consisted of a cyclical procedure of design, implementation, monitoring, assessment and adaptation, with a focus on five guiding areas, defined in accordance with stakeholders' priorities (Funes-Monzote et al., 2002): (1) Farming System Agro-diversity, (2) Farm Productivity and Energy Use Efficiency, (3) Nutrient (re)Cycling and Nutrient Balance, (4) Economic Feasibility, and (5) Farmers' Empowerment and Decision-Making. The original farm designs played an important role as starting point in the optimization of crop-livestock interactions.

Various authors have stressed the necessity of including all relevant stakeholders in the design of technological innovations through participatory action research approaches (Pretty, 1995; López-Ridaura, 2005; Stilma et al., 2007; Van der Riet, 2008). The methodology applied in our case study was built on such participatory activities that stimulated the dialogue between local knowledge and scientific research to initiate social action towards natural resources management.

3. Towards decentralization and local food self-sufficiency

We have provided evidence that in Cuba currently land and labour productivity and energy use efficiency in small and medium-sized mixed farms in the private sector, where decision-making is highly autonomous, are appreciably higher than in the large-scale specialized farms. Hence, there is scope for substantial increases in production of the Cuban agricultural sector through transformation of the farm structure. The case study in San Antonio de Los Baños illustrates the use of a methodological platform for participatory identification of critical points and design of farming systems, adapted to the local biophysical and socio-economic conditions and the aspirations of local stakeholders.

Targeting food security and food self-sufficiency is probably the most important priority for local and central governments in Cuba and many other developing countries. In evaluating food self-sufficiency and food security, we use as indicator the proportion of the requirements of energy and protein (the two main components of the human diet) that can be met by local food production. Without overlooking the importance of continued increases in milk production in the original DFS as their social mandate, establishment of MFS has been shown to be a powerful strategy to increase production through improved nutrient (re)cycling and sustainable intensification. Differences in conversion efficiencies from light energy in crop and livestock products contribute to the observed differences in land productivity between specialized and mixed farming systems in terms of energy and protein.

An additional target that must be addressed by the policy makers at all spatial levels, is the reduction in negative environmental impacts of agriculture (CITMA, 1997). Work on reducing environmental impact of agriculture in countries of Europe, USA, Asia, Africa and Latin America, reflect the interest in the topic since the middle of the 1980s (NRC, 1989; Van Keulen et al., 1998; Nell, 1998; Ottaviani and Pastore, 2003). There is still increasing interest in and continuing research on the development of integrated solutions to problems faced by small-scale farmers, in particular for less-favourable, heterogeneous and dynamic environments (cf. Tittonell et al., 2006; 2007a). This is even more urgent in countries where increasing population pressure leading to resource shortages, and inappropriate agricultural practices have been combined with inadequate agricultural policies, as in Kenya (Tittonell, 2008). Conditions in Cuba are relatively favourable with abundant land, low population pressure, experience acquired in low-input technologies during the last 15 years, high levels of education and health of the population, as well as the conducive social and institutional organization that make conditions for development of the MFS model more favourable.

If the mixed systems presented in this thesis would be gradually adopted on 3 Mha (half of the land suitable for agriculture of Cuba), it would be possible to meet all the food needs of the Cuban population within a period of three years (Table 1). At this moment, the small farmers, on about 25% of the total suitable agricultural land (half of the total land currently cultivated) produce 65% of the total domestic food sales. The process of land re-allocation would probably lead to farm sizes varying from 20 to 50 ha, depending on type of production, intensification level, labour availability, proximity to markets, local population density and biophysical characteristics (soils, rainfall, temperature, seasonal variation, etc.). Small farmers operating at reasonable levels of land productivity and resource use efficiency currently cultivating about 1.5 Mha, would need to be monitored and certified, when realizing the objectives of such a programme. Such a transition will need a strong political commitment and a considerable capital investment for technology implementation, research and development activities, where communication and promotion of successful experiences will play an important role. Contrary to the classical top-down centrally planned strategies, location-specific analyses should lead to identification and implementation of the best practices.

Globalization of the world economy stresses the need for competitiveness in the international markets as driver for economic growth (Lipton, 2005). Following the prototype approach (Vereijken, 1999), MFS could play an important role, first in the short-term, as a step in sustainably meeting the food needs of the population, and secondly in the longer-term to ensure a steady re-integration of Cuba in its traditional food export markets. Large-scale adoption of MFS would make the Cuban agricultural system more resilient to extreme events (i.e. hurricanes, droughts, international conflicts or international crises that would hit the tourism sector, etc.). Diversified small-scale production systems and attention for environmental issues could serve as a starting point for a transition towards organic farming. Generating value-added agriculture products would allow small farmers to commercialize their products in the growing tourism sector and for export. Nature conservation and support to the growing sector of small family farms could create conditions for emergence of agro-tourism and other complementary activities that would generate income to invest in the rural areas to improve infrastructure and the living standard of the rural population.

Table 1. The potential of a national conversion programme in Cuba towards sustainable food self-sufficiency by MFS implementation on 3 Mha.

Indicator	Unit	First year	Second year	Third year
Milk production per unit forage area *	Mg ha^{-1} yr^{-1}	0.8	1.2	1.5
Predominant situation **				
Crop proportion	%	10–20	20–30	30–50
Farm size	ha	–50	20–40	–20
Years since conversion	yr	1–2	2–3	+ 3
Energy output	GJ ha^{-1} yr^{-1}	8	10	12
Protein output	kg ha^{-1} yr^{-1}	80	100	120
Energy input ***	GJ ha^{-1} yr^{-1}	5	4	3
Number of people that can be fed ****				
Energy	$\times 10^6$	6.6	8.1	9.9
Protein	$\times 10^6$	9.6	12.0	14.4
Energy efficiency	Output $input^{-1}$	1.6	2.5	4

* About 1.5 Mha (i.e. half of the 3 Mha) would be directly devoted to forage production and the remainder for arable crop production.

** The numbers for each of the three variables considered (crop proportion, farm size and years since conversion) refer to a plausible situation (>50% of the total area in farming) for each stage of the transition to mixed farming. Reference data were obtained from the different chapters of this thesis.

*** The energy inputs for the first and second year are 20-30% higher than the values presented in Table 5, Chapter 4.

**** For calculation of the total edible energy and protein produced on-farm, data from Ensminger et al. (1994) and Garcia-Trujillo (1996) were used, updated with information from Gebhardt et al. (2007). For energy and protein requirements for human consumption, information supplied by FAO/WHO/UNU (1985) and Porrata et al. (1996) was applied.

4. Scope for future research

In the debate on sustainable farming system, intensification mixed crop-livestock farming has been identified as a promising technology. Blackburn (1998) mentions three main factors in favour of MFS: (i) maintenance of soil fertility through recycling of nutrients and through the introduction of rotations, including various crops, forage legumes and trees or through fallowing, whereby grasses and shrubs are re-established; (ii) maintenance of soil biodiversity, minimization of soil erosion, water conservation and provision of suitable habitats for birds; and (iii) optimal use of crop residues. If the stalks are incorporated directly into the soil, they act as a nitrogen trap, exacerbating nutrient deficiencies. However, there are few studies in which all these interactions are analysed in relation to the socio-economic environment.

Major changes in the energy sector, when the sources of fossil fuel become depleted, may constrain the development of intensive (energy-dependent) livestock systems (Leng, 2002; Leng and Preston, 2003). That would threaten the environmental, economic and social sustainability of the highly inefficient conventional-specialized production systems (Pimentel, 1997; 2004) and call for intensification alternatives based on greater use of natural resources. Another major future challenge is increasing the insight in the interactions of ecosystem processes and abiotic factors in the dynamics of diversified agro-ecosystems. In this thesis, we have highlighted several times the influence of agro-diversity on the performance of mixed farms; however, more research is needed to quantify the relations.

Low population density in the countryside is considered a constraint for the development of MFS that are highly labour-intensive. However, labour intensification in Cuba is a reliable and sustainable measure to alleviate the constraints of capital shortages and to re-populate rural areas, if these become more attractive and profitable though agricultural activities and services like agro-tourism and environmental protection. Environmental measures require substantial labour, especially to rehabilitate large land areas that have been deforested, eroded and/or invaded by weedy species. Therefore, the search for diversified systems that ideally combine low requirements for external inputs and adaptability to variable labour supply with acceptable levels of productivity and efficiency deserve priority.

There is still limited understanding of the dynamic and complex inter-relations in low-input agro-diverse smallholder farming systems in heterogeneous and diverse ecological, economic and social environments. Inter-disciplinary studies should be initiated on different crop-livestock systems, using participatory and demand-driven approaches in close interaction with local stakeholders. In practice this means that researchers should become part of inter-disciplinary and multi-stakeholder teams that generate new insights in system design and implementation. A promising research method for such studies is the establishment of prototype farms adapted to the specific conditions of a given area. Further research on dynamic, participatory and multifunctional prototyping could contribute substantially to farmer's interactions with researchers in looking for 'best practices' in solving location-specific critical points.

