Institut für Nutzpflanzenwissenschaften und Ressourcenschutz

der Rheinischen Friedrich- Wilhelms- Universität Bonn

BALANCING NATURAL AND AGRICULTURAL SYSTEMS IN THE ATLANTIC RAINFOREST OF BRAZIL

Inaugural-Dissertation

Zur

Erlangung des Grades

Doktor der Agrarwissenschaften

(Dr. Agr.)

der

Hohen Landwirtschaftlichen Fakultät

Der

Rheinischen Friederich- Wilhelms- Universität

Zu Bonn

Vorgelegt am 06.10.2006

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Diese Dissertation ist auf dem Hochschulschriftenserver der ULB Bonn http://hss.ulb.uni-bonn.de/diss_online elektronisch publiziert

D 98

Tag der Mündlichen Prüfung: 15.12.2006

AKNOWLEDGEMENTS

Deseo expresar mi más profundo agradecimiento a las siguientes personas que hicieron posible la realización y culminación de este trabajo.

En Primer lugar al Prof. Dr. Marc Janssens, por haber sido más que mi primer supervisor, por haberme enseñado el camino de la ciencia y a la vez impartido valiosas lecciones de vida, por haberme allanado el camino en momentos difíciles, por sus ideas visionarias y por su gran paciencia en la conducción y corrección de esta tesis. Un especial agradecimiento a su esposa Frau Janssens por su apoyo moral y por inyectar energía positiva en mi familia.

Al Prof. Dr. Heiner Goldbach, mi segundo supervisor por las correcciones y el valioso aporte científico. Al Prof. Dr. Jürgen Pohlan, por sus valiosos consejos, y por ser un ejemplo de profesionalismo.

Muy especialmente al Prof. Dr. Hartmut Gaese, en primer lugar por su amistad, por haber hecho posible la realización de este trabajo a través del proyecto BLUMEN, por haberme brindado su apoyo científico y humano, por los valiosos consejos, discusiones, por los gratos momentos en campo, y finalmente por apoyar a mi familia.

A mis amigos y colegas de la Unidad Cultivos Tropicales de la Uni-Bonn, Sandra Callado, Silke Mailwes, Oliver Jende, Francisco Marroquim y Zhixin Deng, por compartir su amistad y haberme brindado su apoyo constante, por el debate constructivo e intercambio de ideas en numerosos y recordados seminarios.

A mis amigos y colegas del proyecto BLUMEN: Dra. Sabine Schlüter (Coordinadora), Dr. Jens Wesenberg, Dr. Ditmer Sattler, Nicole Kretschmer, Ivonne Friederich, Udo Nehren, Andre Lindner, por haber compartido las experiencias de campo y haber hecho amena la estadía en Brasil, por compartir sus conocimientos y las interminables discusiones. A todos los estudiantes de Maestría y Diplom del ITT y de la Uni-Leipzig, especialmente a Lucy Mino, Diego Barreiro, Nick Zegels, por haber aportado con sus trabajos de tesis y la recolección de datos.

A todos los investigadores brasileños, especialmente al Prof. Dr. Augusto Piratelli, a la Profa. Dra. Fatina Pina, a Elba dos Santos, por el apoyo incondicional desde el inicio de mi estadía en Brasil y especialmente por su amistad. A todos los estudiantes brasileños y en especial a Juvenal Martin con quien compartimos días duros en campo.

Quedo agradecido a los cientos de agricultores que me permitieron investigar en sus campos, y nos apoyaron para el éxito del proyecto, especialmente a Davi, Roberto, Regiane, Carlim, Seinha, Marcinho y sus respectivas familias, a todos ellos por su amistad y apoyo desinteresado.

El más grande agradecimiento a mi esposa Maria Isabel, por su infinito amor, apoyo y comprensión.

Este trabajo está dedicado a mi querida familia que son mi fuerza e inspiración:

Con amor a mi madre Gertrudis, a mis hermanos Marcos y Julio y familias, a mi hijo amado Carlos Andrés, a mi esposa Isabel y a la memoria de mi padre Julio Miguel

PREFACE

The present doctoral work was carried out from April 2003 to October 2006 under the supervision of Prof. Dr. Marc Janssens, Unit of Tropical Crops, currently belonging to the Department of Crop Science and Resource Conservation (INRES) from the University of Bonn, Germany.

The Unit of Tropical Crops participated in a German-Brazilian project "Biodiversity in Integrated Land Use Management for Economic Natural and System Stability in the Mata Atlântica of Rio de Janeiro (BLUMEN)" Coordinated by Prof. Dr. Hartmut Gaese, executive director of the Institute for Technology in the Tropics (ITT) of the University of Applied Science Cologne. The project was part of the Brazilian - German co-operation programme: "Science and Technology for the Mata Atlântica" launched by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (Cnpq), Brazil and the Bundesministerium für Bildung und Forschung BMBF, Germany.

An interdisciplinary team of researchers from Brazil and Germany started the BLUMEN project in the region of Teresópolis (State of Rio de Janeiro), focussing on the river basin of Rio Preto and the National Park Serra dos Órgãos. Researchers from 8 Institutions took part to this project: UFRRJ-Universidade Federal Rural do Rio de Janeiro, UFRJ-Universidade Federal do Rio de Janeiro, INT-Instituto Nacional de Tecnologia, FIOCRUZ - Instituto Oswaldo Cruz, UFSCar-Universidade Federal de São Carlos, as well as, three German recognized universities: University of Bonn, University of Leipzig and University of Applied Sciences Cologne.

The realization of this project was only possible with the active participation of hundreds of farmers and local organizations, all collaborating actively in the development of this project and especially in the laborious data collection for this thesis.

ERKLÄRUNG

Ich versichere, dass ich diese arbeit selbständig verfasst habe, keine anderen Quellen und Hilfsmittel als die angegebenen benutz und die Stellen der Arbeit, die anderen Werken dem Wortlauf oder dem Sinn nach entnommen sind, kenntlich gemacht habe.

Die Arbeit hat in gleicher oder ähnlicher Form keiner anderen Prüfungsbehörde vorgelegen.

Bonn, den 06.10.2006

SUMMARY

The aim of this work was to find ways of balancing natural and agricultural systems (AS) in the Atlantic rainforest of Brazil. Trade-offs and synergies were analyzed. We propose six hypotheses related to; (i) the contribution of agricultural systems to biodiversity conservation, (ii) the agricultural and natural mosaic in the landscape, (iii) the agriculture as consumer and producer of energy, (iv) the eco-volume as parameter to measure ecological functions, (v) the environmental impacts, quality of inputs, and sustainability, and (vi) the measurement of resilience in natural and agricultural systems.

Energy and emergy analysis, agro-biodiversity assessment, eco-volume, biomass partitioning, cost benefit analysis, surveys, and case studies were used as methodologies during 24 months of field work. The identified agricultural and natural systems were: (i) vegetables systems (leaf, fruit and mixed vegetables); (ii) citrus; (iii) ecological; (iv) cattle, (v) sylvopastoral, (vi) forest fragment and, (vii) forest in regeneration stage (1, 2 and 3 years old)

Agro-climax was defined as the equilibrium point between the natural and agricultural systems. Biodiversity management and conservation activities were analyzed and the corresponding biodiversity indices calculated. Finally, the farmer perception of biodiversity was presented. Ecological and sylvopastoral systems contribute positively to the conservation of biodiversity, on the contrary, dominant cattle systems are the main cause for forest fragmentation, breaking the dynamics of animal and plant populations. The landscape is dominated by fragments, 36.2%, grasses and agriculture 33.7% and forest in regeneration 18.8%.

The main primary agricultural production systems have low energy conversion ratio, and store only small quantities of energy (biomass) in the system. The ecological system has the most efficient use of energy, and saves great biomass quantity in the system. The cattle system presents the lowest values for all energy and biomass parameters causing largest environmental damage. All vegetable systems present positive economic indicators, the cattle only negative ones. The ecological system, presents highest sustainability in ecological terms.

The basin as a system contributes positively to the economy. It gives more emergy than that it takes from the economic system in form of materials and services. This fact represents also a loss of capital. The environmental impact caused by the agricultural systems is moderate as their use of renewable resources is high. Hence, the ecological sustainability is moderate to good.

Eco-volume is an important parameter to measure the ecological function and thequality of natural systems, as well as their interactions with agricultural systems. Reduction of eco-volume represents a negative impact on the ecosystem functionality, which in turn disrupts the supply of goods and ecological services. The eco-volume concept also plays a central role in the measurement of the resilience of natural and agricultural systems. Cattle and vegetable systems have the lowest resilience, ecological and sylvopastoral systems the greatest ones.

ZUSAMMENFASSUNG

Das Ziel dieser Arbeit ist die Bilanzierung zwischen Natur- und Agrarsystemen im Atlantischen Regenwald von Brasilien. Es wurden die Trade-offs und Synergien analysiert. Es werden sechs Hypothesen aufgestellt, die sich beziehen auf: (i) Beitrag des Agrarsystems zur Biodiversitätserhaltung, (ii) Agrar- und Naturmosaik in der Landschaft, (iii) die Landwirtschaft als Konsument und Produzent von Energie, (iv) das Ökovolumen als Parameter zur Messung der ökologischen Funktionen, (v) die Umwelteinflüsse, Input-Qualität und Nachhaltigkeit, (vi) die Messung der Resilienz der Natur- und Agrarsysteme.

Energie- und Emergieanalysen, Bewertung der Agrobiodiversität, Eco-Volumen, Biomassenmessung, Kosten-Nutzenanalyse, Befragung und Fallstudien wurden als Methoden innerhalb von 24 Monaten Feldarbeit durchgeführt. Untersucht werden die Agrar- und Natursysteme: (i) Gemüsebausysteme (Blatt-, Fruchtgemüse und beide in Mischkultur), (ii) Zitrusanbau, (iii) Ökologische Anbausysteme, (iv) Weidewirtschaft, (v) Sylvopastoral, (vi) Waldfragment, (vii) Wald in verschiedenen Regenerierungsphasen (1,2 und 3 Jahre alt).

Agro-climax wird definiert als Gleichgewichtspunkt zwischen den Natur- und den Agrarsystemen. Biodiversitätsmanagement und Naturerhaltungsmaßnahmen werden analysiert und der dazugehörige Biodiversitätsindex kalkuliert. Weiterhin werden die Vorstellungen der Produzenten zur Bedeutung der Biodiversität erfasst. Ökologische und Sylvopastorale Systeme tragen positiv zur Erhaltung der Biodiversität bei. Im Kontrast dazu steht die dominante Weidewirtschaft, die der Hauptverursacher der Waldfragmentierung ist. Die Fragmentierung zerstört die Tier- und Pflanzenpopulationsdynamik. Die Landschaft wird dominiert von Waldstandorten und landwirtschaftlich genutzten Flächen, die zusammen fasst 90% der Fläche einnehmen. Hiervon sind 36,2% Waldfragmente, 33,7% Weide und Ackerbau sowie 18,8% Waldregenerationsflächen.

Die im Untersuchungsraum vorherrschenden Primäragrarsysteme besitzen eine niedrige Energieumwandlung und speichern nur eine geringe Energiequantität (Biomasse). Die ökologischen Systeme haben meist eine effiziente Energiebilanz und sichern eine gute Biomassenquantität in ihren Systemen. Die Weidewirtschaft weist die geringsten Werte für alle Biomassenparameter auf und verursacht gleichzeitig die größten Umweltschäden. Alle Gemüseanbausysteme zeigen positive ökonomische Indikatoren, die Weidewirtschaft als einziges System negative. Die höchste ökologische Verträglichkeit ist erwartungsgemäß in den ökologisch bewirtschafteten Systemen zu finden.

Das Einzugsgebiet, als System, trägt positiv zum Wirtschaftssystem bei. Es gibt mehr Emergy als es vom Wirtschaftssystem in Form von Gütern und Dienstleistungen nimmt. Das bedeutet einen Kapitalverlust für ersteres. Die Agrarsysteme haben moderate Auswirkungen auf die Umwelt, da sie häufig erneuerbare Energien nutzen.

Eco-Volumen ist ein wichtiger Parameter zur Messung der ökologischen Funktion und der Qualität der natürlichen Systeme und ihrer Interaktionen mit den Agrarsystemen. Die Reduzierung des Eco- Volumens hat einen negativen Einfluss auf die Funktionalität des Ökosystems, was wiederum das Angebot von Gütern und „ecolocigal services" unterbricht. Das Eco-Volumen Konzept spielt weiterhin eine zentrale Rolle in der Messung von Resilienz von Natur- und Agrarsystemen. Weide- und Gemüseanbausysteme weisen die geringste, ökologische und sylvopastorale Systeme die höchste Resilienz auf.

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ABBREVIATIONS

%R	Renewability
1-D	Dominance index
AGDM	Aboveground Dry Matter
B/C	Benefit Cost Ratio
C	Carbon
CBD	Convention on Biodiversity
CCAD	Comisión Centroamérica de Ambiente y Desarrollo
CCAD	Comisión Centroamérica de Ambiente y Desarrollo
CE	Electric Conductivity
C_i	Crowding intensity
CIID	Centro Internacional de Investigaciones para el Desarrollo
CIIFAD	Cornell international Institute for Food, Agriculture and Development
CO_2	Carbon dioxide
CPS	Cattle Production System
CPS	Citrus Production System
DM	Dray Matter
ECO	Ecological Production Systems
EER	Emergy Exchange Ratio
EIR	Emergy Investiment Ratio
ELR	Environmental Load Ratio
EPA	Environmental Protection Agency
EYR	Emergy Yield Ratio
FAO	Food and Agriculture Organization
FM	Fresh Mater
FVS	Fruit Vegetable Systems
GHG	Greenhouse Gas
GIS	Geographical Information System
GPP	Gross Primary Productivity
H’	The Shannon Diversity Index
H_{eco}	Eco-height
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
J	Joule
CBD	Convention on Biological Diversity
LVS	Leaf Vegetables Systems
M	Materials
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
Mg	Megagram
MVS	Mixed Fruit and Leaf Vegetable Systems
N	Deposit or interne stokc
NPP	Net Primary Productivity
NPV	Net Present Value
OECD	Organization for Economic Co-operation and Development
OM	Organic Material
PB	Bruto Photosynthesis
PET	Potential Evapotranspiration
Pg	Petagram
PP	Precipitation
R	Extern Energy Source Limited
R_{ch}	Richness (N° sp)
S	Services
SI	Sustainability Index
SPS	Sylvopastoral System
Tr	Transformity
UNDP	United Nations Development Programme
UNDP	United Nations Development Programme
V_{bio}	Bio-Volume
V_e	Volume efficiency
V_{eco}	Eco Volume
V_{loss}	Volume-loss
V_{pot}	Potential eco-volume
WCFSD	World Commission on Forests and Sustainable Development
W_f	Wesenberg factor

CHAPTER I

1. INTRODUCTION

"The environment provides goods and services that sustain human development so we must ensure that development sustains the environment. Better natural resource management increases the income and nutrition of poor people" (The Millennium Goals: 7).

*"The priority must be on maintaining and improving the capacity of the higher potential agricultural lands to support an expanding population. However, conserving and rehabilitating the natural resources on lower potential lands in order to maintain sustainable man/land ratios are also necessary". "There is a need to intensify agriculture by diversifying the production systems for maximum efficiency in the utilization of local resources, while minimizing environmental and economic risks" (*Agenda 21, C: 14.3; 25).

If enough species are extinguished, will ecosystems collapse and will the extinction of most other species follow soon afterwards? The only answer anyone can give is: Possibly. By the time we find out, however, it might be too late. One planet, one experiment (Wilson 1992).

In a wide sense this thesis seeks to contribute conceptually and methodologically to examine and to determine in what ways humanity's relationship with the biosphere is out of balance, and seeks to find how a balance might be re-established.

Agroclimax is the equilibrium point between the natural systems and the agricultural systems. As a methodology it is an instrument to evaluate and plan sustainable farming systems in natural landscapes.