For analysis of data collected in such research, statistical methods should be developed which are more suitable for assessment of such complex integrated systems (Tanaka et al., 2008). Such methods should also draw from relevant economic, social and financial disciplines. Optimization of crop-livestock integration, both within farms and between farms, opens a wide spectrum for research on more efficient use of locally available resources, for instance through optimization of land use patterns. This should lead to identification of the drivers of self-regulation and complementarities in MFS resulting in improved (re)cycling of nutrients and energy. In the final analysis, these technical aspects should be considered against the background of household objectives, while taking into account market demands and financial and social conditions as a step towards establishment of sustainable farming systems.

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Appendices

Appendix 1

Data collection form for farm monitoring

Date_______ Informant ___________Compiler ____________

1. - Identification and localization of the farm
Name: _______________Province: ________________Municipality: __________________

2. - Area of the farm (U.M. hectares)
Total area_____ Agricultural_____ Installations or facilities______
Pastures____ Native____ Improved ____ Legumes____ Fodders____ King grass ____ Sugar cane____ Others____
Crops____ Bush and scrubland____ Spiny woody weeds (marabú/aroma) ____

3. - Productive purpose (mark x)
Dairy__ Beef__ Agriculture__ Mixed__ Non defined__ Other__

4. - Type of organization (mark x)
State farm__ Individual private producer__ UBPC__ CPA__ CCS__ Usufruct__
Name of the organization: Agriculture enterprise, UBPC, CPA, CCS___________________________

5. - Infrastructure (mark x)
Roads, paths and minor roads of access: G___ F___ B___; Type of installations: Typical__ Rustic__

Shade warehouse	Yes___	No___	Conditions G___ F___ B___
Dairy stable	Yes___	No___	Conditions G___ F___ B___
Maternity stable	Yes___	No___	Conditions G___ F___ B___
Animal trap	Yes___	No___	Conditions G___ F___ B___
Bath	Yes___	No___	Conditions G___ F___ B___
Dung heap	Yes___	No___	Conditions G___ F___ B___
Warehouse	Yes___	No___	Conditions G___ F___ B___

6. - Water availability and sufficiency for the animals (mark X)
Water supply for drinking and other uses: G___ F___ B___
Water supply: Pipe___ Dam___ River___ Tanker___ Reservoir___ Well___ Wind mill___

7. - Energy source (mark X) Electricity____ Wind____ Fuel____ Biogas____

8. - Equipment and implements (mark X or number if necessary)
Tractor___ Trailer___ Oxen teams___ Horse cart___ Tanker___ Forage mill ____ Grain mill___ Plough___ Furrower___
Slasher ___ Mechanical milking___

9. - Condition of fences and chutes (mark X) G___ F___ B___
Number of paddocks___; Type of fences: Barb wire ____Electric ____Others____

10. - Intensity of hand labour (U.M. number of workers and hours)
Total workers linked to the production ___ Technicians___ Managers___ Daily average working hours ___ Total hours/man/day ___
Working hours/year ___

11. - Animal and plant biodiversity (U.M. number of crops or economic raisings)

ANIMAL SPECIES					
Species	No. of heads		Species	No. of heads	
PLANT SPECIES					
Crops	Area		Pastures and Forages	Area	
TREE SPECIES					
Fruit trees	No. of individuals	Forestry	No. of individuals	Living fences	No. of individuals

12. - Total productions and yield

Product (animal or plant)	Area (ha)	Production (t)	Yield (t/ha)

13. - Destination of the main productions
Livestock

Destination	Milk	Beef	Others
Industry (milk)			
Animal consumption (milk)			
Self supplying (milk)			
Agricultural market			
Others (robbery, accident, deterioration)			

Agriculture

Main products	*Agricultural market*	State market	*Self consumption*

14. - Bovine herd
Replacement rising in the farm (mark x): Yes___ No___; Composition of total herd (U.M. number of animals):
Females: Cows___heifers___ yearlings___ calves (4-12 months) ___ calves (0-4) ___
Males: Oxen___ Bulls ___ Young bulls___ yearlings___ calves (4-12 months) ___ calves (0-4) ___
Average composition per year of the herd under production (U.M. number of animals):
Number of total cows____ in milk____ Maternity____ Average lactation period ____

15. - Cattle reproduction
Predominant breed (mark x): Holstein__ Zebu __ Brown Swiss__ Jersey __Creole __Crosses__ Others___
Mating method used (mark x): Insemination __Natural service__
If insemination, please, answer: Average reproductive stage per year of the herd
Pregnant___ Inseminated___ Recent___ Empty___
Average age of the herd (years) ___ Average number of births of the herd___ Average age of mount or reproduction (years) ___ Average age at first birth (years) ___ Number of births per year (January - December) ___

16. - Nutrient recycling
Cattle manure utilization for fertilizing crops or forages Yes___ No___ Amount (tons) ______

Organic manure making

Type	Amount	Type	Amount
Compost		Bio digester mud	
Worm humus		Liquid residuals	
Cured cattle dung		Others	

Use of crop residues for animal feeding

Type	Amount (tons)	Type	Amount (tons)

17. - Productive inputs (All of them coming out of the farm, energy as well as for feeding purposes)

Type	Amount	Type	Amount
Concentrates		Fuel diesel (l)	
Filtercake/Molasses/Urea		Electricity (Kw/h)	
Forages		Chemical fertilizer	
Molasses		Herbicides	
Others			

18. - Farm economy (U.M. Cuban Pesos)
Expenses: Total__ Salary__ Inputs and materials __ Feeding __ Services __ Amortization __Others__ *Incomes:* Total __State market selling __ Agricultural private market selling __ Other selling __
Incomes by: Livestock products _____ Agriculture products _____

Selling prices of the products

Product	Unit price for sale	Product	Unit price for sale

19. - Social indicators
Related to labour as an average

Indicator	Direct	Technical	Managers
Average age of workers			
Qualification of labour force			
Primary			
Secondary			
High school and technicians			
University			
Average years of experience			
0-5 years			
5-10 years			
More than 10 years			

Job incentives (mark x): Yes___ No___

Due to (mark x):

a) Living conditions: G__ F__ B__

b) Incomes: Satisfactory __ Not satisfactory__

c) Working conditions: G__ F__ B__

d) Economically linked to results: Yes__ No__; by incentives__ Payment__

e) Personal relations with the working collective: G__ F__ B__

f) Other motivations____

Domestic services (mark x): Electricity ___ Aqueduct water____ Gas___

Appendix 2

Market price information utilized for financial analysis. Adapted from Funes-Monzote et al. (2008).

Product	Price ($CUP\ kg^{-1}$)		Product	Price ($CUP\ kg^{-1}$)	
	Free market	MINAG, 2003		Free market	MINAG, 2003
Anonna	11.1	5.6	Milk, cow [1]	-	1.0*
Avocado	10.0	2.0*	Milk, goat	10.0	2.5
Banana "burro"	2.0	1.3*	Mung bean	22.2	13.3*
Banana "fruit"	4.0	2.0*	Okra	11.1	4.4*
Beans	22.2	13.3*	Onion	22.2	11.1*
Cabbage	2.5	0.5*	Onion leaves	6.7	2.2*
Carrot	11.1	3.3*	Orange	4.0	1.3*
Cassava	5.3	1.8*	Oregano	4.4	2.2
Celery	6.6	3.3	Papaya	8.9	4.0*
Cherimoya	6.3	3.1	Parsley	4.4	2.2
Corn, grain	8.9	4.4*	Passion fruit	10.0	5.0
Coriander	4.4	2.2	Peanuts	22.2	11.1
Cucumber	8.9	2.2*	Pineapple	15.4	4.4*
Custard apple	6.3	3.1	Plantain	10.0	4.9*
Chickpea	26.4	13.2	Pumpkin	4.4	1.1*
Egg plant	11.0	5.5	Radish	33.3	2.2*
Eggs, chicken (u)	2.0	1.5	Red pepper	11.1	6.7*
Garlic	16.7	8.3	Rice	11.0	7.7
Garlic leaves	6.7	3.3	Rollinia	6.7	3.3
Grapefruit	2.2	1.1	Seville orange	3.3	1.7
Green bean	11.1	4.4*	Soursop	10.0	5.0
Guava	8.9	5.6*	Spinach	6.7	3.3
Honey	13.30	6.7	Sweet potatoes	5.3	1.6*
Lemon	5.0	3.5*	Swiss chard	5.0	2.2*
Lettuce	11.1	3.3*	Taro	8.8	7.0
Mamey (Sapote)	15	5.0	Water melon	6.7	2.2*
Mango	11.1	1.3*	Yam	6.7	4.4*
Meat, beef	-	2.1*			
Meat, buffalo	-	2.1	Flowers [2]		
Meat, chicken	44.4	22.2	Dahlia	12.0	1.5
Meat, duck	44.4	22.2	Gladiolus	18.0	2.5
Meat, lamb	50.6	25.3	Zinnia	5.0	0.2
Meat, pork	45.0	22.5	Dianthus	10.0	0.9
Meat, rabbit	45.0	22.5	Callistephus	7.0	0.5
Milk, buffalo	-	1.0*	Marigold	5.0	0.2

Note: Top retailers prices with an * were published as controlled by MINAGRI (2003) due to the high demand of food products. Prices without an * were taken from the free market regulated by offer and demand, located at 19 street and B, Vedado, Havana.

1) Cow and buffalo milk and meat are only sold at regulated (state) markets and in the black market at least at double of its price; 2) Flowers sold in dozens at state prices. Since 1993 until 2004 three currencies, the Cuban peso (CUP), the Cuban convertible peso (CUC) and the U.S. dollar were used in Cuba. In 2004, the U.S. dollar was withdrawn from circulation. One CUC is equal to 1.08 US$ and to 24 CUP. At the time of the data collection of the study ended (2003–2004), 1 € was about 1 CUC. Currently it is about 1.3 CUC. Salaries in Cuba are paid in CUP, which has 24 times less value than the CUC, this situation creates many uncertainties in financial analysis. Social services are obtained without payment or at low costs.

Appendix 3

Conversion factors and energy equivalences for direct and indirect inputs used for calculations.

Direct			Indirect		
Input	Unit	MJ unit^{-1}	Input	Unit	MJ unit^{-1}
Diesel	litre	38.7	Fertilizer (N)	kg	51.5–61.5
Gasoline	litre	3.4	Fertilizer (P)	kg	1.7–12.6
Human labour	hr	1.0	Fertilizer (K)	kg	5.0–11.5
Animal labour	hr	5.9–9.2	Organic fertilizer*	kg	0.3
Electricity	kW h	3.6	Herbicide	kg	238
			Insecticide	kg	184
			Machinery	kg	88

Source: García-Trujillo, 1996.
* Energy expended in manipulation and preparation of 1 kg of organic fertilizer.
1 joule (J) = 0.2388 cal (World Energy Council).

Appendix 4

Recommended energy and protein intake (daily base) for the Cuban population. Adapted from: Porrata et al., 1996 and FAO/WHO/UNU, 1985.

Activity level	Age	Male		Female	
		Energy (MJ)	Protein (g)	Energy (MJ)	Protein (g)
Light	18–30	11.2	80	8.7	63
	30–60	10.9	78	8.7	63
	> 60	9.1	65	7.9	56
Moderate	18–30	12.6	90	9.8	71
	30–60	12.3	88	9.8	71
	> 60	10.3	74	8.9	64
Intense	18–30	14.0	101	10.9	78
	30–60	13.7	98	10.9	78
	> 60	11.4	82	9.8	71
Very intense	18–30	15.4	110	12.0	86
	30–60	15.0	108	12.0	86
	> 60	12.6	90	10.8	77

Appendix 5

Fruit and vegetable products and their protein and energy content (edible part) utilized for calculations of energy and protein production.

Vegetable product	Scientific name	Protein (g 100g^{-1})	Energy (MJ kg^{-1})	Non-edible (%)
Annona, sour sop	*Annona muricata*	1.0	2.8	45
Annona, sweet sop	*Annona squamosa*	2.1	3.9	45
Avocado	*Persea americana*	2.2	5.0	33
Banana fruit	*Musa spp.*	1.1	3.7	36
Banana plantain	*Musa spp.*	1.3	5.1	35
Beans, black	*Phaseolus vulgaris*	21.3	14.2	–
Beans, broad bean	*Vicia faba*	26.1	14.3	–
Beans, chickpea	*Cicer arietinum*	19.3	15.3	–
Beans, lima	*Phaseolus lunatus*	21.5	14.1	–
Beans, mungo	*Vigna mungo*	25.2	14.3	–
Beans, white	*Phaseolus vulgaris*	23.4	13.9	–
Beans, yellow	*Phaseolus vulgaris*	22.0	14.4	–
Cabbage	*Brassica oleracea*	1.3	1.0	20
Carrots	*Daucus carota*	0.9	1.7	11
Cassava	*Manihot esculenta*	1.4	6.7	20
Cherimoya	*Annona cherimola*	1.7	3.1	21
Coconut	*Cocos nucifera*	3.3	14.8	48
Corn. dry grain	*Zea mays*	9.4	15.3	–
Corn, fresh grain	*Zea mays*	3.2	3.6	–
Cowpea	*Vigna unguiculata*	23.5	14.1	–
Cucumber	*Cucumis sativus*	0.7	0.7	3
Eggplant	*Solanum malongena*	1.0	1.0	19
Garlic	*Allium sativum*	6.4	6.2	13
Garlic leaves	*Allium chinense*	1.8	1.2	–
Grapefruit	*Citrus paradisi*	0.6	1.3	50
Green bean	*Phaseolus vulgaris*	1.8	1.3	12
Guava	*Psidium guajava*	2.6	2.9	–
Leek	*Allium ampeloprasum*	1.5	2.6	56
Lemon	*Citrus limon*	1.1	1.2	47
Lettuce	*Lactuca sativa*	1.4	0.6	36
Mamey	*Pouteria sapota*	1.7	3.6	35
Mango	*Mangifera indica*	0.5	2.7	31
Millet	*Panicum miliaceum*	11.0	15.8	–
Okra	*Abelmoschus esculentus*	2.0	1.3	14
Onion bulb	*Allium cepa*	1.1	1.7	10
Onion leaves	*Allium fistulosum*	1.8	1.4	4
Orange	*Citrus sinensis*	0.9	2.0	27
Papaya	*Carica papaya*	0.6	1.6	33
Passion fruit	*Passiflora edulis*	2.2	4.1	48
Peanuts	*Arachis hypogaea*	25.8	23.7	–
Pepper, green	*Capsicum annuum*	0.9	0.8	18

Appendix 5. (Continued)

Vegetable product	Scientific name	Protein (g 100g^{-1})	Energy (MJ kg^{-1})	Non-edible (%)
Pepper, red	*Capsicum annuum*	1.0	1.3	18
Pigeon peas	*Cajanus cajan*	7.2	5.7	52
Pineapple	*Ananas comosus*	0.5	2.1	49
Potatoes	*Solanum tuberosum*	2.6	2.4	–
Pumpkin	*Cucurbita spp.*	1.0	1.1	30
Radish	*Raphanus sativus*	0.7	0.7	10
Rice	*Oriza sativa*	6.6	15.1	–
Sweet potatoes	*Ipomoea batatas*	1.6	3.6	28
Sesame	*Sesamum indicum*	17.7	24.0	–
Soybean	*Glycine max*	36.5	18.7	–
Soybean, green	*Glycine max*	13.0	6.1	–
Spinach	*Spinacia oleracea*	2.9	1.0	28
Sunflower	*Helianthus annuus*	20.8	24.5	–
Swiss chard	*Beta vulgaris*	1.8	0.8	8
Taro	*Colocasia esculenta*	1.5	4.7	14
Tomatoes, green	*Lycopersicon esculentum*	1.2	1.0	9
Tomatoes, mature	*Lycopersicon esculentum*	0.9	0.8	9
Watermelon	*Citrullus lanatus*	0.6	1.3	48
Yam	*Dioscorea spp.*	1.5	4.9	14

Source: USDA National Nutrient Database for Standard Reference. Release 20 (Gebhardt et al., 2007).

Appendix 6

Animal products and their protein and energy content (edible part) utilized for calculation of energy and protein production.

Animal product	Protein ($g\ 100g^{-1}$)	Energy ($MJ\ kg^{-1}$)	Non-edible (%)
Eggs, chicken (44 g)	12.6	6.0	12
Eggs, duck (70 g)	12.8	7.8	12
Eggs, goose (144 g)	13.9	7.8	13
Eggs, quail (9 g)	13.1	6.6	8
Eggs, turkey (79 g)	13.7	7.2	12
Honey	0.3	12.7	–
Meat, beef.	20.7	6.5	45
Meat, buffalo	20.4	4.1	47
Meat, chicken	20.9	7.2	27
Meat, duck	11.5	16.9	27
Meat, lamb	16.7	4.0	55
Meat, pork	16.9	11.0	25
Meat, rabbit	20.1	5.7	35
Milk, buffalo	3.8	4.0	–
Milk, cow	3.2	2.5	–
Milk, goat	3.6	2.9	–

Sources: USDA National Nutrient Database for Standard Reference. Release 20 (Gebhardt et al., 2007); García-Trujillo (1996).