While evolving, agricultural systems are assumed to take advantage of all their potential of intrinsic development and of interactions with natural communities to increase total flow of energy in the system. The systems in agroclimax state try to maximize production as well as bio-capital generation such as biodiversity, biomass, fertility, by taking care to preserve future productive capacity in the long term.

1.1. ECONOMIC, ECOLOGICAL AND SOCIAL PROBLEMS OF AGRICULTURAL DEVELOPMENT

One of the critical questions that the developing countries face is whether agricultural production can be intensified without harming the environment. Are there conditions under which intensification could actually lead to improved environmental outcome or will countries always be faced with trade-offs between intensifying agriculture and achieving environmental goals?

Present mankind endures presently great difficulties alleviating poverty and malnutrition prevailing in major parts of the world (FAO 2003). Moreover, a chain of environmental, economical and social problems are revolving in a vicious circle (Martine 1997, Marcoux 1996). Over the past decades, yield increases from the Green Revolution technologies have been decelerating, and in some cases even stagnating so that growing negative environmental impacts have been revealed (Pingali *et al.* 1995). The actual dominant agricultural systems world wide are a risk because of a combination of several interrelated factors, including lack of fresh water, lack of drainage, and salinization of soil and groundwater resources (Schoups *et al*. 2005). (Schoups *et al.* 2005). Water depletion and soil erosion have already emerged as serious problems for the agriculture. Up to 50 % of the world's arable land is substantially impacted by soil loss which directly affects rural livelihoods and indirectly aquatic resources, lake and river sediment dynamics (Pimentel 2003, Ochumba1990, Kelley 2000). This type of agriculture contributes to the global carbon cycling, whereby high Green House Gas is emitted, specially methane (IPCC 2004) so that global climate change could be accelerated (Duxbury 1995, Lal 2003), and that aquatic and terrestrial biodiversity as well as ecosystem services are severely impeded (Harvey 1996, Alin *et al*. 2002, Tinke 1997, Pimentel 1998). The FAO (1996) estimates a 75% loss of the genetic diversity of cultivated plants since the beginning of our century. By the middle of the next century, there will be about one-third less arable land available per capita and at least an equivalent reduction in the availability of water for agricultural purposes (CIIFAT 1999).

The world has been making progress in improving food security, as measured by the per person availability of food for direct human consumption. However, progress has been very uneven, and many developing countries have failed to participate in such progress (Alexandratos 1988). A doubling of global food production (FAO 1997) would have major impacts on the ability of non agricultural ecosystems to provide services (Daily 1997).

After the Convention of Rio de Janeiro in 1992 there was an increasing concern and interest for internalizing environmental costs (Kumar 2004, Mota 2000). The intrinsic value of natural resources like soil as a contribution to national, regional and local economic productivity is not adequately recorded in financial planning and decision making. as well as the service of the natural systems (TMGs 2005). As a consequence, long-term sustainability is challenged by degrading natural resources (Cohen 2006), and by improper functionality of ecosystems. There is also a need to develop quantitative tools that can be used to support policy makers (Bouman 1999), to understand the functions of natural systems and to identify equilibrium stages within agricultural systems.

1.2. TRADE-OFFS AND SYNERGIES BETWEEN AGRICULTURAL AND NATURAL SYSTEMS

> *"The protection of the environment and the development of food production are closely linked. Not only are they compatible, but we cannot have one without the other. If we do not protect the environment, we cannot continue to produce food. If we do not develop sustainable food production systems we cannot protect the environment". (Mba 1989, p7)*

The debate about the trade-off between economic development and environmental quality has started in the 1960s (Lee 2001). In 1972, the low-income nations emphasized at the UN conference on the Human Environment, that environmental protection was a luxury they could not afford (Sandbrook 1992). Later on in the 70s, efforts were made to identify "win-win" scenarios. In the 80s and 90s conservationists published many documents to show synergies between environmental protection and economic development (WCED 1987, World Bank 1992).

Developing countries must produce more food in the future. According to projections of IFPRI (Leisinger 2002), the demand of cereals, roots and tubers will increase by more than 50% at the horizon 2020 (Rosegrant 2001), implying an enormous threat to the conservation of natural resources and to their service function (Höynk *et al.* 2003).

Trade-offs and synergy analyses help finding an equilibrium point, as a multi-disciplinary organizing principle and conceptual model for the design and organization of research and development projects in order to quantify and assess the sustainability of agricultural production systems (Crissman 1998).

Sustainable agriculture meets human needs for food, enhances quality of life of people, protects the integrity of natural systems, and last but not least, is economically profitable. Making a transition to agricultural sustainability involves difficult choices and an understanding of the complex trade-offs and synergies associated with different agricultural pathways.

In fact, this equilibrium stage is the central point of this thesis. We hope to unwrap these queries from different points of view, (i) analyzing biodiversity and its uses in different agricultural systems, (ii) quantifying energy and its efficiency, (iii) explaining energy transformations within living systems, (iv) partitioning aboveground biomass, (v) evaluating the capacity of sequestrating carbon, (vi) estimating inputs coming from natural systems and economic systems, (vii) calculating the load capacity of agricultural and natural systems, and finally, (viii) proposing the first simple method to measure the resilience of agricultural and natural systems to be developed in future studies.

1.3. OBJECTIVES

General: To balance both natural and agricultural systems, and to analyze their trade-offs and synergies in the Atlantic rainforest of Brazil.

Specifics:

i. To evaluate genetic resources of plants in a dynamic, ecological and economic complex, and to assess agro-biodiversity in seven farming systems that occur within agro-ecosystems and natural systems.

ii. To evaluate the environmental impact, the load capacity and the use of natural and economic resources using a common unit.

iii. To balance biomass of natural and agricultural systems, to calculate energy ratio, energy production, consumption, accumulation, as well as, the carbon sequestration capacity.

iv. To determine the land use types and their distribution in the water-basin of Côrrego Sujo in Teresópolis district.

v. To test the eco-volume concept and the resilience index for the measure of ecological quality and functionality of agricultural and natural systems.

1.4. HYPOTHESIS

Hypothesis 1. Contribution of the agricultural systems (AS) to the biodiversity conservation

Agricultural systems can reduce the pressure on the fragments and deforested areas, improve the cycle of water, influence the dispersion of fauna and flora, offer better resources and habitat for the survival of plants and animals, and also play an important role as bio-corridor and buffering reserves.

This hypothesis refers to the capacity of the different AS, the use, management and conservation of biodiversity, within the systems and also as part of the landscape in general. Starting from the degraded situation of the natural systems, it is assumed that certain AS could be quite favorable for biodiversity conservation. The social and economic context in the region is also assumed as important because these have influence on the management and conservation of the natural resources.

Hypothesis 2. The agricultural and natural mosaic in the landscape

> *Economic, geographical and environmental positive conditions for agriculture make that crop monoculture systems increase and dominate the landscape. In these landscapes that are mosaics of agricultural systems and natural vegetation, the ecological function of the natural systems, in casu fragments are affected by the surrounding agricultural systems.*

In highly modified landscapes with a mosaic of land use systems, the natural systems are affected both directly and indirectly, not only by AS but also by tourism and other economic activities. As a consequence, goods and services offered by the natural systems decrease. It is also admitted that the advance of the agricultural frontier is largely influenced by the physical-natural conditions and market demand. It is also assumed that agricultural systems may have intrinsic negative effects.

Hypothesis 3. Agriculture as consumer and producer of energy

> *The primary agricultural production can be directly a substantial energy and carbon producer through conversion of natural energy sources like sun and rain into biomass and indirectly, it can save great quantities of energy through its efficient use.*

This hypothesis refers to the different capacities that AS have to produce and consume energy. Some of these systems could end up being magnificent producers of energy, others, on the contrary, are characterized by high energy consumption and low conversion efficiency. Also, AS use different inputs, which in turn use different types of energy for manufacturing. For this reason they could be more dependent of non-renewable natural resources. Some AS may have the capacity to produce more biomass and to accumulate it in the system as a part of the intern capital, which eventually may be used as renewable energy.

Hypothesis 4. Environmental impacts, quality of inputs, and sustainability

> *By quantifying inputs of agricultural systems on a common basis using "emergy" analysis, comparisons across agricultural systems and their environmental impacts are made possible. Moreover, appropriate scenarios to achieve greater sustainability can be identified.*

With this hypothesis it is assumed that AS can be compared not only with each other but also with the surrounding natural systems, using the same units. This comparison is possible through the emergy theory that is a powerful method to measure the environmental and economic impacts caused by AS. This hypothesis also refers to the loss of natural capital of a region, and to the quality of the inputs. It allows identifying different scenarios, within which it is possible to replace less efficient systems through others with the objective to increase sustainability and to balance natural and AS.

Hypothesis 5. Eco-volume (V_{eco}) as parameter to measure ecological functions

> *Eco-volume is an effective and important parameter to measure the ecological function and the quality of natural systems, and their interactions with agricultural systems.*

Eco-volume would be a concept that integrates the relationship among species, as well as the vertical and horizontal structures of the ecosystems. In this sense it would be an important method to measure the quality and the ecological functions of a system as a whole. Some systems would have the capacity to increase their eco-volume and impact on the ecosystem functionality either directly or indirectly. Also it is assumed that plants compete more for limited resources like space and light, rather than for dry matter.

Hypothesis 6. The measurement of resilience in natural and agricultural systems

> *Eco-volume makes possible the measure of the resilience of agricultural and natural systems, whereby comparisons between both systems are made possible and the evolution in time can be monitored.*

Assuming that hypothesis 5 holds true, then, it is further assumed in hypothesis 6 that by comparing the present state of an ecosystem with its possible climax, it is eventually possible to measure its resilience. The resilience of the systems could have high correlations with biodiversity and with other parameters like energy flows and biomass production.

CHAPTER II

2. GENERAL FRAMEWORK OF AGRICULTURAL AND NATURAL SYSTEMS ANALYSIS

In this chapter we want to draw a general framework encompassing (i) the general problems of agriculture; (ii) its implications with biodiversity, the economic importance of crop genetic resources, the potential and constraints of biodiversity conservation in agricultural landscapes; (iii) the relationships of agriculture with thermodynamics, focusing on agriculture as a consumer and producer of energy, whereby the applications of thermodynamics laws in the evaluation and planning of systems; (iv) the importance and capacity of natural and agricultural systems in the emission and sequestration of carbon; (v) the evaluation of resilience of agricultural and natural systems (eco-volume, eco-climax, agriculture-climax, ecosystems functionality), and finally (vi) the current and future tendencies of agriculture.

From its onset the concept of sustainable development has endured continuous discussion and numerous variations. Actually, many investigators avoid to using the term and prefer inventing countless new ones, all describing one and the same concept. To better frame discussions in this thesis we make a small revision of this concept in §2.1.

2.1. SUSTAINABLE DEVELOPMENT

The concept of sustainable development is difficult to define and quantify, to a large extent because it is a multifaceted concept. Many authors distinguish a growth component, a distribution component and a environmental component (Veeman 1991, Munasinghe 1990). The definition of sustainable development from the economic point of view has criticized by a large number of movements present widely disparate reform agendas (Ruttan 1992, Goodland 1991). Perrings *et al*. (1994) focuses the concept towards a more ecological point of view by highlighting resilience and stability of biological and physical systems. Barbier (1991) and Pearce (1990), claim that a necessary condition for sustainable development is the constancy of the natural capital stock. For Solow (1993) it is a sustained growth or the maximum flow of income whilst maintaining the capital stock. Norgaard (1991) and Pearce *et al.* (1990) say that allocation mechanisms can ensure its achievement and lead to a "socially optimal" intertemporal allocation of natural resources (Co-evolutionary approach). Stressing the unique environmental, economic and social features of sustainability is the first step towards an interpretation that is sufficiently rigorous to provide the useful tools needed for practical analysis and policy making.

The World Commission of Environment and Development (WCDE 1987) gives the widely accepted definition of sustainable development as "*Satisfying the needs of the present generation without compromising the satisfaction of the needs of future generations*".

Common sustainability criteria that sustainable agriculture has to meet are *efficiency* to maintain and increase productivity. *Resilience and biodiversity* are key aspects to support ecosystems and maintenance of the *basic life support functions of the environment*. The *use of renewable resources* should be used at rates less or equal to the natural rate of generation, and the assimilation of waste and pollutants should be at rates less than or equal to the assimilative capacity of the environment. The *cultural diversity* needs to be respected and finally, basic needs satisfied, and poverty alleviated.

2.2. AGRICULTURE AND BIODIVERSITY

There is a need to suitably express the enormous importance of agrobiodiversity for the food security of future generations, for the sustainability and stability of the agricultural ecosystems of the world, and as a source of original material for breeding and innovations. Its conservation and sustainable utilization must be formulated as a political priority in all important areas of politics (Hammer 2003).

The focus on the Biodiversity Convention at the United Nations Conference on Environment a Development (UNCED) may be taken as a reflection of this new awareness. Although research on biodiversity has been high on the scientific agenda for the past decade, the link between biodiversity and sustainability assessment is still weak. Biodiversity has an ambiguous role in sustainability assessment. On the one hand, it is in the focus on what needs to be sustained. On the other hand, biodiversity is proposed as a means to assess the sustainability of complex systems (Becker 1998). The International Convention on biological Diversity, agreed in 1992, aims at conserving biodiversity, including genetic resources, wild species and habitats. Part of this task is to quantify the linkages between human activities and biodiversity, including agriculture. This is not an easy task, and few countries have systematic difficulties in linking changes in biodiversity associated with agriculture to specific policy measures (OECD 2003).

Biological diversity (biodiversity) has no single standard definition. One definition holds that biological diversity is a measure of the relative diversity among organisms present in different ecosystems. Diversity in this definition includes diversity within species and among species, and comparative diversity among ecosystems. The relationship between biodiversity and ecosystem functioning has emerged as a central issue in ecology as human activities are precipitating species extinctions (Loreau *et al*. 2001, Sala 2000 both cited by Thebault, 2003). Biodiversity refers to all living things and to the interactions between them: a vast array of organisms with an almost infinite complexity of relationships. (Wilson 1985, Wood 1999). *Agrodiversity* is a term of the 1990s, referring to interactions between agricultural management practices, farmers' resource endowments, bio-physical resources, and species. If it is to have practical use, it must be codified as a basis for analysis. (Brookfield 1999)

Estimations of the total number of species on earth range from 5 to 300 million, of which about 1.5 million have been described, and less than 0.5 have been analyzed for potential economic benefit properties (Miller *et al.* 1985, CBD 2001), and about 75000 species of plants are suitable for human consumption. Of these, only twenty are used as food, and four of them have to bear most of the "load" i.e. wheat, rice, soybeans and maize (Kern 1998).

Until recently, agricultural land was not regarded as important for biodiversity. Conservation activities had focussed almost entirely on protected sites. However, the importance of farming activities to biodiversity is emerging (Feehan 2001). The diversity of cropping systems, crop species and farm management practices has received increasing attention in recent years as a way of spreading risk and supporting food security in resource-poor farming systems (Tengberg et al. 1998). On-farm conservation is a special form of in situ conservation based on the groundwork of traditional farming and gathering methods (Hammer 2004). Management practices that increase the spatial and temporal diversity within fields can enhance production and reduce the environmental impacts of crop production (George 1971, Kort 1988, Bezdicek 1989, Olson 1995, Pohlan 2002)

Agro-biodiversity can, (i) provide crop and livestock genetic resources, as the basis for food production, and the development of agricultural raw materials, such as renewable energy through biomass (OECD 2003); (ii) enrich society through maintaining and enhancing the variety of wildlife habitats and wild species related to agriculture, of value for economic, scientific, recreational, aesthetic, intrinsic, landscape and other amenity purposes; (iii) facilitate the functioning of ecosystems, life-support systems, such as nutrient cycling, protection and enrichment of soils, pollination, regulation of temperature, local climates, and watershed filtration (Parris 2001). (iv) provide the source of most of the world's food products, their improvement, and the development of new resources (Smale 2002)

The effects of agriculture on biodiversity are of considerable importance because farming is the human activity occupying the largest share of the total land area (Gaese *et al.* 2005). Even for countries where the share of agriculture in the total land area is smaller, agriculture can help by increasing the diversity of habitat types. The expansion of agricultural production and intensive use of inputs over recent decades is considered a major contributor to the loss of biodiversity. At the same time certain agricultural ecosystems can serve to maintain biodiversity, which may create conditions to favour species-rich communities, but that might be endangered by following or changing to a different land use, such as forestry. Agricultural food and fibre production is also depend on many biological services. This can include, for example, the provision of genes for development of improved crop varieties and livestock breed, crop pollination and soil fertility provided by micro-organisms (Parris 2001).

Obstacles for conservation

The major reason for the unsustainable use of biodiversity is set by individuals exploiting biodiversity and watinng to increase immediate economic benefits ll together. Any attempt to conserve biodiversity will be perceived as a cost by those involved in the exploitation, both in terms of forgone benefits and actual cost of conservation (Groombridge 1996). Other important obstacles are limited knowledge regarding important functions of the environment and insecurity and risk regarding current and future environmental impacts. It is also difficult to assess the indirect use values and non use values (Müller 1997). Low value is attributed to their biological resources, unsustainable exploitation of resources, and to the insufficient knowledge about ecosystems and species (Klink 1996).

Economic importance of crop genetic resources

The available assortment of crop varieties and the genes they carry determine annual yields and the crop's vulnerability to disease and abiotic stress. Yield growth and yield instability have economic value, while maintaining diversity on farms may entail efficiency trade-offs in the short term (Smale 2002). Many farmers in the developing world depend on the diversity of the varieties and crops they grow for their own consumption and wellbeing. By contrast, in some advanced economies, there are niche markets for scarce traditional varieties and consumers may be willing to pay to conserve certain attributes of agriculture, such as its biodiversity (Smale 2002).

Potential of biodiversity conservation in agricultural landscapes

In mosaic landscapes where agricultural systems are prevailing it is difficult to conserve biodiversity. Some agricultural systems contribute extremely to the degeneration of natural ecosystems, but other might even contribute positively in the recuperation of degraded ecosystems, such as is often the case with agroforestry systems, sylvopastoral systems, ecological systems, etc. (Schroth *et al*. 2004, Laurance 2004). These systems could play a role in helping to maintain a higher level of biodiversity, both within and outside protected areas, when compared with the severe negative effects resulting from more drastic land transformations. Where landscapes have been denuded through inadequate land use or degraded agricultural areas have been abandoned, revegetation with agroforestry practices can promote biodiversity conservation (Schroth 2004).

Agroforestry systems, sylvopastoral systems, ecological systems help reduce pressure of additional land deforestation for agricultural purposes. They can also provide habitat and resources for partially forest-dependent native plants and animal species (Laurence 2004). In tropical land use mosaics, ecological processes and characteristics such as microclimate, water and nutrient fluxes, pest and disease dynamics, and the presence and dispersal of fauna and flora may be significantly influenced by agroforestry elements (Thurston 1999, Torquebiau 1992, Schroth 2004). The indirect value of agroforestry systems can also extend to other environmental benefits, such as carbon sequestration, watershed maintenance, and buffering against climate change induced biome shifts. Furthermore, nutrients cycling in natural forest systems is often highly conservative as nutrients are quickly and efficiently recycled within the system, whereas agricultural systems often exist at the other extreme with high nutrient losses (Gascon 2004).

Some benefits from biocorridors are that they facilitate faunal movements and plant dispersal (Bennet 1990, Forman and Deblinger 2000), whilst providing habitat for resident species of plants and animals (Laurance and Laurance 1999), facilitating the spread of diseases, weeds, and undesirable species (Hess 1994), aiding to the ecosystems resilience process, and increasing the habitat quality (Henein and Merriam 1990).

Opportunities for conserving agrobiodiversity in situ could offer solutions to these concerns within regions of marginal value for agricultural production (Bardsle 2003, Smale 2002).

2.3. AGRICULTURE AS A CONSUMER AND PRODUCER OF ENERGY

"Everything is based on energy. Energy is the source and control of all things, all values, and all actions of human beings and nature" (Odum & Odum 1976, p.1)

History need of energy for human existence is an age old story. Initially the fire was generated with stone to burn biomass which was essential to cook food and save men from cold. Later on, the iron age came in and coal became the major source of energy. After invention of IC engines and automobiles, petroleum became the major energy source. As the conventional energy sources started depleting, the search for non-conventional energy sources started (Tomar 1995).

In the period 1860 to 1914 other energy sources were found and made available besides coal and vapour. During this change natural resources begin to experiment deteriorations and pressure. From the vision of traditional economy, the environment was seen as raw material source and receiver of waste coming from production processes and consumption (Mota 2004).

Energy availability and use is a critical factor influencing the organization of modern societies and their systems of agriculture. For millennia, the agricultural systems of the world were run on locally available, contemporary energy sources and materials, and fostered the growth of complex, locally-adapted economic, cultural and knowledge systems - albeit in a world with far fewer people than today (Pimentel & Pimentel 1979, Pimentel 1989)

Agriculture plays a key role in the process of transition toward more sustainable energy use patterns. First, the agricultural sector is itself a user of energy, not only in primary production of commodities, but also in food processing and distribution of agricultural products. Secondly, the agricultural sector substantially contributes to energy supply, in particular through the production of biomass, including fire wood, agricultural by-products, animal waste, charcoal, other derived fuels and increasingly through production of energy crops (Lansink *et al.* 2002).

Agriculture is essentially an energy conversion process, transforming of solar energy, fossil fuel products and electricity into food and fiber for human beings. Primitive agriculture involved little more than scattering seeds on the land and accepting meagre yields. Modern agriculture, however, combines petroleum-based fuels to power tractors and self-propelled machines with energy-intensive fertilizers and pesticides, resulting in greatly increased yields. Various parts of the world are at different stages of agricultural development; therefore, energy-use practices vary widely (Peart 1992).

Without adequate attention to the critical importance of energy to all of these aspects, the global social economical and environmental goals of sustainability cannot be achieved (El Bassam 1998). The importance of energy in agricultural productions, food preparation and consumption is evident and essential (UNDP 1997). The second reason that energy is acquiring special importance is that agriculture once again may called upon to be a supplier of energy, rather than only a consumer (Lockeretz 1982). At present, the world's conventional oil reserves are estimated to be 1 trillion barrels and at current rates of consumption it is estimated that these reserves will not be sufficient to meet the increasing demand by the year 2020 (UNDP 2000, Lansink *et al.* 2002).

Considering the limited resources of the small farmers for the energy production and the important function of an opportune arrangement of the resources to increase the yield, the "Grupo Consultivo de Investigación Agrícola Internacional" (GCIAI) indicated the necessity to make investigations on the energy subject on the agricultural production systems (FAO 2005).

2.4. THE THERMODYNAMIC AND EMERGY ANALYSIS

Thermodynamics is the branch of science that studies energy and its transformations. Usually, thermodynamics is associated with heat, but the subject deals not only with heat but also with all forms of energy. The principles of thermodynamics are well established and provide a foundation for the understanding of physical, chemical and biological systems.

Definitions

Work may be defined as organized motion and is measured in Joules (J). Work can be mechanical, electrical, magnetic or of other origin.

Energy is the same as motion or ability to move. There are different forms of energy, e.g. potential energy, kinetic energy, pressure energy, etc. and they are all measured in Joule (J).

Enthalpy is the amount of energy a system releases if the system's temperature drops (assuming the pressure is constant) to 0 K. Heat contents is, therefore, another word for enthalpy.

Entropy is a measurement of the disorder in the motion, and it is measured in Joules per Kelvin (J/K).

Exergy is measured in the same unit as energy and its definition is work (organized motion) or ability to perform work for a system in a specified area. Exergy is the part of the energy that can be used as an energy source. Thus each process implies that exergy is consumed and it is therefore always related to the surrounding.

Emergy, spelled with an "m", is a universal measure of real wealth of the work of nature and society made on a common basis" (Odum 2000). Emergy can be defined as the total solar equivalent available energy of one form that was used up directly and indirectly in the work of making a product or service (Odum 1996, 2000). Emergy analysis considers all systems to be networks of energy flow and determines the emergy value of the streams and systems involved. (see 3.3.1 and more definitions are presented in annexe 2)

Thermodynamic Laws

The first law of thermodynamics: *Energy can not be created or destroyed. However it can be converted in other kinds of energy*. In other words, energy that flows into a system must be fully accounted for in other forms of energy. This is, total energy in a closed system remins constant, which is why an energy balance (where the total input is equal to the total output) can be stated for each process.

The first law of thermodynamics: *Heat cannot spontaneously go from a lower to a higher temperature*. Or: *Heat cannot be converted into only work.* This law places limits on how energy may be converted, because there are always losses in the transformations (Hovelius 1997)

Energy is a relevant parameter to study the sustainability of systems. It is also, essential to most human activities, including agriculture. Too much energy means wastage, global warming and other environmental pressures (Simoes 2001). Energy might be more sensitive and a concrete indicator in guiding us for better resource allocation (Wilson 1974, Chou 1993). Resources of agricultural production can also be discussed in terms of land energy and labour (Doyle 1990). The increased productivity by hectare leads to a decline of energy use efficiency. Intensive production brought a high dependence on inputs from non-renewable resources. Systems analysis of agricultural production is the first step to study this situation (Hill 1976).

Emergy analysis (Odum 1986) is an evaluation method, which provides a general category i.e. emergy, for measurement of heterogeneous flows within the ecosystem, as well as an instrument to account for interactions between physical flows in nature and the economy and monetary flows within internal and external markets of natural resources and goods. Emergy analysis is a promising tool to evaluate resource use and production of agricultural methods. Emergy analysis is a form of energy analysis that quantifies values of natural and economic resources to quantify the value of large-scale environmental support to the human economy (Odum 1998). It is viewed as a "donor-side" evaluation approach because it values items based on energetic inputs as opposed to consumer preferences. Solar emergy is used to determine the value of environmental and human work within a system on a common basis: the equivalent solar energy required to produce each service or product. The fundamental assumption of emergy analysis is that the contribution of a resource is proportional to the available energy of one kind required to produce the resource (Brown & Herendeen 1996)

Agriculture operates at the interface between nature and the human economy and combines natural resources and economic inputs to produce food. Typically, high quality, non-renewable energies from the human economy are utilized to capture and concentrate lower quality, renewable energies. Intensive agricultural methods rely more on resources purchased from the economy, while less intensive and indigenous methods typically rely more on natural inputs. Because most types of agriculture depend on a combination of natural and economic inputs, it is necessary to account for both in equivalent terms when comparing the resource use of agricultural methods (Campbell 1998).

Maximum Empower Principle. This optimizing principle is one of the most daring aspects of emergy analysis. Having its roots in work done by Lotka (1922), the Maximum Empower Principle claims that all self-organizing systems tend to maximize their rate of emergy use or empower (Odum, 1996, 1988). That is, "ecosystems, earth systems, astronomical systems, and possibly all systems are organized in hierarchies because this design maximizes useful energy processing." Thus, this principle can determine which species or ecosystems or any system will survive.

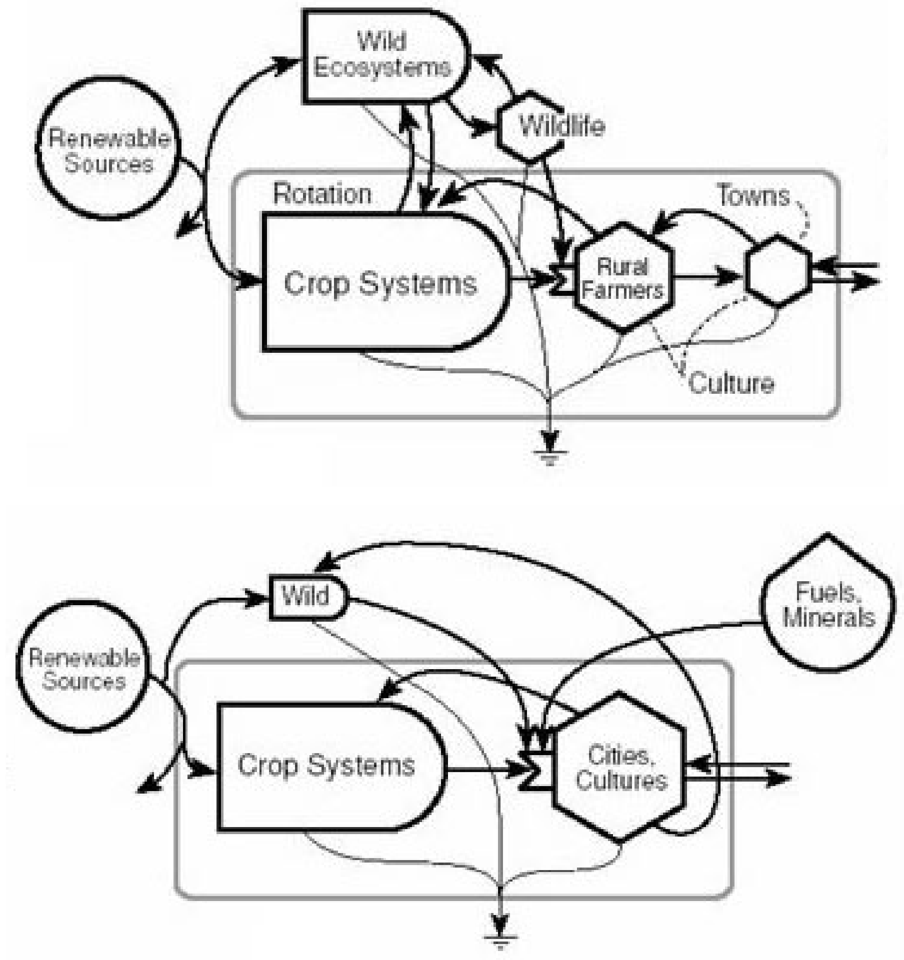

Figure 2.4.1. Energy systems diagram depicting the energy development in human society through the successive stages of agrarian society, and urban society, running mainly on fossil fuels (Redrawn from Haden 2003. See appendix 2 for a description of the energy symbols).

Graph 2.4.1 illustrates that the systems always allow the entrance of natural energy of the economy, industry, etc. The human and economic activities in a same way need to care for energy of the environment (Aroudo 2004). On the right side of the same graph, it can be observed that the latter system has no more interactions with the wild system on the left, and are hence, more dependent on fossil energy. Dalgaard (2002) shows three main reasons for limiting the use of fossil energy. First, fossil energy is a limited resource which, as far as possible, should be conserved for the coming generation (Brown *et al.* 1998). Secondly, combustion of fossil energy leads to classical pollution via compounds of sulphur and nitrogen, which damage the environment via acidification, eutrophication etc. (Illerup *et al.* 1999). Finally, combustion results in emission of the greenhouse gas carbon dioxide (CO_2). This gas is responsible for most of the anthropogenic changes in the earth-atmosphere energy balance, which may lead to global climate changes (IPCC 1997).

Clearly, the anthropocentric view is dominant today, but the emergy view can still provide invaluable information that can be used for sustainable development and eventually, economic evaluation will have to adopt a more ecocentric view if it intends to guide humanity to its survival (Hau 2004).

The emergy theory also has been criticized and observed by several authors like (Spreng 1988, Mansson 1993, Ayres 1998, Cleveland *et al*. 2000) the points are showing in Table 2.4.1, the same critics have been refuted by (Patten 1993, Odum 1995a, 1995b), but finally some are without a definitive explanation or with persistent doubts

Table 2.4.1. Positive and negative aspects of emergy methodology

Positive	**Negative**
It provides a bridge that connects economic and ecological systems. The economic and ecological aspects can be compared on an objective basis that is independent of their monetary perception.	The emergy theory of value ignores human preference and demand.
	Lack of adequate details about the underlying methodology.
Emergy analysis provides an ecocentric evaluation method.	Discrepancies with the Maximum Empower Principle
It is scientifically sound and shares the rigor of thermodynamic methods.	There seems to be much confusion about the relationship between emergy and other thermodynamic properties.
Emergy analysis recognizes the different qualities of energy or abilities to do work	Is difficult, if not impossible to know the inputs and processes over a long period like from the prehistoric period onwards.
Emergy analysis provides a more holistic alternative to many existing methods for environmentally conscious decision making.	Problems of quantifying transformities
Emergy analysis can quantify the contribution of natural capital for sustaining economic activity	Tenuous physical and biological foundations to assign monetary values to ecological products and services

2.5. CARBON IN TROPICAL SYSTEMS

A significant part of greenhouse gas (GHG) emissions in tropical countries is associated with land conversion and high deforestations rates (Brown *et al*. 1996a). The tropical systems act as sinks for atmospheric CO_2 in form of large volumes of biomass per hectare (Lugo & Brown 1992). Land clearing, which often causes the burning of the forest biomass, leads to net emissions of carbon dioxide and other GHGs (López 2005).