Summary

Current developments in the Cuban agricultural sector are influenced by three fundamental drivers: diversification, decentralization, and the aim for national food self-sufficiency. These drivers emerged at the beginning of the 1990s as a consequence of the economic crisis associated with the collapse of the Soviet Union. In the period 1960–1990, the mainstream of the Cuban agricultural sector was characterized by specialized-industrial, intensive production technologies, depending on external inputs. This industrial model led to spectacular increases in land and labour productivity, but was inefficient and harmful to the natural environment. Chapter 2 sets the scene by examining the history of Cuban agriculture with emphasis on the period of highly intensive systems and the transition to low external input systems following the economic crisis in the early 1990s. The fact that Cuba has been the only country in the world to experience such a dramatic downward shift in intensity, may turn out to be a blessing in disguise, when it serves as a starting point for development of sustainable agriculture at national scale.

Since the early 1990s technological innnovations have been introduced in all branches of agriculture and scientific institutions have tested environmentally sound technologies on a large scale. However, these efforts have focused on substitution of inputs, and the bio-physical and socio-economic aspects of agricultural development are insufficiently integrated. Therefore, this thesis focuses on the analysis of mixed crop-livestock farming systems (MFS), based on agro-ecological principles and participatory methods of dissemination that might serve as effective tools in the transformation of Cuban agriculture.

This thesis deals with conceptual, practical and methodological issues that constrain a comprehensive transition from specialized dairy farming systems (DFS) to MFS at farm and regional levels. An ECOlogical Framework for the Assessment of Sustainability (ECOFAS) was applied as a methodology for evaluating, monitoring, comparing, analysing and designing land use management strategies for the conversion of DFS into MFS. A three-stage research programme included: (i) assessment of the consequences of conversion of a ‘Low External Input’ DFS into MFS by monitoring the dynamics of 15 Agro-Ecological and Financial performance Indicators (AE&FIs) in two mixed systems with 25 (C25) and 50% (C50) of the area devoted to arable cropping, respectively, over a six-year period at experimental scale (stage 1), (ii) examining whether the results from the small-scale experiment were also attainable under commercial conditions, and for a larger number of farms (stage 2) and (iii) identification of alternative local MFS strategies to guide the process of conversion

towards more integrated and sustainable land use (stage 3), using San Antonio de Los Baños municipality as an example.

The study at small scale (stage 1) demonstrated that land and labour productivity, energy use efficiency, and economic profitability all were higher in the mixed farm prototypes (Chapter 3). The converted farms were characterized by the presence of large numbers of plant and animal species, i.e., about six times those at the beginning of the study. Grain crops, root and tuber crops, vegetables, tree species, and new pasture and forage species were introduced in the mixed farm prototypes. This higher diversity led to a more even supply of animal feed in the course of the year, thus alleviating the constraint associated with fluctuating pasture production, one of the major problems in tropical livestock production systems. Milk yield per unit farm area was somewhat higher than before the conversion to mixed farming, although up to 50% of the total farm area was used for arable and horticultural crops, and, therefore, not directly for producing animal feed. This increase was the result of the introduction of various innovations in the mixed farms, e.g., cultivation of high-yielding perennial forages, grass-legume associations and leguminous trees and use of crop residues as animal feed, resulting in more and better quality animal feed throughout the year. This also led to a higher milk yield per unit forage area after conversion, i.e. from 1.8 Mg ha^{-1} to 3.1 and 4 Mg ha^{-1} in the two mixed systems. In terms of total production (expressed in energy and protein, the two main components in human nutrition), yield of livestock products in both mixed farms exceeded the yields in year zero, on top of which crop products were harvested. The highest energy (27.1 GJ ha^{-1} yr^{-1}) and protein (191.3 kg ha^{-1} yr^{-1}) outputs, achieved at farm C50, were associated with high 'additional' crop production.

Increasing the efficiency of input use was identified as an important objective in the management of the prototype mixed farms. Energy input linearly decreased with time since establishment on farm C25, while on farm C50 it showed a parabolic pattern with a maximum in year three, in parallel to the labour inputs, and was lower on farm C25, due to the smaller area devoted to crop production. Realizing high levels of production, at the lowest possible level of inputs would indeed be an advantage under the conditions of scarcity and uncertain supply of inputs prevailing in Cuba. This is a strong argument in favour of continuation of MFS, even when the economic situation improves. Higher energy use efficiencies on the mixed farms were primarily the result of transformation of part of the pasture area into arable crops, leading to an increase in total energy output and a reduction in total energy input. Energy use efficiency showed an increasing trend with time after conversion on both farms, associated with decreases in total energy input, mostly in the form of human labour, while energy output was stable. The two mixed farms achieved higher gross margins and higher benefit-cost ratios than the specialized farm. This was the result of the inclusion of arable food and feed crops, the high productivity per unit farm area, and the higher prices for crop products than for milk and meat. Therefore, increasing whole farm income by selling crop products in regions where arable farming is possible, might be a suitable strategy for supporting cattle operations and making dairy farming more attractive.

In scaling-up the analysis from prototype experimental farms to commercial farms, Chapter 4 examined characteristics of a range of current specialized DFS and MFS in Cuba to determine their efficiency in the process of food and feed production (stage 2). The central question was whether the favourable results of MFS obtained in the small-scale experiment were also attainable in larger commercial farms. Therefore, data were collected on 93 farms from around the country for a period of one year. The farms were classified according to four predictor variables: farm type (TY), years since conversion from DFS to MFS (YC), crop (=non-grassland) proportion (CP) and farm size (FS). Farms were compared based on 12 pre-selected Agro-ecological Indicators (AEIs), using analysis of variance and Tukey's HSD tests. The twelve AEIs were also subjected to a principal components analysis and related to the four predictor variables by reduced-rank regression, also known as redundancy analysis. Three farm types were distinguished: mixed farming experimental (MFe), mixed farming commercial (MFc) and specialized dairy farming (DFS). Classification of farming systems on the basis of the four predictor variables TY, YC, CP and FS showed strong associations among them. In fact, the characteristics of mixed farms overlapped with those of small- and medium-scale farms, and with the ones with greater crop proportions. Mixed farms, with significantly greater bio-diversity, were also more productive, more energy-efficient and showed better nutrient management than the specialized DFS, which performed poorly in terms of the selected AEIs.

The results showed that multi-factorial hypotheses can be tested using reduced rank regression (redundancy analysis), as a comprehensive method of representation and analysis of multiple interactions. The biplots allowed us to detect and demonstrate the impact of complex interactions between indicators measured and predictor variables defined. Furthermore, by combining the results from linear associations between two factors, with the visual outcome of redundancy analysis, we obtained more comprehensive explanations for farming system performance. Such a combination of methods (uni-variate and multi-variate) enabled an integrative analysis and interpretation and appeared a powerful tool for analysis of agro-diverse environments in our study.

Multi-functionality and bio-diversity appeared to be two primary features of the mixed farm types of small size (≤ 10 ha). Higher proportions of farmland dedicated to

cash crops resulted in higher values for the farm agro-diversity indicators, i.e. species richness, diversity of production and reforestation index. The farms with the highest CP (45–75%) achieved the highest values of productivity in terms of milk yield per unit forage area (3.6 Mg ha^{-1} yr^{-1}), energy output (21.3 GJ ha^{-1} yr^{-1}) and protein output (141.5 kg ha^{-1} yr^{-1}). Farms with high CP demanded a three times higher human labour intensity than those with medium CP, which in turn was more than twice that for farms with low CP. Higher CP was associated with lower energy cost of protein production, higher energy use efficiency, and higher organic fertilizer doses.

In stage 3, mixed and specialized farms in San Antonio de Los Baños municipality were characterized (Chapter 5). Agro-ecological and financial indicators, as well as others related to soil and socio-economic issues were tested as in previous stages. Application of participatory research methods allowed inclusion of farmers' perspectives in the definition of sustainability goals within strategies for the development of MFS at regional level. The results of a comprehensive six-step cyclical process of farm diagnosis, characterization and comparison provided evidence of the advantages of mixed farming systems over specialized farming systems under low-input agriculture conditions. Local stakeholders (farmers, researchers, extension workers and representatives of the Ministry of Agriculture in the municipality) identified critical points which led to definition of alternative strategies for agriculture in the region as a way to operationalize sustainability. These strategies focused on overcoming the current technological, environmental and socio-economic constraints for livestock farming systems in the region.

Three main societal groups are involved in the application of such strategies: (a) 'new' farmers (urban and rural) that emerged during the years of economic difficulties, (b) small traditional mixed farmers and their families who inherited and own the land, and preserved significant traditional knowledge on the management of locally adapted-diversified farming systems, and (c) a growing number of members of UBPC, production units with a cooperative structure, that farm state lands that were given free of charge to the cooperative in permanent usufruct.