Carbon sequestration is now a recognized forest management strategy with enormous economic implications, due primarily to the advent of "carbon credits." Carbon credits are awarded to entities ranging from companies to countries, and allow C emissions above levels negotiated in international treaties in exchange for a proportional C sink established on the landscape (Silver 2000).

The actual tropical land use have a significant impact on the global carbon cycle through increased rates of C emissions to the atmosphere and the loss of above- and belowground C accumulation and storage capacity. Current estimates suggest that approximately 1.6 (± 0.5) Pg (petagram = 10^{15} g) of C are lost annually from the conversion of tropical forests (Brown *et al*. 1996b). In their aboveground biomass, secondary forests accumulate approximately 94 Mg C ha^{-1} (30 years old and 20 m high) (Puig 2005). Tropical secondary forests have been reported to accumulate up to 5 Mg C ha^{-1} yr^{-1} during the first 10 to 15 years of regrowth, its sequestration capacity 2 to 3.5 Mg C ha^{-1} yr^{-1} (Brown & Lugo 1990). Rates of above-ground C accumulation in plantations range from 0.8 to 15 Mg C ha^{-1} yr^{-1}, during the first 26 years following establishment (Lugo *et al*. 1988).

Intensive pasture management in Brazil resulted in lower soil C pools, eight years following deforestation, than sites that were less intensively used (Buschbacher *et al*. 1988). The effects of climate on soil C accumulation with reforestation are not well known. In mature tropical forests, soil C pools tend to decrease exponentially as the ratio of temperature to precipitation increases, corresponding to a gradient from wet to dry forests (Brown & Lugo 1982). Tropical forests store approximately 206 Pg C in the soil (Eswaran *et al*. 1993).

Carbon sequestration by forest systems is a finite process. Biomass may eventually reach a maximum sequestration potential and no longer reduce the amount of CO_2 in the atmosphere. The time period required to reach such stage is not well known, but it has been speculated that such a limit is reached in the first 50-100 years following forest establishment (Silver 2000).

Agricultural land might need to be considered a candidate for carbon trading in the future (Puig 2005). Schimel (2001) considers in the same way that regrowth on abandoned agricultural land, fire prevention, longer growing seasons, and fertilization by increased concentrations of carbon dioxide and nitrogen have been proposed as possible mechanisms responsible for the uptake. Defries (2002) considers that carbon fluxes from tropical deforestation and regrowth are highly uncertain components of the contemporary carbon budget.

2.6. ECO-VOLUME, ECO-CLIMAX, AGRO-CLIMAX AND SYSTEMS FUNCTIONALITY

Eco-volume is the aboveground quantifiable space or volume limited by a uniform vegetation stand and its height, within which coexist wide interactions among biotic and abiotic components. This concept emphasizes the interrelationships between species living within the boundaries of a volume, and encompasses a biocenosis adapted to specific conditions in a given place.

V_{eco} = land area x eco-height (Janssens 2004a)

Eco-height: renders a weighed average over time and across the different vegetation community fractions. In this case, a vegetation reaches community status as from canopy closure onwards and its height will be given by the domineering (upper layer) plants.

Ovadia (2002) indicates that there is no clear methodology to measure the ecological function and quality of natural systems, and their interactions with agricultural systems, determining the interactions between biotic and abiotic components in ecosystems, and include the vertical structure in vegetation communities.

The eco-volume as unit contains many components that interact in large and complexes networks, higher trophic structure, nutrient fluxes, etc. A vertical structure can also be distinguished like the strata in forest. The eco-volume can suffer periodic or abrupt changes based on natural phenomena or man-made alterations. Eco-volume has additionally effect on precipitations (eco-precipitations[1]), as well as on regulation of other ecological functions like microclimate and water cycles. Eco-volume leads directly into such areas as water cycling, Gross Primary Productivity (GPP), Net Primary Productivity (NPP), and energy flow.

Agroclimax

Janssens *et al.* (2004a, 2005), defines agroclimax like the relative stabile biomass production from an orchard or farming system and determines the allometric relation to estimate the gross photosynthesis. He contends that aboveground gross photosynthesis is close to four-fold the litter fall.

$B_f \approx 4 * L_f$

Where: B_f = Gross photosynthesis; L_f = Litter fall

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[1] *Eco-precipitations are complementary rains generated by ecological sound management of a watershed basin.*

Janssens *et al*. (2005) compares the biomass production of orchards with natural systems in climax state. And propose the notion agro-climax as an alternative to that of eco-climax. Each agro-climax is characterised by a certain level of agro-diversity, contributing in its manmade way to biodiversity (Fig. 2.6.1).

Eco-climax and Eco-volume potential

Eco-climax is defined by Odum (1969) as the culmination state after a succession in a stabilized ecosystem in which maximum biomass (or high information content) and symbiotic function between organisms is maintained per unit of available energy flow. This *Eco-climax state* will be considered as the stage at which *eco-volume potential* is highest. This state will be described here under.

When the system approaches its climax, the increase in net productivity rate of the plants is consumed by its own heterotrophs. The system comes into equilibrium and reaches peak efficiency at channelling the energy of the sun into the food web of the community Whittaker (1970) (Fig. 2.6.2)

Odum (1969) describes the basic conflict between the strategies of man and the organisation of nature. The goal of agriculture as now generally practiced is to achieve high rates of production (P) of readily harvestable products with little standing crop (B) left to accumulate on the landscape, in other words, a high P/B efficiency. Nature's strategy/organisaton, on the other hand, as seen in the outcome of the successional process, is directed towards the reverse efficiency, a high B/P ratio. Economic activities want to obtain as much production from the landscape as possible, by developing and maintaining early successional types of ecosystems, usually monocultures (Figure 2.6.4).

The maximal biomass phase reached during succession cannot be maintained in the long-term absence of major disturbance, whereas similar patterns of decline occur in forested ecosystems spanning the tropical, temperate, and boreal zones (Wardle *et al*. 2004). The general patterns of a 100-day autotrophic succession in a microcosm are very similar with a hypothetical model of 100-year forest succession[2] (Kira & Shi-dei 1967, Cooke 1967) (Fig. 2.6.3)

A climax community is one that has reached the stable stage. Stability is attained through a process known as succession, whereby relatively simple communities are replaced by those more complex. Stable climax communities in most areas can coexist with human pressures on the ecosystem, such as deforestation, grazing, and urbanization. Polyclimax theories stress that plant development does not follow predictable outlines and that the evolution of ecosystems is subject to many variables (Odum 1969)

[2] *The gradual and orderly process of ecosystem or community development brought about by changes in species populations that culminate in the production of a climax characteristic of a particular geographic region (EPA 2005)*

Ecosystems

Ecosystems are very complex and composed of many individuals of multiple species of organisms which interact with each other and their abiotic environment to produce complex structures, dynamics and energy flows. Eco-volume has approached this problem by assuming that it is sufficient to abstract all this complex interactions, among individuals in populations, and characterize ecosystem function simply in terms of net changes in numbers or bio-volume[3] of individuals at the level of whole populations. Abstracting such individual-scale detail is reasonable if the effects of individual-level interactions attenuate on the time scale of changes in population density (Agrawal 2001). Understanding the functioning of ecosystems still remains a challenge up tp now Paine (1966) & Daily (1993) conclude that the functionality depends on the identities of the species the ecosystems contain and hypothesized that number of species plays a major role.

Ecological succession defined by Odum (1963) cited by Odum E. (1969), follows three steps: (i) It is an orderly process of community development that is reasonably directional. (ii) It results from modification of the physical environment by the community; that is, succession is community controlled even though the physical environment determines the pattern, the rate of change, and often sets limits as to how far development can go. (iii) It culminates in a stabilized ecosystem in which maximum biomass (or high information content) and symbiotic function between organisms are maintained per unit of available energy flow (Fig. 2.6.3).

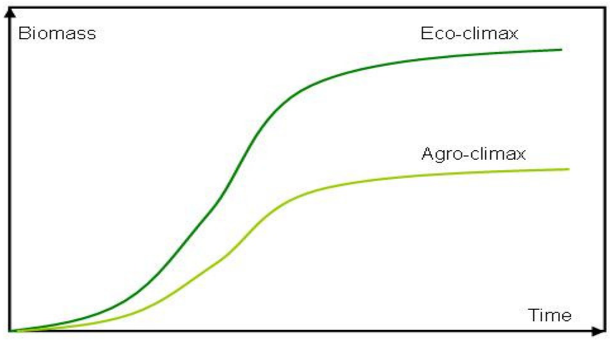


Fig. 2.6.1.

Fig. 2.6.1. Eco-climax and agro-climax equilibria. Janssens et al. (2005) Each agro-climax is characterized by a certain level of agro-diversity, contributing in its manmade way to biodiversity. The apparent global photosynthe-sis can be approximated through the measurement of litter fall.

[3] Bio-volume is the volume of stem, branches, roots, rootlets, twigs and leaves

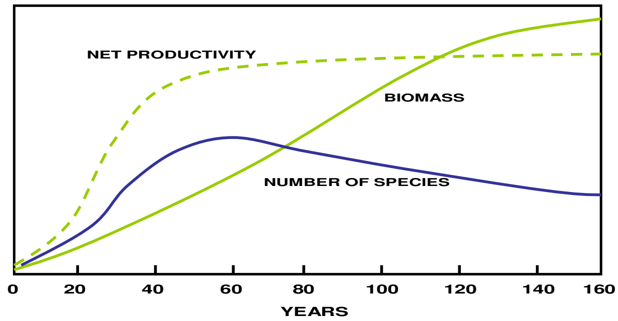


Fig. 2.6.2.

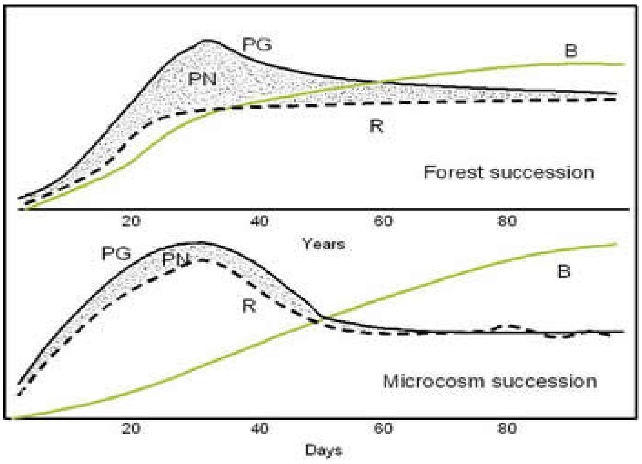


Fig. 2.6.3.

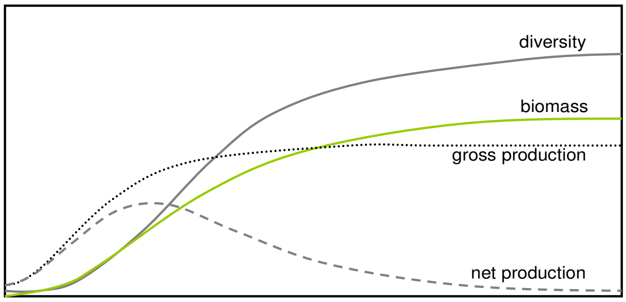


Fig. 2.6.4.

Fig. 2.6.2. The graph (from Whittaker 1970) shows the changes in number of species, bio-mass, and net productivity during secondary succession in a temperate deciduous forest over a pe-riod of 160 years.

Fig. 2.6.3. Comparison of the energetic of succession in a forest and a laboratory microcosm. PG. Gross production; PN. Net pro-duction; R. total community respiration; B. total biomass (Odum 1969). The general pa-tterns of a 100-day autotrophic succession in a microcosm based on data of Cooke (1967) is compared with a hypothetical model of 100-year forest succession as presented by Kira and Shi-dei (1967).

Fig. 2.6.4. The graph shows the changes of d diversity (blue), b biomass (green), pg gross pro-duction (orange), db net produc-tion (pink) over the period of succession until climax. The growth of biomass depends on renewable outside energy sources, but also on the diversity. As the quantity of biomass increases, it provides niches for seeding from outside to increase the diversity. The greater the diversity the more productivity.

2.7. DEVELOPMENT PERSPECTIVES OF AGRICULTURE

Everyone in the world depends on nature and ecosystem services to provide the conditions for a decent, healthy, and secure life. The pressures on ecosystems will increase globally in coming decades unless human attitudes and actions change. Human activities have taken the planet to the edge, further threatening our own well-being. (MEA 2005)

The World Commission on Forests and Sustainable Development (WCFSD 1999) has called attention to a global need to restore the functional integrity of nature. Sustainability Impact Assessment of economic, environmental, and social effects triggered by governmental policies has become a central requirement for policy design. The three dimensions of this assessment are inherently intertwined and subject to trade-offs. Quantification of trade-offs for policy decision support requires numerical models in order to assess systematically the interference of complex interacting forces that affect economic performance, environmental quality, and social conditions (Böhringer 2006)

Agricultural systems are tremendously complex. None of their fundamental processes can be successfully addressed in isolation. Innovative and interdisciplinary research is needed for integrating, rechecking and transforming knowledge in diverse areas of science to assure that everyone has access to sufficient food to live a healthy and productive life. And that is what agricultural science is: the continuous rechecking and integration of knowledge about complex natural systems to balance food production with environmental constraints (Langensiepen 2004)

The model of sustainable development, on which the international community agreed at the 1992 United Nations Conference on Environmental and development in Rio de Janeiro, is to reconcile the improvement of the economics and social living conditions with the long-term conservation of the natural resources of life. Only in this way can we succeed in also offering future generations suitable opportunities of development (Schulze-Weslarn 1997). The important topics are (i) Policy and management; political discussion including economical, cultural and social issues, including population control policy. (ii) Energy and inputs: energy resources, fertilizers, plant protection, ecological farming, science, research and technology. (iii) Genetic resources: identification, evaluation, and utilization of plant genetic resources. (iv) Climate: constraints and impacts. (v) Soil and water: resource and requirements (El Bassam 1998).

The «one problem, one solution approach» is no longer adequate and must be replaced by some form of system analysis that considers man as a part of, not apart from, the environment. Before the long-term economic performance and ecological sustainability of a given agricultural system can be ascertained, the origin and quality of the energy and material inputs used to increase crop yields and economic and labour efficiencies must be carefully considered. New accounting procedures are needed that consider production efficiency inclusive of its economic, ecological and social context, because these contexts are not generally accounted for economic analyses of agricultural systems.

Agriculture becomes a potential major Carbon sink (Lal 1997), agriculture can potentially provide carbon sequestration services by altering their management practices to increase the carbon in their soil (Antle 2003). Alternative agricultural tillage, crop rotations, livestock waste disposal, and other practices influence the level of carbon in farm soils (Tweeten 1998).

The links between the agricultural sector and the Millennium Development Goals at household level are the next, (i) goal, ensure environmental sustainability.

(ii) Direct link, agriculture practices can be both direct causes of and important immediate solutions to environmental degradation, and (iii) indirect, more productive agricultural technologies, withdrawal of agriculture from marginal, sensitive environments, more profitable agricultural sector, reduced migration to urban slums. (iv) Relation with nature, first, agricultural sector is as likely to have negative ramifications on the environment as positive. Unprofitable agricultural systems tend to unsustainably mine environmental resources. The second, declining environmental resource base is an erosion of the foundation for the agricultural economy. Finally, (v) the complementary requirements are the minimization of negative environmental externalities[4] of agricultural investments, participatory planning processes required. Relatively equitable distribution of agricultural assets across the population, and environmental costs of agricultural production incorporated into economic assessments of production systems (MDGs 2006).