Our results showed that in comparing different systems, the issue is not simply one of high or low input, specialization or diversification, but that farming system-specific characteristics and the way in which inputs and agro-diversity are interrelated and managed also are at stake. We found that in low external input agriculture, when comparing specialized and mixed farming systems, the latter achieved higher levels of food production and higher energy and protein production, as a result of more efficient use of available resources on farm (or locally). The unique position of the Cuban agricultural sector, both, nationally and internationally, provides a context in which these results are highly relevant. High oil prices, climate change and high prices for

food in the international markets, combined with national awareness of the necessity to substitute food imports for nationally grown food, as well as the recent government decision to make all unproductive land available for cultivation, open a wide spectrum of possibilities for adoption of the alternative technologies. Diversification, decentralization and movement towards food self-sufficiency are major trends in Cuban agriculture. However, these trends must be translated into systematic and consistent policies to ensure reliable and sustainable production, as well as agriculture's contribution to a viable economy.

Samenvatting

Huidige ontwikkelingen in de Cubaanse agrarische sector worden gestuurd door drie fundamentele bewegingen: diversificatie, decentralisatie en het streven naar nationale zelfvoorziening in voedsel. Deze bewegingen ontstonden kort na 1990 naar aanleiding van de economische crisis, die het gevolg was van de val van de Sovjet Unie. Tussen 1960 en 1990 werd de Cubaanse agrarische sector grotendeels gekenmerkt door gespecialiseerde, geïndustrialiseerde en intensieve productiesystemen, die afhankelijk waren van invoer van grondstoffen uit het buitenland. Dit industriële model leidde tot een spectaculaire toename in land- en arbeidsproductiviteit, maar was inefficiënt en schadelijk voor het milieu en de omgeving.

In Hoofdstuk 2 wordt de geschiedenis van de Cubaanse landbouw beschreven, met name de periode met zeer intensieve systemen en de transitie naar lage-input systemen na de economische crisis. Het feit dat Cuba het enige land ter wereld is dat een zo dramatische val in intensiteit van landbouwproductiesystemen heeft doorgemaakt kan echter ook beschouwd worden als een kans om duurzame landbouw te ontwikkelen op nationale schaal.

Sinds 1990 zijn technologische innovaties geïntroduceerd in alle agrarische sectoren, en onderzoeksinstellingen hebben op grote schaal milieuvriendelijke technologieën getest. Echter, deze inspanningen waren vooral gericht op vervanging van de externe inputs, en de bio-fysische en socio-economische aspecten van agrarische ontwikkeling zijn hierbij onvoldoende geïntegreerd. Daarom heeft dit promotieonderzoek zich gericht op de analyse van gemengde (integratie van akkerbouw en veeteelt) landbouwproductiesystemen (MFS), gebaseerd op agro-ecologische principes en gebruikmakend van participatieve voorlichtingsmethoden, welke mogelijk effectieve middelen zijn om een transformatie van de Cubaanse landbouw tot stand te brengen.

In deze thesis worden conceptuele, praktische en methodologische aspecten behandeld die van belang zijn bij een grootschalige overgang van gespecialiseerde melkveehouderijsystemen (DFS) naar MFS op bedrijfs- en regionaal niveau. Een ecologisch raamwerk voor beoordeling van duurzaamheid (ECOFAS) is toegepast als methode voor het ontwerpen, implementeren, monitoren, vergelijken, evalueren en analyseren van strategieën bij de omschakeling van landgebruik van DFS naar MFS. Het onderzoeksprogramma bestond uit drie fasen: i) vaststellen van de consequenties van het omschakelen van ‘laag extern input’ DFS naar MFS door het monitoren, gedurende een periode van 6 jaar, van 15 Agro-Ecologische en Financiële Indicatoren (AE&FIs) in twee gemengde systemen met 25 (C25) en 50% (C50) van het land in

gebruik voor akkerbouwmatig geteelde gewassen in rotatie op experimentele schaal (fase 1); ii) nagaan of de resultaten van de kleinschalige gemengde systemen ook gerealiseerd kunnen worden onder commerciële omstandigheden en voor een groter aantal bedrijven (fase 2), en iii) identificeren van alternatieve lokale MFS strategieën om het proces van omschakeling naar meer geïntegreerd en duurzamer landgebruik te begeleiden (fase 3); dit aan de hand van het voorbeeld van de gemeente San Antonio de Los Baños.

De studie op kleine schaal (fase 1) toonde aan dat land- en arbeidsproductiviteit, efficiëntie van energiegebruik en economische winstgevendheid allemaal hoger waren in de gemengde bedrijfssystemen (Hoofdstuk 3). De omgeschakelde bedrijven werden gekenmerkt door een grote verscheidenheid aan planten- en diersoorten, namelijk zesmaal meer dan aan het begin van de studie. Granen, wortelgewassen, groenten, bomen, en nieuwe grasland- en ruwvoedersoorten werden geïntroduceerd in de gemengde bedrijfssystemen. Deze grotere diversiteit leidde tot een constanter aanbod van diervoeders in de loop van het jaar, waardoor de beperkingen van de in de loop van de tijd, onder invloed van de weersomstandigheden (m.n. neerslag), sterk fluctuerende graslandopbrengsten grotendeels konden worden opgeheven. Deze variabiliteit in graslandopbrengsten is één van de grootste problemen in tropische dierlijke productiesystemen. Melkproductie per eenheid bedrijfsoppervlakte steeg ten opzichte van de periode voor de omschakeling naar het gemengde systeem, ook al werd tot 50% van het totale bedrijfsoppervlak beteeld met gewassen die niet direct als diervoeders werden gebruikt. Deze toename was het resultaat van het introduceren van diverse innovaties op de gemengde bedrijven; bijvoorbeeld het verbouwen van hoogproductieve meerjarige ruwvoeders, mengsels van grassen en vlinderbloemigen, vlinderbloemige bomen en het gebruik van gewasresten als diervoeders. Dit resulteerde in een kwalitatief en kwantitatief betere voedervoorziening gedurende het hele jaar. Per eenheid oppervlak aan ruwvoeders nam de melkproductie toe van 1.8 Mg ha^{-1} (DFS) tot 3.1 (C25) en 4 Mg ha^{-1} (C50) in de twee gemengde systemen. Wat betreft de totale productie (uitgedrukt in energie en eiwit, de twee belangrijkste componenten van menselijke voeding) werden de hoogste opbrengsten aan energie (27.1 GJ ha^{-1} jr^{-1}) en eiwit (191.3 kg ha^{-1} jr^{-1}) op bedrijf C50 behaald, dat ook de hoogste productie van de akkerbouwmatig geteelde gewassen realiseerde.

Het verhogen van de gebruiksefficiëntie van inputs werd geïdentificeerd als een belangrijke doelstelling in het management van het prototype gemengd bedrijf. In de loop van de tijd verminderde de energie input lineair op bedrijf C25, terwijl deze op bedrijf C50 een parabolisch patroon vertoonde met een maximum in het derde jaar. De arbeidsinzet liep parallel met de input aan energie en was lager op bedrijf C25 vanwege het kleinere areaal in gebruik voor akkerbouwgewassen. Het realiseren van hoge productieniveaus bij een zo laag mogelijk niveau van externe inputs is een voordeel in de situatie van Cuba met schaarste aan en onzekere beschikbaarheid van externe inputs. Dit is een sterk argument om MFS verder te promoten, zelfs wanneer de economische situatie verbetert. De hogere efficiëntie van energiegebruik op de gemengde bedrijven was voornamelijk het resultaat van de omzetting van een deel van het grasland in bouwland, wat leidde tot een toename in totale energieproductie en meestal tot een afname in aanvoer van energie. De efficiëntie van energiegebruik nam op beide gemengde bedrijven toe met de tijd na het omschakelen. Dat was een gevolg van het feit dat het totale energiegebruik afnam, voornamelijk in de vorm van menselijke arbeid, terwijl de productie van energie stabiel bleef. De twee gemengde bedrijven behaalden hogere marges en betere opbrengsten/kosten verhoudingen dan het gespecialiseerde bedrijf. Dit was het resultaat van het opnemen van akkerbouwgewassen in de rotatie, de hogere productiviteit per eenheid bedrijfsoppervlakte en de hogere prijzen voor akkerbouwgewassen dan voor melk en vlees. Daarom is het verhogen van het totale bedrijfsinkomen via het verkopen van akkerbouwproducten, in regio's waar akkerbouw mogelijk is, een geschikte strategie om rundveebedrijven te ondersteunen en de melkveehouderijsector aantrekkelijker te maken.