The importance of accounting for nature's services is gaining wide acceptance (Holliday *et al.* 2002, Daily 1997). It becomes valuable to have another methodology to evaluate and to design the agricultural production systems, because the neoclassical economy does not have the capacity to overcome its deficiencies in the measurement of sustainability (Ulguiati 1998), the loss of biodiversity and the energetic emergent crisis are threatening global society. The methodology that we present in this work combines methodologies of energy and emergy evaluation, systems analysis, agrobiodiversity, and socio-economic analysis. Agroclimax helps to identify trade-offs, synergies from the agricultural systems on farm, local or regional level. Identification of these allows decision makers to formulate policies that would lead to achieving the goals of sustainable agriculture.

[4] *Meade (1973) defines externalities as consequences that arise from situations where actions of one system affect the production or well being of others, especially the welfare of systems who are ex-ternal to that decision.*

CHAPTER III

3. METHODOLOGY

Agro-climax analysis is proposed as an environmental assessment tool grounded in a multi-disciplinary approach including system analysis, thermodynamics, agro-biodiversity concepts like diversity and eco-volume, offering a biophysical alternative to conventional economic analysis. Agro-climax analyses consider resource use efficiency and yield, conservation and use of agro-biodiversity, importance of eco-volume and its environmental impact, the crucial issue of dependency on external resources and finally, the overall load placed on the environment by an economy or production process, as decisive factors determining sustainability.

The methodology allows also multiple dimensions of resource use to be considered on a common basis, which in turn generates understanding regarding the environmental trade-offs that must be made to increase economic efficiency. Having evolved from ecological and energetic considerations, agro-climax analysis can identify which forms of agriculture are more efficient at capturing and utilizing resources.

Agro-climax can be defined as:

> *"the state of agricultural systems in which sustainability components reach a balance, in function of a production system combining environmental and socio-economic factors within a region"*
>
> It is considered that agricultural systems can evolve to take advantage of all their potential for inherent specific (singular) development as well as for interacting with natural communities to increase total flow of energy in the system. The systems in agro-climax state try to maximize production and long term capital generation (as e.g. biodiversity, biomass, fertility), taking care to not threaten future productive capacity.

To corroborate this concept Lorenz (2003) and Dewar (2003) say that some systems tend to maximize power like self-organized systems. Odum (1996, 1998) proposes the Maximum Empower Principle contending that all self-organizing systems tend to maximize their rate of emergy use.

3.1. STUDY AREA

The application of the agro-climax methodology is applicable to all eco-regions and agro-ecosystems. The present study was developed mainly in a basin in the Atlantic Rain Forest of Brazil, and some of the data that support this evaluation of the methodology were also taken in Benin, Cameroon, and Mexico.

The mountainous region of the Atlantic Forest that formerly was one of the most diverse regions on earth is at present time covered with less than 8% of the original native forest. The existing ecological and economic resources of this region are of great importance for Brazil and even for the rest of the world (SOSMA 2006).

Fragmentation of the landscape, high biodiversity loss, high agricultural activity, be it intensive or extensive, and diversity of farming systems are important characteristics to evaluate the agro-climax methodology and its reach.

The main area for the evaluation was developed in the districts 2 and 3 of the Municipality of Teresópolis - Rio de Janeiro (Map 1). The central point is located at the Latitude of -22°24´43.2 and a longitude of 42°67´, with an altitude of 871 meters above sea level, whereas the average altitude of the whole municipal territory lies at 910 masl. The municipality has a total surface of 849.6 km^2, out of which 385 km^2 were taken as project area. The basin where most of the studies were concentrated was " Côrrego Sujo", having 9 micro-basins and convering an area of 53 km^2 (Map 1 and 4).

3.2. PHYSIC-NATURAL AND CLIMATIC DESCRIPTION

The *climate* of Teresópolis is typical of the Brazilian mountainous region, with oscillations of temperature and precipitation because of the difference of altitudes (from 300 to 1500 masl). The analysis of the climate was based on data from the meteorological station of Teresópolis located at 874 masl, latitude 42°58´12´´, longitude 42°58´42´´.

The historical data show two marked periods, the dry season with 5 months of water deficit and the humid season where 79% of the annual precipitation (1671mm) is concentrated (Fig. 3.1). The yearly average temperature is 17.7 °C. The total evaporation is 557.3 mm and the total annual radiation is 1931.3 hours.

From June to August, it rains between 10 and 20 days per month, whereas on yearly average 7 rainy days per month are recorded. The maximum precipitation registered in 24 hours was on 27/02/66 with 134.1 mm. The relative moisture remains almost constant during the whole year, with an average of 83%. The cloudiest month is December reaching a value of 8 in a scale from 1 to 10, while the less cloudy month is July with 5.

The wind blows with more frequency from SW direction, and the yearly average speed of the wind is 2.3 m sec^{-1}.

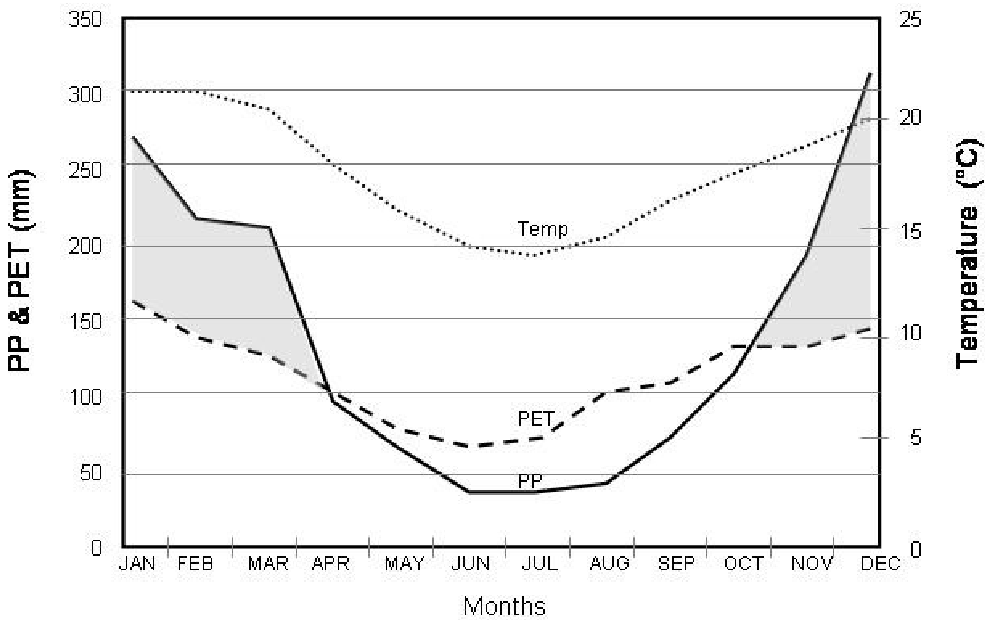


Figure 3.1. Climadiagram of Teresópolis - Rio de Janeiro, period 1943 - 2002. Modified from FAOCLIM 2001; Climatic Station of Teresópolis. The figure shows two marked periods, the dry station with 5 months of water deficit and the humid station where is concentrated 79% of the annual precipitation (1671mm). The yearly average temperature is 17.7 °C.

The most important soils present in the basin are latosol, cambisol, gleisol, alluvial and litolitic soils and are described as follows:

Red-yellow Latosol: Texture half to loamy, coloration net-yellow, thickness more than 2 m, low fertility and high aluminum concentration, pH from 3 to 5, average 4.3, CE 058 µv. In the Layer "A" it has bigger concentration of organic matter of natural and anthropic origin. The use that it is given in the region is mainly cattle grazing, horticulture and some permanent cultivations. They are mostly located on colluvial pediments.

Cambisol: Texture half to loamy, reddish coloration, thickness up to 1.5 m, low fertility and high Al concentration, pH 3 to 5, average 4.8, CE 060 µv. In the layer "A" it has bigger concentration of organic matter of natural origin and anthropic. The common uses in the region are cattle raising, horticulture and some permanent cultivations.

Gleysol: Naturally they present loamy texture, clear coloration, variable thickness, low fertility and aluminium excess. Current Measurements show pH. 4,2 to 6, average 5,2, these soils are conditioned for the horticultural production with addition of fertilizers, pH correction, Al concentration, etc. Located in alluvial plains.

Alluvial: Loamy texture, clear coloration, variable thickness, natural low fertility, high aluminium concentrations, pH from 3,9 to 5.9, average 5,3. Soils are intensely corrected in the Layer "A" for the intensive production of vegetables. They are located in plains.

Litolitic: Half texture, clear yellow colour, half thickness 0,30 to 0,70 m, very low fertility, high aluminium concentration, pH from 3 to 5, average 4,1. In few areas it is devoted to grass cultivation.

The Municipality of Teresópolis corresponds mainly to the basin of the "Río Preto", of which its biggest tributaries are in order of importance: Rio Paquequer (270 km^2 approx.), Bengala (136 km^2 approx), Sebastiana (Frades, 189 km^2), Corrego Sujo (53 km^2 approx), Serra do Capim, Formiga. (Map 3)

3.3. AGRO-CLIMAX EVALUATION

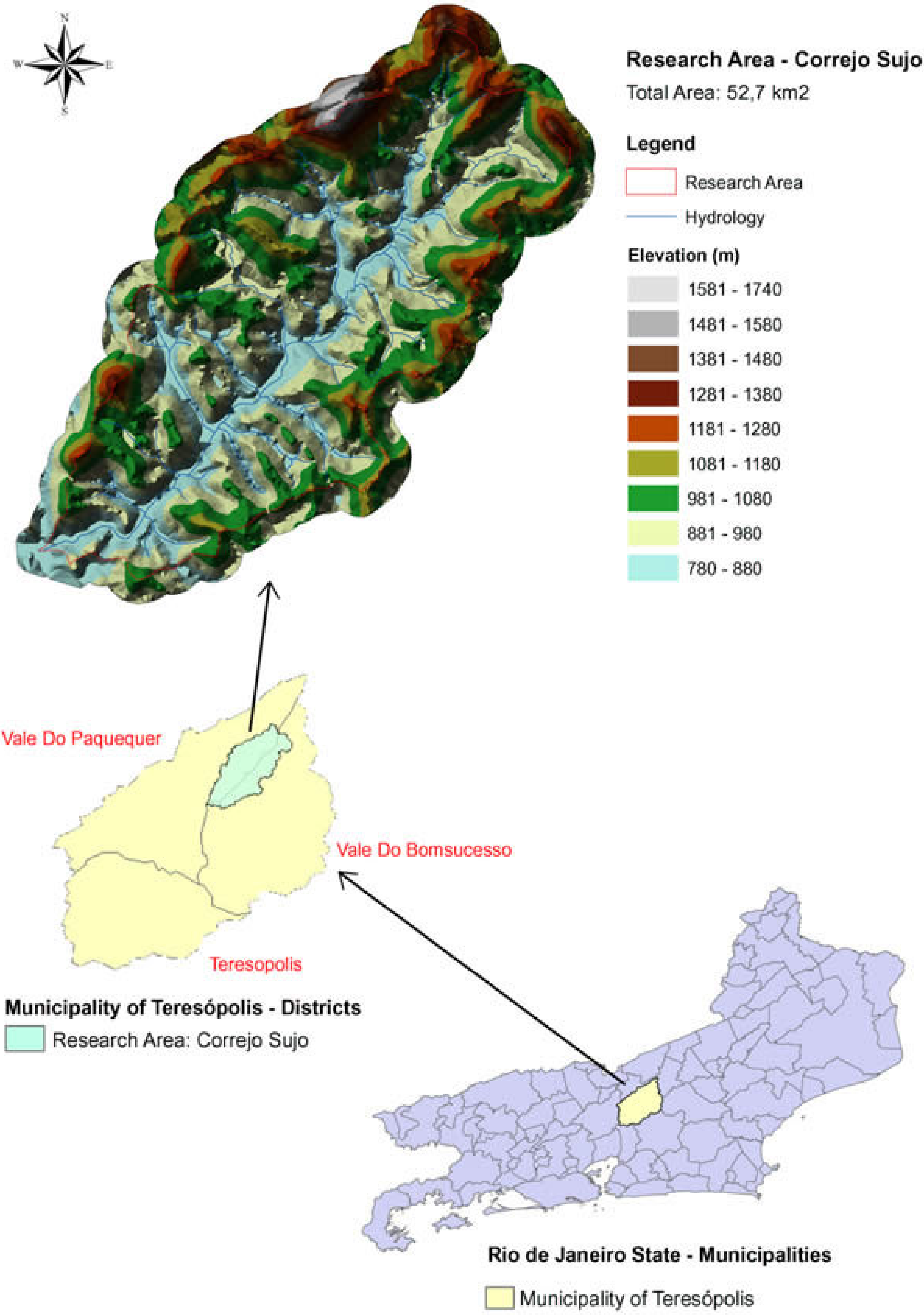
For the evaluation and confirmation of the hypotheses agro-climax evaluation combined 4 methodologies: the thermodynamic approach, the agro-biodiversity appraisal, the socio-economic rating, and eco-volume indicator. The combination of these methodologies allows obtaining a holistic vision of the situation and function of agricultural and natural systems. Only in this way it is possible to plan sustainable development.

3.3.1. EMERGY

> *Emergy can be defined as the total solar equivalent available energy of one form that was used up directly and indirectly in the work of making a product or service.* (Odum H.T. 1996, Odum E.C.2000).
>
> *Emergy expresses the cost of a process or a product in solar energy equivalents. The basic idea is that solar energy is our ultimate energy source and by expressing the value of products in emergy units, it becomes possible to compare apples and pears.* (Jorgensen 2001, p. 61)

The emergy methodology (Odum, 1996, 1988) is a quantitative evaluation method which valorizes the nature input to the economical systems. Emergy is a measure of direct and indirect supporting energy needed in different work processes supporting a product or a service (money, mass, energy, information), using a common unit. For this purpose, it makes use of systems theory, thermodynamics, biology and of open operation systems among which the universal hierarchy of energy, the auto-organization and establishment of largest possible flow of available energy in the system will be adopted.

Map 1. Rio de Janeiro state, Municipality of Teresópolis and Côrrego Sujo basin. Based on data from IBGE (2003)

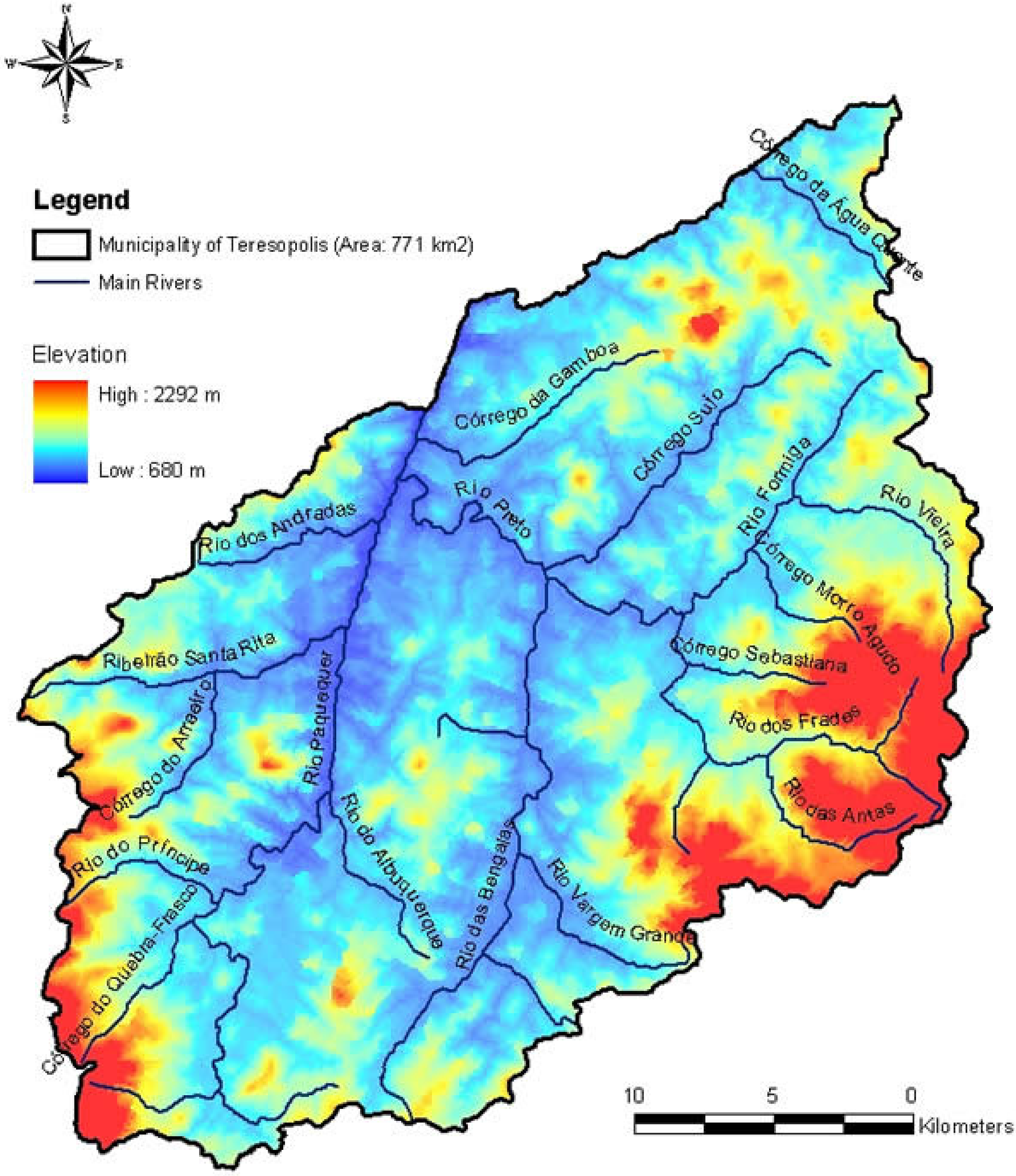


Source: Source: BLUMEN (2006), Eds. Lange & Kretschmer 2006.

Map 2. Political division of the Teresópolis Municipality. Based on data from IBGE (2003)

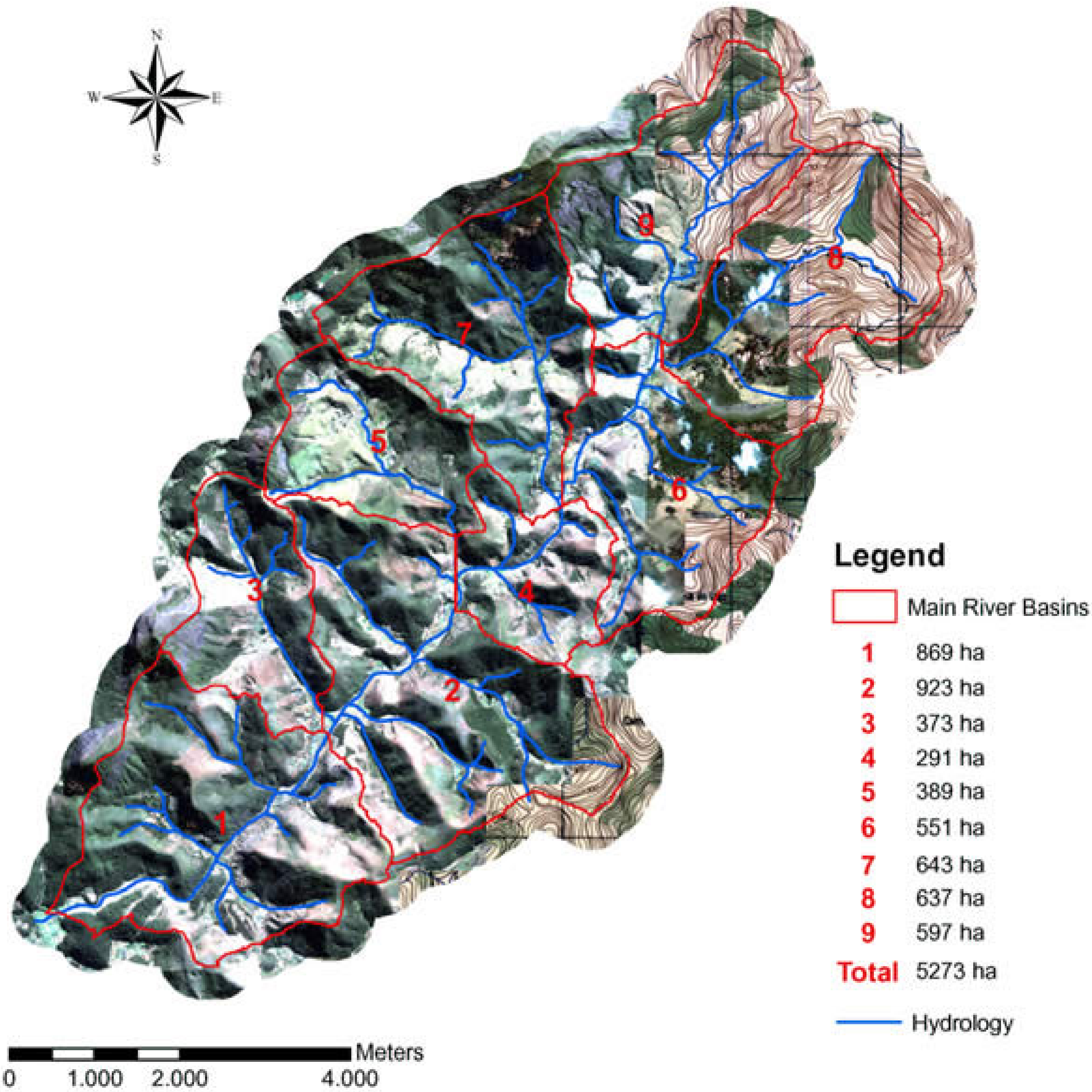
Source: BLUMEN (2006), Eds. Lange & Kretschmer 2006.

Map 3. Hydrology and elevation of the municipality of Teresópolis. Layers based on data from IBGE (1999 and 1983)



Source: BLUMEN (2006), Eds. Meier *et al*. 2006.

Map 4. Basin of Côrrego Sujo divided in 9 micro-basins. Based on data from IBGE (2003).



Source: Source: BLUMEN (2006), Eds. Meier *et al*. 2006.

In this method all processes are nested as environmental processes outside the analytical window. Hence, all definitions are therefore related to the overriding energy systems networks. The basic unit of measurement used is solar joules. It refers to the accumulated amount of energy used up in the chain behind a good or service and denotes its emergy value also coined as Solar Emergy Jouls, abbreviated as *sej*.

The transformities are the keys in the emergy analysis. They describe the amount of energy, expressed in (sej J^{-1}) or (sej g^{-1}), which has been used to create a flow or resource. A product's emergy divided by its energy is a quotient defined as its transformity. Thus, the transformity is the same as the emergy of one type required to make a unit of energy of another type.

What follows is a brief description of the methods used in performing the analyses specific to this thesis, Odum (1984, 1996), gives a detailed explanation of the application of emergy accounting procedures for a variety of systems.

The *procedure for the emergy evaluation* is described and summarized by Haden (2003) in three steeps: the first one consists of drawing the energy system diagram, the second one elaborates the emergy evaluation table and the third one the calculation of the emergy indicators as well as the summary diagrams.

An *energy systems diagram* is drawn using the symbols of the energy language of systems ecology (after Odum 1971) to graphically represent ecological energy components, economic sectors and resource users. The circulation of money through the system and the circuit language are described in Annex 2.

The various components and subsystems are connected with arrows that indicate energy flow as well as causal interactions, material and information flows. The boundaries of the systems studied in this thesis are two: a farm system level and a basin level with all the natural and human components (Fig. 3.2)

The second step corresponds to the *emergy table* and includes the emergy values of all components in the overview diagram, extracted from above-mentioned sources. Table 3.1. is a sample emergy evaluation table. Column 1 of the table gives the line number of each item and is a footnote reference for the emergy calculations that are available in Appendix 3a. Column 2 records the name of the item and the units of raw data for that item, usually Joules, grams or Reales (Brazilian currency). Column 3 gives the quantity of the component recorded in Joules, grams or Reales. The energy, material or currency flow for each item is then multiplied by its respective transformity, which is given in column 4. The product of the raw data and the transformity equals the total emergy contribution of that component to the system. The transformities used in this study were gathered from previously published analyses. Column 5 contains letters referring to the study from which each transformity was taken. The studies are listed by their corresponding letter in

Appendix 3a. The total emergy contribution of the component to the system is listed in column 6.

The emergy flows have been calculated taking into account the amounts of natural resources, material inputs and services for each production system. Those tables contain data of inputs per hectare per production unit in a period of one year.

Table 3.1. Sample emergy evaluation table.

Note	Item	Data	Solar transformity (Units yr^{-1})	Source	(sej/unit)
1	Sun	1,296E+11	1	[6] [7]	1,30E+11
2	Wind	3,06E+09	2,45E+03	[8]	7,49E+12
3	Rain	1,08E+11	4,70E+04	[9] 10]	5,07E+15
...	...	...	...	...	...

The *Summary Diagrams* shows all aggregated emergy inputs coming from the economy system as service or materials and from the natural system as renewable or not renewable resources.

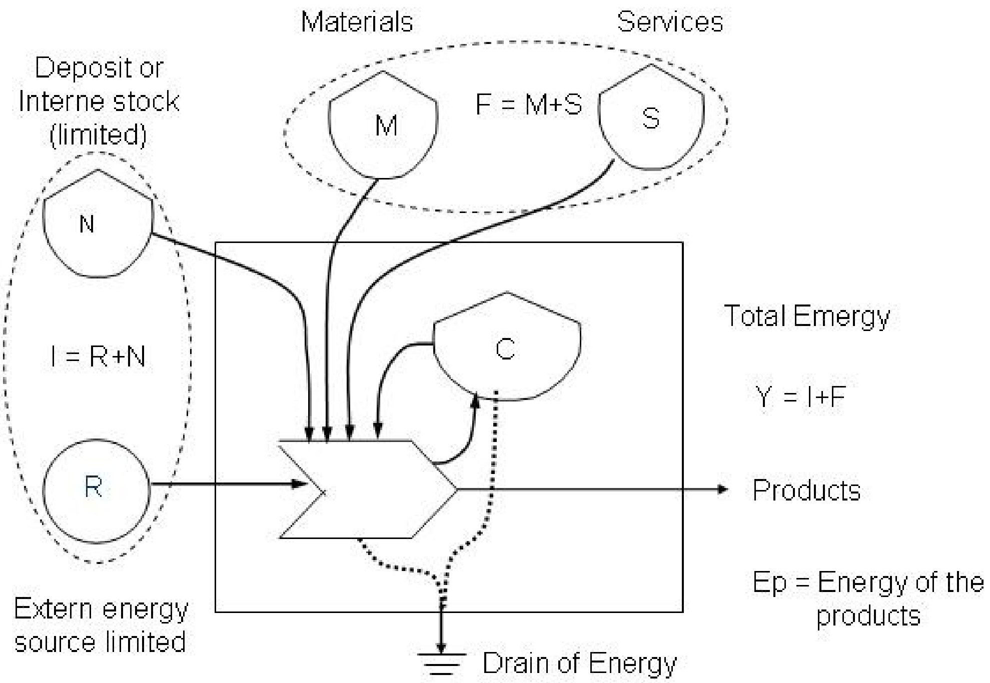


Figure 3.2. Aggregated emergy input and outputs coming from the economy system as service and materials and from the natural system as renewable and not renewable resources.

In Fig. 3.2, R is the sum of the renewable emergy flows supporting the economy (i.e. rain, waves, tide); N is the sum of non-renewable resources from within the system (national) boundary; M is the sum of all materials used or paid in the system; S is the sum of all services used or paid in the system; Y is the total consumed emergy; Ep is the total energy produced from the system and C is the capital of the system (biomass, biodiversity, water, soil fertility, etc).

After tabulating the material and energy flow data for the system in question and correcting for their emergy contributions using transformities, a number of *emergy ratios and indices* can be calculated. The used indices to determine the sustainability of the "Côrrego sujo" basin and different farming systems were the following:

Emergy Yield Ratio (EYR): it evaluates the efficiency of a production unit or process. If the relationship is smaller than 1 the system consumes more than what it produces. *EYR = Y/F.*

Environmental Load Ratio (ELR), measures the environmental impact. When the relation has a high value it suggests that the system uses high technological levels in terms of emergy. *ELR = (N+F)/R.*

The *Emergetic Investiment Ratio (EIR)* measures the dependence of the system from bought products, and indirectly measures the environmental loads. The value increases proportionally with the dependence. *EIR = F/I.*

The *Emergy Exchange Ratio (EER)* measures the capital loss of the system. If the values are smaller than 1, it means that the system transfers positively to the economic urban system.

*EER = Y/income*3,18E12*

The *Sustainability Index (SI)* gives a general measure of ecological sustainability. The SI assumes that the objective goal of sustainability is to achieve the highest yield ratio attainable while placing the least load possible on the environment. High SI figures indicate that the emergy yielded by a production process or economy is to a high degree reliant on renewable emergy flows and therefore more compatible with the local environment. *SI = EYR/ELR*

Transformity (Tr) is the amount of energy expressed in (sej J^{-1}) or (sej g^{-1}), which has been used to create a flow or resource. *Tr = Y/Ep (Sej* J^{-1}*)*

Renewability (%R) indicates the percentage of renewable emergy in relation to the total emergy used from the system. %R *= R/Y*100 (%)*

3.3.2. ECO-VOLUME

Eco-volume is the aboveground quantifiable volume limited by the uniform vegetable composition and its height, in which coexist and wide interactions are developed among biotic and abiotic components.

Eco-volume is the product of the area occupied by a uniformed type of vegetation and its eco-height.

Eco-height renders a weighed average over time and across the different vegetation community fractions. In this case, a vegetation reaches community status as from canopy closure onwards and its height will be given by the domineering (upper layer) plants.

The general hypothesis of the eco-volume is: if eco-volume increases, then the possibility to harbour more biomass and biodiversity grows, whereas energy flows and their positive effects on the microclimate will improve by the same token. The quality of Veco can be measured in the easiest way by the total exposed plant bio-surface which it is composed of and by the production of annual litter fall, which in turn determines gross photosynthesis at equilibrium when multiplied by 4. Hence, Pb= 4 x Litter fall (Janssens *et al*. 2004b)

Eco Volume (V_eco). Surface of given phytocenose or agricultural system multiplied by the eco-height. Eco-Volume normally to be expressed on ha basis. It is expressed in m^3ha^{-1}.

Eco-height (H_eco). It is the average height of a plant community, weighed over time and across community components.

Bio-Volume (V_bio). Bio-volume, is the total volume of the plants (trees, bushes, herbaceous, etc) that occupy a certain space. The concept is based on the hypothesis that plants mainly compete for space. It is expressed in m^3ha^{-1} . A very quick approach proposed by Janssens *et al.* (2005) was assumed: that a plant is an assembly of tubes and that all parts could be squeeze within a cylinder formed by: *Vbio = Basal area x Heco.*

Crowding intensity (Ci) measures the colonized volume by a crop, weeds, trees, etc. *Ci= Vbio/Veco*

Wesenberg factor (Wf). Is the opposite to the Ci. *Wf= V_eco/V_bio = 1/Ci*

Volume efficiency (Ve). Relates the yield expressed in $US or energy with the lost Veco w.r.t. the maximal eco-volume at eco-climax in the same locality. It measures the efficiency in relation to the potential V_eco (V_pot). It is expressed in m3 MJ^{-1} or m^3 $\$US^{-1}$.