Voor het opschalen van prototype proefbedrijven naar commerciële bedrijven is in Hoofdstuk 4 een analyse gemaakt van de kenmerken van een groot aantal gespecialiseerde DFS en MFS in Cuba, om de efficiëntie van voedsel- en voederproductie te bepalen (fase 2). De centrale vraag was of de gunstige resultaten van de kleinschalige MFS ook haalbaar waren op grotere commerciële bedrijven. Hiervoor zijn gedurende één jaar gegevens verzameld van 93 bedrijven, verspreid over het hele land. De bedrijven werden geclassificeerd op basis van vier karakteristieken: bedrijfstype (TY), lengte van de periode na omschakeling van DFS naar MFS (YC), het aandeel akkerbouw (= niet-grasland) op het bedrijf (CP) en bedrijfsgrootte (FS). De resultaten van de bedrijven werden vergeleken aan de hand van twaalf Agro-Ecologische Indicatoren (AEIs), gebruikmakend van de variatietest en Tukey's HSD test. De twaalf AEIs werden ook onderworpen aan een Principale Componenten Analyse (PCA) en gerelateerd aan de vier klassificatiekarakteristieken via een reduced-rank regressie, beter bekend als redundatieanalyse (redundancy analysis). Drie bedrijfstypes werden onderscheiden: gemengde proefbedrijven (MFe), gemengde commerciële bedrijven (MFc) en gespecialiseerde melkveebedrijven (DFS). Classificatie van de bedrijfssystemen op basis van de vier voorspellende variabelen TY, YC, CP en FS toonde sterke onderlinge correlaties aan. Zo bleken de kenmerken van gemengde bedrijven grotendeels samen te vallen met die van kleine en middelgrote bedrijven, en met die van bedrijven met een hoog aandeel akkerbouwland.

Gemengde bedrijven, gekenmerkt door een significant grotere biodiversiteit, vertoonden daarnaast een hogere land- en arbeidsproductiviteit, een hogere efficiëntie van energiegebruik, en beter mineralenbeheer dan de gespecialiseerde DFS, die slecht presteerden met betrekking tot de geselecteerde AEIs.

Deze resultaten tonen aan dat multi-factoriële hypothesen goed getest kunnen worden met redundatieanalyse als een samenvattende methode om verschillende interacties te analyseren en te presenteren. De biplots boden de mogelijkheid om complexe interacties tussen gemeten indicatoren en voorspellende variabelen te identificeren en te illustreren. Bovendien verschafte de combinatie van lineaire associaties tussen twee factoren en de visuele resultaten een goed inzicht in de prestaties van bedrijfssystemen. Deze combinaties van methoden (uni-variabele en multi-variabele) leidden tot een geïntegreerde analyse en interpretatie en bleken een krachtig hulpmiddel te zijn voor analyse van agro-diverse systemen.

Multifunctionaliteit en biodiversiteit bleken de twee belangrijkste kenmerken te zijn van de kleinschalige (≤ 10 ha) gemengde bedrijven. Het gebruik van grotere delen van het bedrijfsoppervlak voor akkerbouwgewassen resulteerde in hogere waarden van de indicatoren voor agro-biodiversiteit op het bedrijf, soortenrijkdom, diversiteit van productie en herbebossingsindex. De bedrijven met de hoogste CP (45-75%) realiseerden de hoogste melkproductie per eenheid ruwvoeroppervlakte (3.6 Mg ha^{-1} jr^{-1}), en de hoogste energie- (21.3 GJ ha^{-1} jr^{-1}) en eiwitproductie (141.5 kg ha^{-1} jr^{-1}). Op bedrijven met een hoge CP was de menselijke arbeidsinzet driemaal zo hoog dan op bedrijven met een intermediaire waarde voor CP, die op hun beurt meer dan het dubbele gebruikten ten opzichte van bedrijven met een lage CP. Een hogere CP was geassocieerd met lagere energiekosten voor eiwitproductie, hogere efficiëntie van energiegebruik en toediening van hogere doses organische mest.

In fase 3 werden gemengde en gespecialiseerde bedrijven in de gemeente San Antonio de los Baños geanalyseerd (Hoofdstuk 5). Net als in de vorige fasen, werden met name agro-ecologische en financiële indicatoren gerelateerd aan bodem en socio-economische karakteristieken, geanalyseerd. Het toepassen van participatieve onderzoeksmethoden in deze studie maakte het mogelijk de perspectieven van boeren mee te nemen in het bepalen van duurzaamheidsdoelen binnen strategieën voor de ontwikkeling van MFS op regionaal niveau. De resultaten van een alomvattend cyclisch proces bestaande uit zes stappen met betrekking tot bedrijfsdiagnose, karakterisering en vergelijking van bedrijfsresultaten, toonden duidelijk de voordelen van gemengde systemen ten opzichte van gespecialiseerde systemen onder low-input omstandigheden. Lokale stakeholders (agrariërs, onderzoekers, mensen van de voorlichtingsdienst, en vertegenwoordigers van het Ministerie van Landbouw uit de gemeente) identificeerden kritieke punten, die als basis dienden voor het formuleren van alternatieve strategieën om de landbouw in de regio te ontwikkelen als een manier om duurzaam ondernemen concreet te maken. Deze strategieën richtten zich op het opheffen van de huidige technologische, ecologische en socio-economische beperkingen voor ontwikkeling van een duurzame veehouderij in de regio.

Drie belangrijke sociale groepen zijn betrokken bij het ontwikkelen en toepassen van de strategieën: a) 'nieuwe' agrariërs (in de stad en op het platteland) die gedurende de economisch moeilijke jaren begonnen zijn met het opzetten van landbouwbedrijven, b) kleine traditionele gemengde agrariërs met hun familie, die het land hebben geërfd en in eigendom hebben, en belangrijke traditionele kennis hebben bewaard met betrekking tot het beheer van lokaal aangepaste en diverse landbouwsystemen, en c) een groeiend aantal leden van UBPC's, productieeenheden met een coöperatieve structuur, met land dat in bezit is van de staat, maar gratis voor langere tijd aan de coöperatie in bruikleen is gegeven.

Onze resultaten hebben aangetoond dat bij het vergelijken van verschillende landbouwproductiesystemen niet simpelweg hoge of lage input, specialisatie of diversificatie, aan de orde is, maar dat bedrijfsspecifieke karakteristieken en de manier waarop externe inputs en agrarische diversiteit interacteren en beheerd worden, ook belangrijke bijdragen leveren. We vonden bij het vergelijken van gespecialiseerde melkvee- en gemengde lage-input systemen, dat de laatste systemen hogere niveaus van voedsel-, eiwit- en energieproductie wisten te behalen, als resultaat van het efficiënter benutten van de beschikbare bronnen op het bedrijf (of in de regio). De unieke positie van de Cubaanse landbouw, zowel nationaal als internationaal, vormt een context waarin deze resultaten zeer relevant zijn. Hoge olieprijzen, klimaatverandering, hoge voedselprijzen op de internationale markten, gecombineerd met de nationale bewustwording van de noodzaak om voedselimporten te vervangen door nationaal geproduceerd voedsel, naast de recent genomen overheidsbeslissing om al het onproductieve land beschikbaar te stellen voor productie, openen een breed spectrum aan mogelijkheden om de alternatieve technologieën toe te passen. Diversificatie, decentralisatie en bewegingen richting zelfvoorziening voor voedsel zijn grote trends in de Cubaanse landbouw. Echter, deze trends moeten vertaald worden in systematische en consistente beleidsmaatregelen om betrouwbare en duurzame productie te verzekeren en om de landbouw bij te laten dragen aan een levensvatbare economie.

Resumen

Los avances actuales del sector agrícola cubano están influenciados por tres factores fundamentales: la diversificación, la descentralización y la búsqueda de la autosuficiencia alimentaria, los cuales emergieron a inicios de los años 90 como consecuencia de la crisis económica asociada al colapso de la Unión Soviética. En el período 1960-1990 la agricultura cubana se caracterizó por el empleo de tecnologías de producción intensivas, especializadas y dependientes de insumos externos. Este modelo industrial permitió espectaculares incrementos de la productividad de la tierra y del trabajo, sin embargo, resultó ser ineficiente y nocivo al medio ambiente. En el Capítulo 2 de esta tesis se examina la historia de la agricultura cubana y se hace énfasis en las consecuencias de los sistemas altamente intensivos, así como en la transición hacia otros de bajos insumos externos con posterioridad a la crisis de los años 90. El hecho de que Cuba haya sido el único país en el mundo en experimentar un cambio tan dramático en la intensidad de la producción, podría convertirse en una bendición en medio de la desgracia, en tanto ha servido como punto de partida para el desarrollo de una agricultura sostenible a escala nacional.

Desde comienzos de los años 90 se han introducido innovaciones tecnológicas en todas las ramas de la agricultura y las instituciones científicas han evaluado tecnologías alternativas a gran escala. No obstante, estos esfuerzos se han centrado en la sustitución de insumos, mientras los aspectos físicos y socio-económicos del desarrollo agrícola no se han integrado suficientemente. Por lo tanto, esta tesis concentra la atención en el análisis de los sistemas mixtos ganadería-agricultura (MFS), basados en principios agroecológicos y métodos participativos de diseminación que pueden servir como herramientas efectivas para la transformación de la agricultura cubana.

Este estudio aborda elementos conceptuales, prácticos y metodológicos que limitan la verdadera transición de los sistemas ganaderos especializados (DFS) en MFS a nivel de finca y regional. Se aplicó un marco ecológico para la evaluación de la sostenibilidad (ECOFAS) con el objetivo de evaluar, monitorear, comparar, analizar y diseñar estrategias de uso de la tierra para la conversión de DFS en MFS. Un programa de investigación en tres etapas incluyó: i) la evaluación de las consecuencias de la conversión de DFS con 'Bajos Insumos Externos' en MFS mediante el monitoreo de la dinámica de 15 indicadores de desempeño agroecológico y financiero (AE&FIs) en dos sistemas mixtos con 25 (C25) y 50% (C50) del área dedicada a cultivos agrícolas, respectivamente, durante un período de seis años a escala experimental (etapa 1); ii) el examen de los resultados experimentales obtenidos a pequeña escala y la manera en que estos podrían ser alcanzados también bajo condiciones comerciales y para un

mayor número de fincas (etapa 2); y iii) la identificación de alternativas locales de sistemas mixtos para guiar el proceso de conversión hacia un uso más integrado y sostenible de la tierra (etapa 3), tomando como ejemplo el municipio San Antonio de los Baños.

El estudio a pequeña escala (etapa 1) demostró que la productividad de la tierra y la fuerza de trabajo, el uso eficiente de la energía, y la rentabilidad económica fueron en todos los casos más elevados en los prototipos de fincas mixtas (Capítulo 3). Las fincas convertidas se caracterizaron por la presencia de un alto número de especies de plantas y animales, cerca de seis veces superior que al inicio del estudio. En los prototipos de fincas mixtas se introdujeron nuevas especies de granos, raíces, tubérculos, vegetales, árboles, pastos y forrajes. Este incremento de la diversidad condujo a un suministro incluso mayor de alimentos para los animales durante el año, aliviando así las limitaciones asociadas con la fluctuación en la producción de pastos, uno de los grandes problemas de los sistemas ganaderos tropicales. Los rendimientos de leche por área de la finca fueron superiores a los obtenidos antes de la conversión a sistemas mixtos, aunque hasta un 50% del área total de la finca se destinó a cultivos agrícolas y hortícolas, por lo que no estuvo directamente vinculada a la producción de alimento animal. Este incremento se debe a la introducción de varias innovaciones en las fincas mixtas, como el cultivo de forrajes perennes de alto rendimiento, la asociación de gramíneas y leguminosas, y el uso de los residuos de cosechas como alimento animal, resultando en mayor disponibilidad y mejor calidad de estos alimentos todo el año. Ello también derivó en rendimientos de leche por unidad de área de forraje superiores después de la conversión, desde 1.8 Mg ha^{-1} hasta 3.1 y 4 Mg ha^{-1} en los dos sistemas mixtos. En términos de la producción total (expresada en energía y proteína, los dos componentes principales de la nutrición humana), el rendimiento de los productos ganaderos en ambas fincas mixtas excedió a los del año cero, sin contar las producciones extra de cultivos. Los mayores niveles de energía (27.1 GJ ha^{-1} $año^{-1}$) y de proteína (191.3 kg ha^{-1} $año^{-1}$), logrados en al finca C50, estuvieron asociados con altas producciones agrícolas “adicionales”.

El incremento de la eficiencia en el uso de los insumos se identificó como un objetivo importante en el manejo de los prototipos de fincas mixtas. En la finca C25 el empleo de insumos energéticos disminuyó linealmente con el tiempo desde su establecimiento, mientras que en la finca C50 mostró un patrón parabólico con el máximo en el tercer año, en correspondencia con el incremento de la fuerza de trabajo, y fue inferior en la finca C25 debido a que en ésta el área dedicada a la producción agrícola fue menor. Alcanzar altos niveles de producción con la menor cantidad de insumos posibles, sería una verdadera ventaja bajo las condiciones que prevalecen en Cuba de escasez e incertidumbre en cuanto a los suministros externos. Este es un fuerte argumento a favor de la continuación de los MFS, incluso cuando la situación económica mejore. La mayor eficiencia energética de las fincas mixtas fue resultado, primeramente, de la transformación de parte del área de pastos en cultivos, lo que derivó en un incremento de la energía que sale del sistema y una reducción en la que entra. La eficiencia energética mostró una tendencia al aumento con el tiempo a partir de la conversión en ambas fincas, asociada a la disminución de la energía total que entra al sistema, fundamentalmente como fuerza de trabajo, en tanto la energía que sale se mantuvo estable. Las dos fincas mixtas alcanzaron mayores beneficios brutos y mejor relación costo-beneficio que la finca especializada como consecuencia de la inclusión de cultivos, la alta productividad por unidad de área de finca, y los precios superiores de los cultivos con respecto a la leche y la carne. Por lo tanto, incrementar los ingresos de la finca con la venta de productos agrícolas en regiones donde ello sea posible, puede ser una estrategia adecuada para apoyar las actividades ganaderas y hacer la producción de leche más atractiva.

Al escalonar el análisis de los resultados obtenidos en fincas experimentales prototipo a fincas bajo condiciones comerciales, el Capítulo 4 examina las características de una serie de DFS y MFS en Cuba para determinar su eficiencia en el proceso de producción de alimento para humanos y para el ganado (etapa 2). La cuestión central radicó en comprobar si los resultados experimentales obtenidos a pequeña escala pueden lograrse en fincas mayores, a escala comercial. Para ello se colectaron datos de 93 fincas de todo el país durante un año. Estas fincas fueron clasificadas de acuerdo con cuatro variables predictivas: tipo de finca (TY), años desde la conversión de DFS en MFS (YC), proporción de cultivos (=no pastos) (CP) y tamaño de la finca (FS). Las fincas se compararon a partir de 12 Indicadores Agro-Ecológicos (AEIs) preseleccionados, utilizando análisis de varianza y pruebas HSD de Turkey. Los 12 AEIs también fueron sujetos a un análisis de componentes principales y se relacionaron con las cuatro variables predictivas mediante análisis de redundancia *(reduced-rank regresión).* Se distinguieron tres tipos de fincas: mixtas experimentales (MFe), mixtas comerciales (MFc) y especializadas en producción de leche (DFS). La clasificación de los sistemas de producción sobre la base de las cuatro variables TY, YC, CP y FS mostró fuertes asociaciones entre ellas. De hecho, las características de las fincas mixtas coincidieron con las de pequeña y mediana escala, y también con las de mayores proporciones de cultivos. Las fincas mixtas, con una biodiversidad significativamente superior, fueron más productivas, tuvieron mayor eficiencia energética y mostraron mejor manejo de los nutrientes que las especializadas DFS, cuyo desempeño en los indicadores seleccionados fue pobre.

Los resultados mostraron que hipótesis multifactoriales pueden ser evaluadas mediante análisis de redundancia como un método preciso para representar y analizar múltiples interacciones. El uso de gráficos biplots permitió detectar y demostrar el impacto de las interacciones entre los indicadores medidos y las variables predictivas definidas. Pero además, al combinar los resultados de las asociaciones lineales entre dos factores con el resultado visual del análisis de redundancia, se obtuvieron explicaciones más puntuales sobre el desempeño de los sistemas agrícolas. Tal combinación de métodos (univariado y multivariado) posibilitó estudiar e interpretar con mayor integración los resultados, como una potente herramienta para el análisis de los ambientes agro-diversos propios de este estudio.

La multifuncionalidad y la biodiversidad parecen ser los dos rasgos fundamentales de las fincas mixtas a pequeña escala (≤10 ha). Las altas proporciones de tierra dedicadas a cultivos permitieron elevar los valores de los indicadores de agro-diversidad de la finca: riqueza de especies, diversidad de la producción e índice de reforestación. Las fincas con mayor CP (45-75%) alcanzaron los valores más elevados de productividad en términos de rendimiento de leche por unidad de área de forraje (3.6 Mg ha^{-1} $año^{-1}$), salida energética (21.3 GJ ha^{-1} $año^{-1}$) y producción proteica (141.5 kg ha^{-1} $año^{-1}$). Las fincas con altas CP demandaron una intensidad de fuerza de trabajo tres veces superior a aquellas con niveles medios de CP, que a su vez duplicaron la de las fincas con bajo CP. Altas CP se asociaron con más bajos costos energéticos de la producción de proteína, mayor eficiencia energética y dosis superiores de fertilizantes orgánicos.