Ve=(V_pot-V_eco)/Yield (Fig. 3.3 a, b)

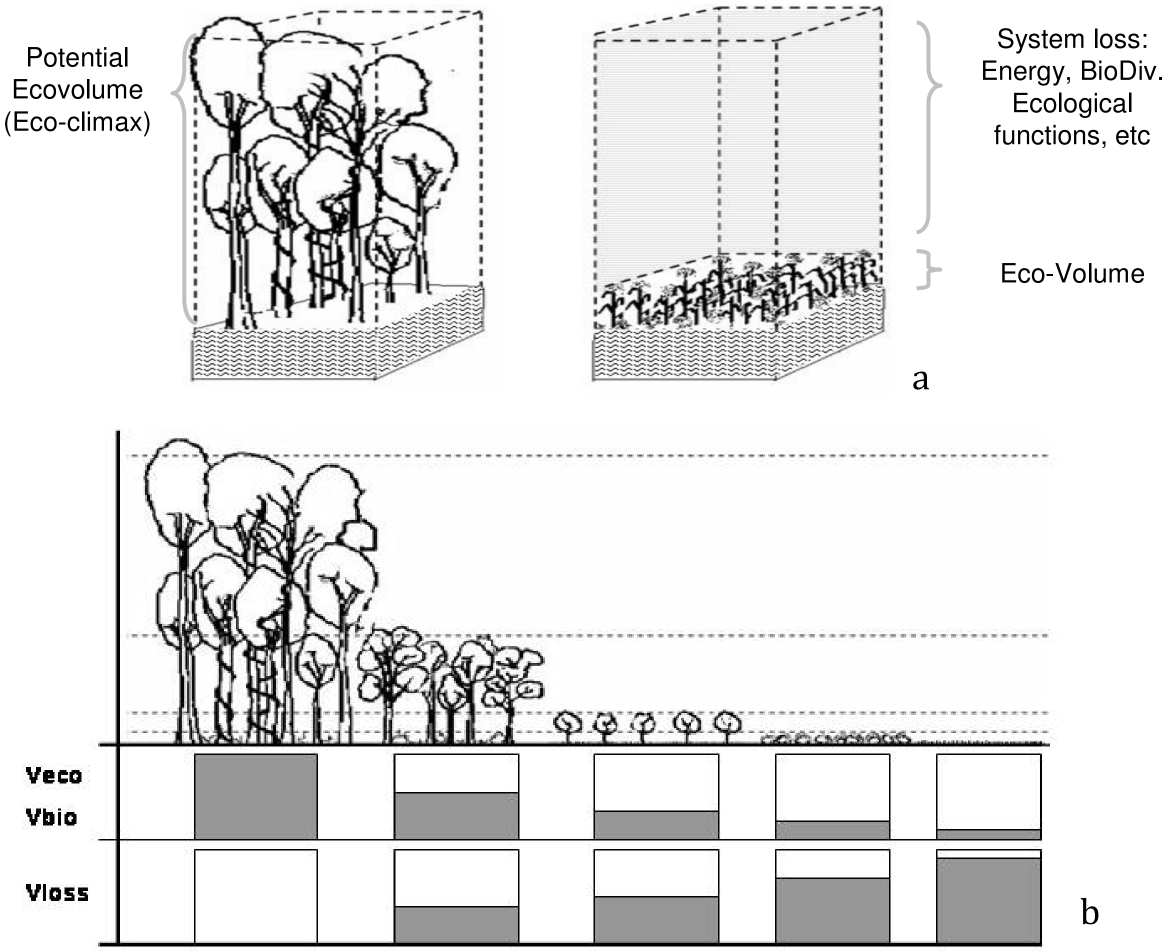


Fig. 3.3. a: Illustration the Potential Eco-volume and the lost of V_eco. b: illustration of different vegetation communities and its general relation of V_eco, V_bio and V_loss.

3.3.3. AGRO-BIODIVERSITY

Before we explain the methodology it is very important to know what will be understood under agro-biodiversity. Several definitions are circulating and each author tends to define it accord to his research framework as illustrated here under.

Agro-biodiversity is commonly used to mean the diversity of useful plants in managed ecosystems and many authors connect the term with direct use of biological species, including all crops, semi-domesticated and wild species. Since the 90's it was to integrate that part of the whole agro-ecosystem that is actively managed by farmers, within which many components would not survive without the human interference, it means, the indigenous knowledge and culture are integral parts of agricultural biodiversity management.

From that perspective many factors are important as diversity management, biophysical diversity, organizational diversity, short-term and longer-term change in cropping and management practices.

Qualset *et al*. 1995 defines as agro-biodiversity "All crops and livestock and their wild relatives, and all interacting species of pollinators, symbiosis, pests, parasites, predators, and competitors". Brookfield & Padoch 1994 defines it 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"

We accept the suggestion from Brookfield (2001) with only two observations: the first one is that the agro-ecosystems are connected to the naturals systems and the second one is that the farmers manage the genetic resources also in an ecological context. In the agro-climax framework agro-biodiversity includes the management of the field and fallow areas, wide range of plants and other biota, includes management of biophysical resources and technology, agricultural practices, and disease management. In that sense we understand agro-biodiversity as:

> *"The dynamic variation in farming systems that occurs within and between agro-ecosystems and natural systems. It arises from the many and changing ways in which farmers manage diverse genetic resources in dynamic ecological and socio- economic contexts"*

For the development of this research work only the plant diversity was considered i.e. cultivated crops, herbaceous cover, bush stratum, forest in regeneration state and secondary forest (Map 4). 16 farms (cases studies) and 106 production units were evaluated to determine the agro-biodiversity management, socio-economic situation, and interactions at the household level. The data were collected at farm and plot level.

Generally, they were evaluated in 3 groups of agro-biodiversity indicators proposed by OECD (2003): (a) Use and management of biodiversity, (b) Indicator of agricultural crop genetic resources, and (c) Community diversity (here not considered).

a. Use and management of biodiversity

Different questionnaires were developed to collect the information regarding use and management of resources. The main topics were socio-cultural and socio-economic data, availability of physical-natural resources, management and use of plant diversity, and finally analysis of the problem complex (Annex 8). These surveys were implemented according to the following phases:

Preparation, with the consultation of experts for one month. Reports and secondary information were collected about climate, vegetation, land holding, population, satellite maps, etc.

Previous test of the survey. 12 preliminary surveys were tested in the field and the deficiencies were readjusted, mainly in the formulation form and for the separation of the information.

Execution in the field. 164 rigid surveys were carried out as a main tool to characterize the production systems and management of resources. Morevover, 28 informal interviews were taken. Three participative workshops were carried out: the first two to collect information and to create discussion about topics of resources use and problem complexes, the last workshop was for validation of the information, in which the obtained results were discussed and adjusted, making a total of 260 productive units among interviewees and participants of the workshop.

During two years 16 case studies were carried out. These investigation points have been selected through the following criteria: (i) The production systems are different, (ii) The agricultural, forest and/or cattle components exist in the production systems, (iii) The points are well distributed in the study area, (iv) The farmers agree with the investigations, and (v) The points are also of interest for the evaluation of agro-climax.

Statistical analysis and interpretation. A database was designed in Excel, and the data were processed and analyzed with simple calculations of average, sum, frequency, percentage, correlations, ANOVA, etc.

b. Indicator of agricultural crop genetic resources

Plot level data were collected from each unit of the farm. For each unit, the area was measured, and the different species of crops and trees identified and enumerated. The richness, abundance and dominance, richness and evenness through Shannon diversity index, Simpson diversity index were calculated (Pielou 1969, Magurran 1988, Lessandria 2002). The values obtained from the above calculations were analysed statistically to test for significance of differences.

The Shannon Diversity Index (H'), is a measure of the average degree of "uncertainty" in predicting to what species an individual chosen at random from a collection of S species and N individuals will belong. This average uncertainty increases as the number of species increases and as the distribution of individuals among the species becomes even. Thus, H' has two properties that have made it a popular measure of species diversity: (i) H' = 0 if and only if there is one species in the sample, and (ii) H' is maximum only when all S species are represented by the same number of individuals, that is, a perfectly even distribution of abundances. (Merman 2004, Magurran 1988, Eiden 1994)

$$H' = -\sum_{j=1}^{S} P_i \cdot \ln P_i \quad \text{(Shannon Diversity Index, Magurran 1988)}$$

Where P_i is the proportion of crop area composed of species i.

The Shannon index is high when the relative abundance of the different species in the sample is even, and is low when few species are more abundant than the others. When all species in a sample are equally abundant, it seems intuitive that an evenness index should be maximum and decrease toward zero as the relative abundances of the species diverge away from evenness

The Evenness (E) is the ratio of observed diversity to maximum diversity. *E* has values between 0 and 1.0. The less variation in populations between the species, the higher *E* is.

. $E = \frac{H'}{H_{\max}}$ or $E = \frac{H'}{\ln S}$ (The Evenness (E), Magurran 1988)

The *Simpson* is a *dominance index*, which is suited for inter-varietal diversity combining the number of varieties planted with their relative importance (Meng *et al.* 1998).

$$D = 1 - \sum_{j=1}^{S} P_i^2$$

The *H'* and *E* indices, which are generally referred as *alpha diversity*, indicate richness and evenness of species within a locality, but they do not indicate the identity of the species and where they occur. Consequently, variation in composition of species among the different farms and systems was determined by computing *Beta diversity*. *Beta diversity (â)* expressed in terms of a similarity index between different habitats in the same geographical area (Huston 1995).

â = 1 - Cj , where *Cj* is Jaccard's similarity index (Magurran 1988)

Cj = j/(a+b - j)

where

j = the number of species shared by any two sites a and b,

a = the number of species in site a, and

b = the number of species in site b

The Net Present Value (NPV), Benefit cost Ratio (B/C), Internal Rate of Return (IRR), labour intensity from each production unit were also calculated and analyzed.

A GIS data base was developed, and with this tool all land use types and habitats, fragments, regeneration forest, grass land, afforested areas, cultivated areas, etc. (Map 5) were drawn.

3.3.4. PLANT BIOMASS ASSESSMENT

The determination of the biomass was important for the energy calculations, emergy and eco-volume. During 18 months (6/2004-12/2005) biomass production and partitioning was measured. Six types of vegetation were evaluated: Forest, fragments (secondary forest), forests in regeneration of 1, 2 and 3 years, aquatic plants, horticultural cultivations, clean grasses and sylvo-pastoral systems.

Litter fall of 4 fragments of 9, 23, 39 and 62 ha was collected. Litter collectors of 1x1 m were installed at soil level, 6 in each fragment along a diagonal transect (Fig. 3.4a). The samples were collected monthly, and were separated for leaves, branches and fruits. Taking advantage of the clearing activities in regeneration areas foro agricultural purposes, small parcels of 2x2 m were marked that represent the heaps where farmers pile up the cleaned biomass. A total of 6 areas were evaluated at the rate of 2 plots for each of age categories 1, 2 and 3 years respectively, making a total of 36 widely distributed plots (Fig. 3.4b). It was weighed only once. In the flooded areas distribution of vegetation was homogeneous, reason why only two plots of 2x4 m for each area were necessary (Fig. 3.4c). The phytomass was collected every 4 months. In grass areas plots of 4 m^2 (2x2 m) the biomass was collected every 3 months, 1 m^2 each time (Fig. 3.4d). In the crop parcels the ridges were taken as plot parcels as commonly used for horticultural production. They were about 1.2 m wide and 20 m long (Fig. 3.4e). The phytomass was measured at harvest, and the total biomass production and its partitioning were determined as well as the percentage that stays in the systems and the quantity that leaves as commercial product. Finally, in the sylvo-pastoral systems the grass methods of biomass collection with parcels of 10x40 m were adopted (Fig. 3.4f) to determine the forest species biomass. For most of these species the destructive method was applied taking advantage of the thinnings. Total biomass was also calulated through volume measurements and its specific wood weight.

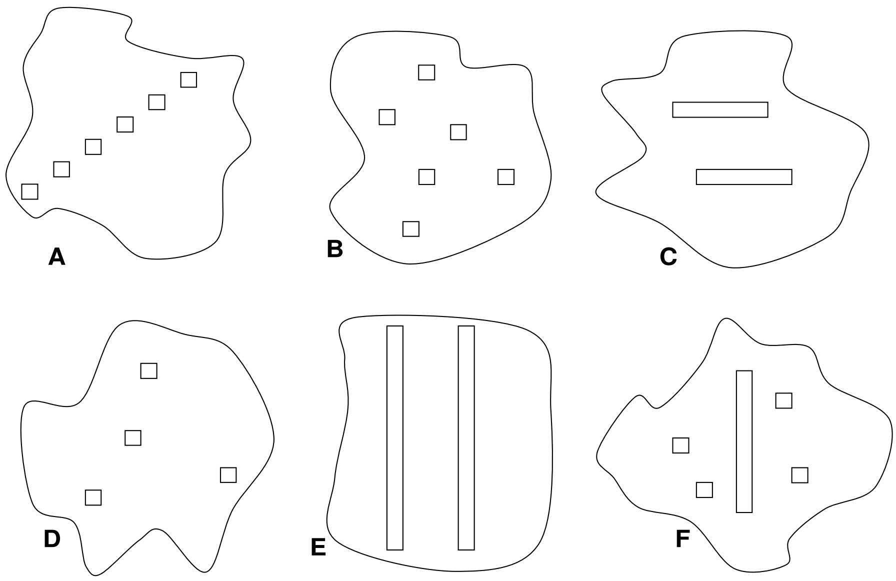


Figure 3.4. Plot design for litter collection and phytomass measurement parcels. A. Fragments, 6 collectors for fragment in diagonal position, to cover the borders and the central part. B. Forests in regeneration, it was taken 6 points at random of 2x2m. C. Flooded areas, vegetable material of parcels of 2x4 m given m their homogeneity was collected. D. Grasses, 4 collectors of 1x1m, were marked per lot. E. Agricultural, given the production system in ridges 1.20x20 m parcels was taken. F. Sylvopastoral, parcel of 10x40 m for forest species, combined with 4 marked areas of 1x1 m for the determination of the grass production.

CHAPTER IV

4. FINDINGS AND DISCUSSION

4.1. LAND USE DESCRIPTION

In total the municipality of Teresópolis has 24 micro-basins further subdivided into 86 "nano-basins". The water-basin of concern in this study, "Côrrego Sujo", has a surface of 5323 ha, divided in 8 micro-basins to facilitate the data collection. The digitalization of the images "Iconos" gave the land use division presented in the Table 4.1.1 and Map 5.