En la etapa 3 se caracterizaron las fincas mixtas y especializadas del municipio San Antonio de Los Baños (Capítulo 5). En ella se evaluaron los mismos indicadores agroecológicos y financieros de etapas anteriores. Aplicar métodos participativos de investigación permitió incluir las perspectivas de los campesinos en la definición de metas para la sostenibilidad como parte de las estrategias para el desarrollo de los MFS a nivel regional. Los resultados de un detallado proceso cíclico en seis pasos para el diagnóstico, caracterización y comparación de las fincas, evidenciaron las ventajas de los sistemas mixtos sobre los especializados en condiciones de una agricultura de bajos insumos. Los actores locales (productores, investigadores, extensionistas y representantes del Ministerio de la Agricultura en el municipio) identificaron puntos críticos que posibilitaron la definición de estrategias alternativas para la agricultura en la región como forma para hacer operativa la sostenibilidad. Estas estrategias concentraron la atención en superar las actuales limitaciones tecnológicas, ambientales y socioeconómicas de los sistemas de producción ganaderos del territorio.

Tres grupos sociales básicos están involucrados en la aplicación de tales estrategias: a) los “nuevos” productores (urbanos y rurales) que surgieron durante los años de dificultades económicas; b) los pequeños productores de fincas mixtas tradicionales y sus familias, que heredaron y poseen la tierra, preservando un significativo conocimiento tradicional en el manejo de sistemas de producción diversificados y localmente adaptados; y c) un número creciente de miembros de las UBPC, unidades de producción con una estructura cooperativa, que laboran en tierras estatales otorgadas en usufructo gratuito e indefinido a la cooperativa.

Nuestros resultados muestran que al comparar diferentes sistemas, la cuestión no radica solamente en si los insumos son altos o bajos, si existe especialización o diversificación, sino también en las características específicas del sistema agrícola, así como la forma en que los insumos y la agro-diversidad se interrelacionan y gestionan internamente. También comprobamos que en la agricultura de bajos insumos externos, cuando se comparan los sistemas especializados y mixtos, estos últimos alcanzan mayores niveles de producción de alimentos y mayor producción de energía y proteína, debido al uso más eficiente de los recursos disponibles en la finca o la localidad. La singular posición del sector agrícola cubano, tanto a nivel nacional como internacional, ofrece un contexto en el cual estos resultados son altamente relevantes. El cambio climático, los altos precios del petróleo y de los alimentos en los mercados internacionales, combinados con la conciencia nacional sobre la necesidad de sustituir los alimentos importados por otros producidos en el país, así como las recientes decisiones del gobierno de cultivar todas las tierras improductivas, abren un amplio espectro de posibilidades para la adopción de tecnologías alternativas. La diversificación, la descentralización y el movimiento hacia la autosuficiencia alimentaria son tendencias principales dentro de la agricultura cubana; sin embargo, estas deben traducirse en políticas sistemáticas y consistentes que aseguren una producción factible y sostenible, así como la contribución de la agricultura a una economía viable.

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Curriculum vitae

Fernando Rafael Funes Monzote was born on January 6th, 1971 in Havana, Cuba. He lived until the age of 12 at the Institute for Animal Sciences (ICA) where his parents, Marta and Fernando were both researchers. His secondary and high school studies combined education with service work according to the standard Cuban curriculum. After graduating from high school in 1988, he spent two years in the military service as fire-fighter. In 1990, he began his studies at the Agronomy Faculty of the Higher Institute of Agricultural Sciences of Havana (ISCAH), today the Agrarian University of Havana where he combined studies with two years as president of the Student's League (Federación Estudiantil Universitaria). After obtaining his degree of Agronomy Engineer in 1995, he worked as researcher at the Pasture and Forages Research Institute of the Ministry of Agriculture of Cuba (IIPF) for ten years. Throughout this period he has been closely involved with the former Cuban Organic Agriculture Association (ACAO) that in 1999 won the Right Livelihood Award, also known as The Alternative Nobel Prize and with other Cuban and International NGOs through consultancy and development work. He earned his Master of Science degree in Agroecology and Sustainable Rural Development at the International University of Andalusia, Spain (1996–1998). In 1998, he participated in the 26th Course on Dairy Farming in Rural Development at the International Agricultural Centre (IAC), Wageningen, The Netherlands. In 2001, he was accepted for PhD studies at Wageningen University within the Plant Sciences Department of the C.T. De Wit Graduate School PE&RC. In 2002, he received a grant from the International Foundation for Science (IFS) under the project B/3213, which financed part of this doctoral thesis research. Over six years of cooperation with Wageningen University he has organized three international events: The First and Second International Symposium on Agro-ecological Livestock Production (SIGA 2001 and 2004), and the Course-Workshop on Livestock, Environment and Sustainability (2003). He has participated in over 20 international events in 10 countries and has taken part in five international technical missions. In 2006, he was appointed at "Indio Hatuey" Research Station of the University of Matanzas, associated with the Cuban Ministry of Higher Education.

PE&RC PhD Education Certificate

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

Review of Literature (5.6 ECTS)
- Towards sustainable agriculture in Cuba (2002)

Title of Project Proposal (7 ECTS)
- Ecological Framework for Assessment of Sustainability (ECOFAS) to design alternative Mixed Crop/Livestock Farming Systems in Cuba (2001)

Laboratory Training and Working Visits (10.5 ECTS)
- Livestock Organic Farming in Emilia Romaga and Perugia; Ass,Italiana per la Agricoltura Biológica, Italy (2001)
- Organic agriculture in Canada, from production to markets; University of British Columbia, Canada (2002)
- Livestock Farming Systems in the Latin American region; Universidad Autónoma de Yucatán, Mexico (2002)
- Ecological farming (focused to energy self-sufficiency in mixed farms and CO_2 emissions reduction); FIBL, Switzerland (2006)
- Exchange of experiences with various Spanish institutions; SEAE, University of Zaragoza, Valencia and Salamanca, Spain (2006)
- Local innovation and mixed farming systems; BOKU, Viena, Austria (2007)
- Family farming agriculture and agroecology in Brazil; EMBRAPA, ABA, State of Paraná, Centro Ecológico Ipé, Brazil (2007)

Post-Graduate Courses (6.4 ECTS)
- Livestock as the focal point of sustainable farming systems, University of Yucatán, Merida, Mexico; University Autonoma de de Yucatán, International Foundation for Science (IFS) (2002)
- Multivariate analysis applied to agroecosystems, Havana, Cuba; Pastures and Forage Research Institute (2003)
- International Course-Workshop on Livestock. Environment and Sustainable Development, Havana, Cuba; Pasture and Forages Research Institute, Animal Science Institute, International Agricultural Centre (2003)

Competence Strengthening / Skills Courses (5.6 ECTS)

- Writing proposal and development of project: Participatory identification of agroecological strategies for San Antonio de Los Baños municipality; Ministry of Science and Technology, Cuba (2001)
- Writing national project crop-livestock reference farms for the development of the Cuban livestock sector; Ministry of Agriculture, Cuba (2002)
- Techniques for writing and presenting scientific papers; PE&RC (2004)
- Writing project proposal: project BIOMAS on renewable sources of energy and mixed farming systems; University of Matanzas, Cuba (2007)

Discussion Groups / Local Seminars and Other Meetings (10.7 ECTS)

- Scientific Council Pasture and Forages Research Institute (2001-2005)
- Livestock, development and sustainable agriculture (Agroecological network IIPF) (2001-2005)
- National Program of Environment and Agriculture Advisory Committee of CITMA (2001-2005)
- Agricultural production systems (2004)
- Renewable sources of energy in mixed farming systems, BIOMAS (2006-2008)
- Organic agriculture and reduction of greenhouse gases emissions (2006-2008)
- Farmers experiments and farmers innovations in organic farming (2006-2008)
- Agriculture, health and environment (2007-2008)

International Symposia, Workshops and Conferences (13 ECTS)

- 17th Meeting of the Latin American Association for Animal Production (ALPA), Havana, Cuba (2001)
- I International Symposium on Agroecological Livestock, Havana, Cuba (2001)
- Training of Change Agent for Development, Tuxtepec, Oaxaca, Mexico (2002)
- Responding to the Increasing Global Demand for Animal Products, University of Yucatán, Merida, Mexico (2002)
- Livestock: the key to sustainable farming systems, University of Yucatán, Merida, Mexico (2002)
- 14th IFOAM Organic World Congress, Victoria, Canada (2002)
- International Course-Workshop on Livestock, Environment and Sustainable Development, Havana, Cuba (2003)
- Electronic Conference "Diversified Livestock Systems for Alleviating Rural Poverty in Latin America", CATIE-LEAD-FAO (2003)
- V International Workshop on Phytogenetic Resources, Sancti Spíritus, Cuba (2003)
- II International Symposium on Agroecological Livestock, Havana, Cuba (2004)
- V Congreso de la Sociedad Española de Agricultura Ecológica, Zaragoza, Spain (2006)
- 5th Congreso Brasleiro de Agroecologia Guaraparí, Brazil (2007)
- 16th IFOAM Organic World Congress, Modena, Italy (2008)

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