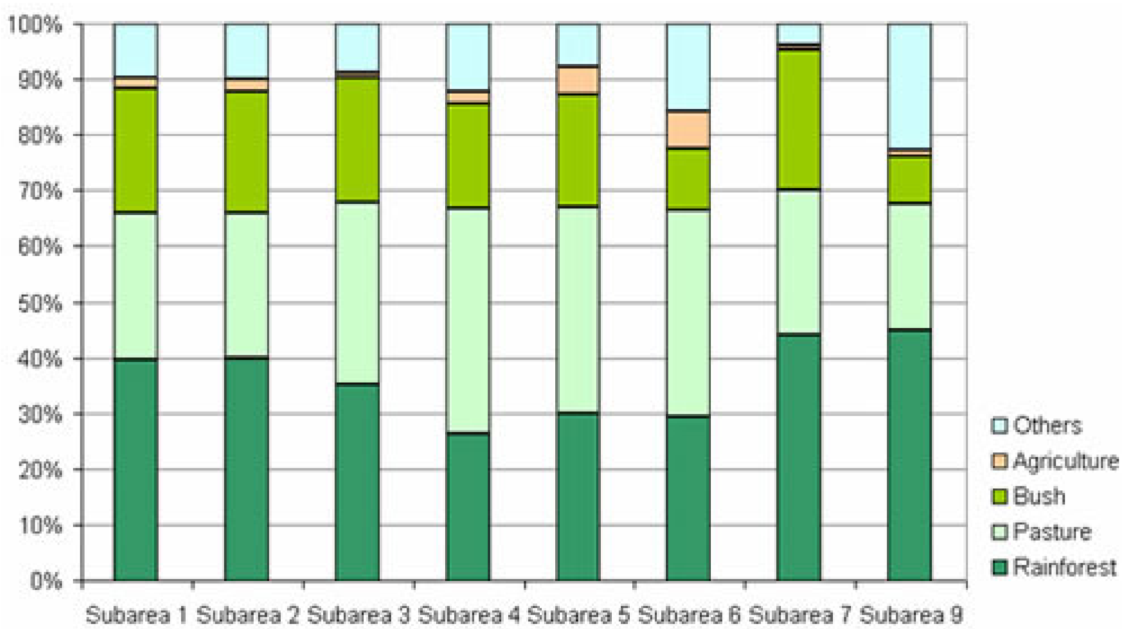
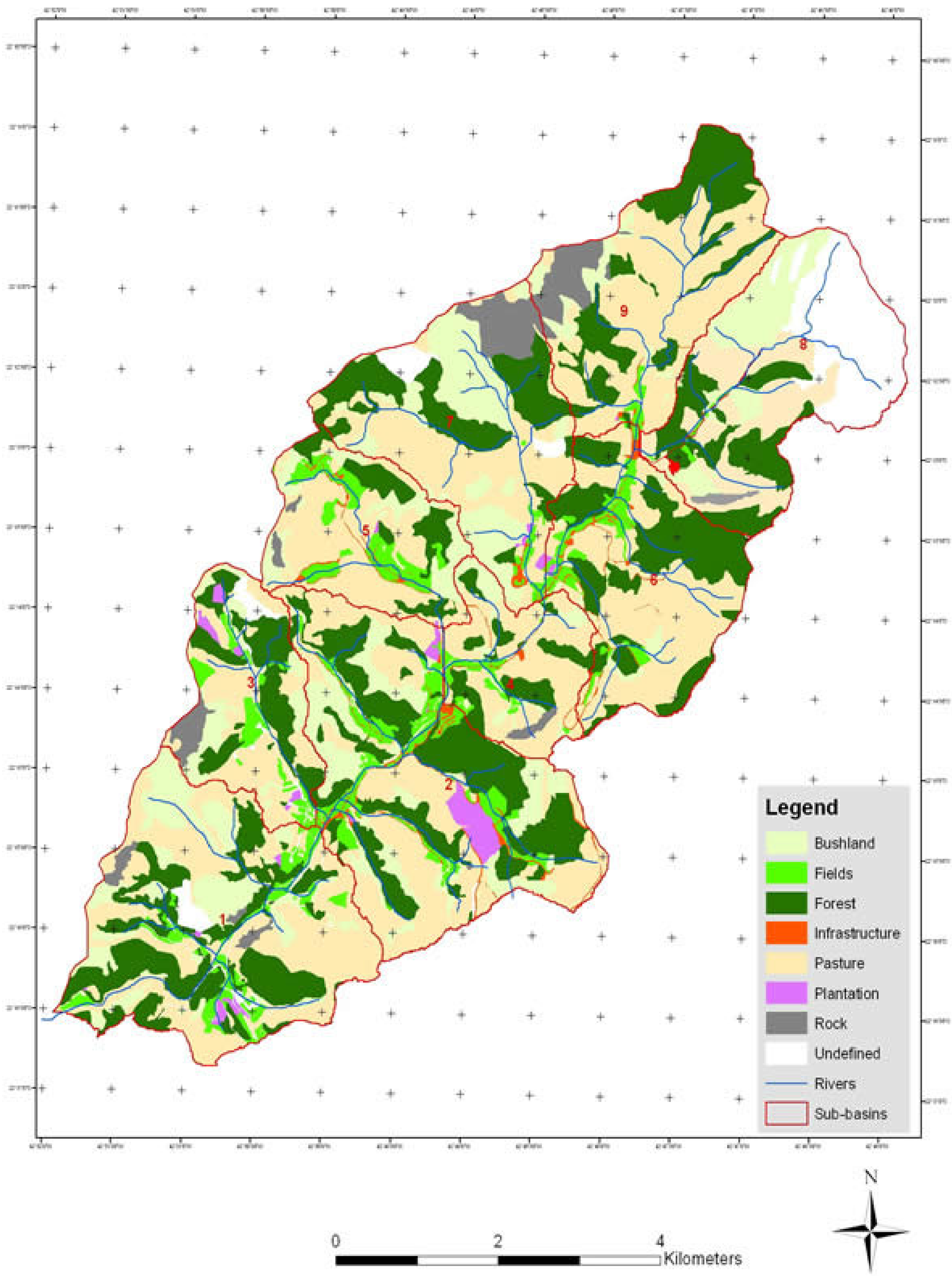


Figure 4.1.1. Share of different land use types for each sub area (in %)

Forests occupy the biggest area with 36.2%, followed by the grasses (31.1 %), bushes (18.8 %), the areas corresponding to rocks, open areas, colonies (11.4%), and with 2.6 % in the last position is the crop area (Table 4.1.1 and Figure 4.1.1)

Map 5. Land use of Côrrego Sujo basin.



Source: Source: BLUMEN (2006), Eds. Meier *et al*. 2006.

Tabla 4.1.1 Land use (ha) within the micro-basin "Côrrego Sujo" as subdivided in 8 sub-areas

Classes type	**% of total area**	**Area (ha)**	**sub-area 1 (%)**	**sub-area 2 (%)**	**sub-area 3 (%)**	**sub-area 4 (%)**	**sub-area 5 (%)**	**sub-area 6 (%)**	**sub-area 7 (%)**	**sub-area 9 (%)**
Setlement	0.20	11	0.13	0.12	0.31	0.12	0.03	0.06	0.39	0.44
Agriculture	2.59	138	1.86	0.74	4.93	2.3	1.04	1.01	2.18	6.65
Pasture	14.98	797	8.12	13.8	17.77	12.84	17.37	22.16	5.49	22.27
Pasture mix	16.09	857	18.2	18.9	19.2	27.71	8.7	0.8	20.51	14.72
Rain-forest	36.16	1925	39.56	35.23	30.05	26.34	43.94	44.75	39.92	29.49
Forestry	0.83	44	0.76	0.01	0.01	0	0.78	1.19	3.9	0
Water	0.13	7	0.16	0.17	0.15	0.12	0.05	0.06	0.23	0.1
Soil open	1.89	101	1.35	1.15	0.82	2.41	0.21	0.3	2.54	6.37
Rock	8.33	443	7.27	7.51	6.51	9.45	2.72	21.18	3.03	8.96
Bush	18.80	1000	22.58	22.37	20.26	18.71	25.15	8.49	21.81	10.99

Source: BLUMEN (2004)

In general the wavy relief of the mountainous area is dominated by three components, the first are the fragments of the Atlantic forest that extend in the higher parts or on steep slopes; the second component is composed of hillside pastures where *Brachiaria* dominates, and in some cases covers complete hills; and the third component encompasses agriculture in the river-beds. Many grass swards are actively regenerating and eventually end up in bush vegetation (*Capoeiras*). The most important land covers are described in the Table 4.1.2.

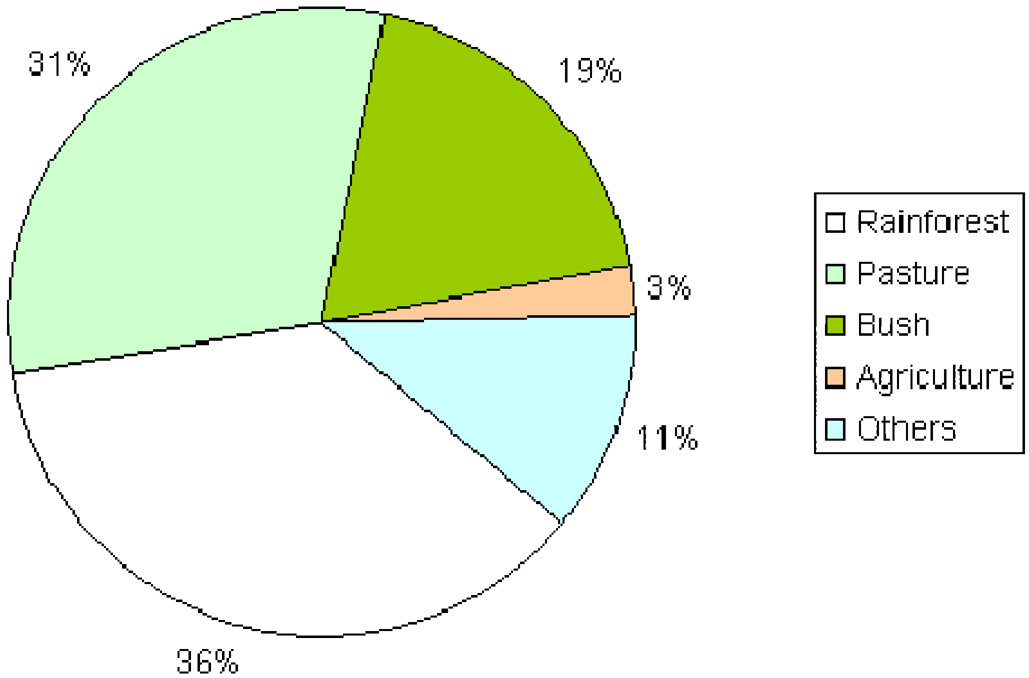


Figure 4.1.1. Share of different land use types for the Côrrego Sujo

Table 4.1.2. Land cover description

Land Cover	Description
Developed forest	Presence of species older than 30 years, high presence of epiphytes and lianas, and the canopy is closed. This kind of vegetable covering corresponds to most of the coverings of the national park and some fragments.
Forest of intermediate development	The semi-arboreal and bushes species prevail; the arboreal vegetation begins to show predominant, little presence of epiphytes. Most of the small fragments.
Forest in initial development condition	Lacking epiphytes, the gramineous cover prevail, the bushes and herbaceous plants can reach up to 4 meters high. Many abandoned pastures with more than 5 years in so far not burnt.
Grasses and bushes	Presence of clean areas with gramineous plants for shepherding in some cases with thin bushes.
Agricultural	Horticulture predominance, besides areas with citrus
Vegetation of waterlogged areas	*Typha domingensis* dominates; characteristic waterlogged land. Besides these conservation units and the National park, around 212 fragments which have an area average of 12.8 ha are observed in the region

Of the 2954 existent establishments in Teresópolis a little more than 2500 have positive conditions for agricultural production. Manpower is enough to increase cultivation area or to intensify production. On the average there are three people per farm unit, totally dedicated to production. The population growth in the region remained constant in the last years, i.e. less than 1% of annual growth.

The property holding on average is 6.8 ha, where 66% of the proprietors have more than 17 ha and 54% less than 1 ha ("*mediators*" i.e. landless workers sharing half of the harvest with the land owners). The production units with agricultural speciality have on average 33% forest area, 22% horticultural cultivation, and 14% pasture.

In general, the municipality disposes of enough water for all purposes. The topography is undulating with 12 steep mountainous areas that, at the same time, are forest reserves with ample water resources. The residents' testimonies indicate that the water resource was never a problem neither for human consumption nor for agriculture, but that in the last 50 years the flow has decreased in some cases as far as 50%, due to deforestation and to the loss of many small water sources. According to our survey one out of every 6 small sources has dried off and two are in danger of drying off. Since the horticultural production was intensified 40 years ago, water quality is visibly degrading at first sight, with bigger cloudiness and transport of solid materials mainly because of erosion.

From the farmer's point of view (98% of the cases), the soil fertility is considered very good to good, only very few responded that soils have fertility problems. In fact soils of this region have fertility from medium to low, but with the intense handling of fertility by means of soil pH correction through constant organic and inorganic fertilization, "artificial" soils with good fertility are obtained.

The agriculture in the region is characterized by intensive, small (less than one ha) but often irrigated horticultural production systems. This horticultural system has little or none interaction with the cattle and forest subsystem. The inputs such as organic and inorganic fertilizers are introduced to the system. The plants are produced in the region using good quality seed. Most of the young plantlets are produced locally in specialized nurseries. The products of the system are marketed by different channels, mostly dominated by middlemen who take the production to the surrounding markets. The productive units generally opt for diversification market strategies, since the prices are quite fluctuating during the whole year.

From 1793 ha under agricultural production 74% (1327 ha) correspond to cattle production (CPS) and syslvopastoral systems (SPS) 2%. The average animal load is 11 animals pro 10 ha. Extreme values of 2 up to 67 animals pro 10ha were found. In the humid season the average milk production is 7.5 l d^{-1}, and in the dry season of 4.5 l day^{-1}. After 40 months of fattening the meat livestock produces approximately 165 kg of clean meat/head that are marketed through middlemen and sold in bordering markets. The rest 24% is occupied mainly by horticultural systems.

The intensive horticultural systems are the most important economic activity and occupies circa 403 ha. Mainly five types of horticultural systems exist in the region: (i) the leaf vegetables systems (LVS=58% of all units), i.e. all leafy cultivations that have cycles shorter than 5 months as for example, lettuce, cabbage, spinach, etc., (ii) The fruit vegetable systems (FVS=20%), having a cycle longer than 5 months, such as, vegetable pear, lady fingers, squashes, cucumber, tomato, *Solanum gilo* etc., (iii) The Mixed Fruit and Leaf Vegetable Systems (MVS) (15%), that combine both the LVS and the FVS, for example, vegetable pear with lettuce, (iv) The Perennial Cultivations (CPS) (5%), that have perennial cycle such as mint, tangerine, etc. and finally (v) The Ecological Production systems (ECO) that are very rare (<2%) (Details from each farming system are described in § 4.2)

CONCLUSIONS ABOUT LAND USE

The landscape is dominated by three components: forests (fragments, 36.2%), grasses (31.1%) and forest regeneration (18.8%). This landscape tends to change little by little, replacing pastures either by horticulture or in places with steeper slope, by forest regeneration. The cropped area is only 2.6% of the total available land.

The production conditions are very favourable for vegetables in terms of physical and market conditions. These conditions are threatened by deforestation, though. Further, the intensive production systems themselves impair the quality of water resources. In some areas erosion threats the sustainability of the production systems.

4.2. AGROBIODIVERSITY

The agricultural evolution in Brazil has been a unique case in the world. The widespread extension of coffee, cocoa, sugar cane and manioc plantations and the extraction of the "*Pau Brasil*", Brazil wood, *Caesalpinia echinata* have been important causes for the current status of ecological losses in the Mata Atlântica. Production intensity and acreage extension have accelerated in the last 100 years leading towards disastrous effects on forest loss and soil depletion.

The introduction of coffee in 1718, cocoa in 1746, and sugar cane in 1746 (Homma 2003) started the development of the typical agricultural production structure in the Mata Atlântica rainforest. At about the same time large-scale cattle raising was introduced.

The Mountain Region of Rio de Janeiro was found to be difficult to access. Therefore, the sporadic presence of coffee did not have the devastating character as in other regions. The first agricultural settlements in this region were established approximately 110 years ago with the introduction of yams and kidney bean (*Phaseolus vulgaris*) for domestic consumption. It was only a few years later that some farmers planted coffee with commercial purposes and that African grasses were introduced for pasture land, at the cost of forest land. It was only in the 1930s that the population growth in the Mountain Region of Rio de Janeiro accelerated accompanied by a specialization of agricultural production systems towards kidney bean, corn, beet, carrot and some other vegetables.

Since the 1940s and 1950s a new era has come up in the agricultural production systems, in response to the high demand of vegetables in Rio de Janeiro. The former production systems of one annual crop or perennial crops was changed to intensive systems of multicrop cycles, specializing more and more the horticulture with the corresponding increase in the use of agrochemicals. Animal husbandry, however, was decreasing although pasture areas remained stable, if not increasing further.

4.2.1. LANDSCAPE

The mountainous areas is dominated by three components: the first are the fragments of the Atlantic forest that extend either in the higher parts or steeper landscapes; the second component are wide pastures on hillsides where *Brachiaria decumbens* dominates; and the third component encompasses agriculture in the river-beds (Thalweg). It is also frequently observed that current grass swards regenerate little by little to become "Capoeiras" (bush vegetation) (Figure 4.2.1 a).

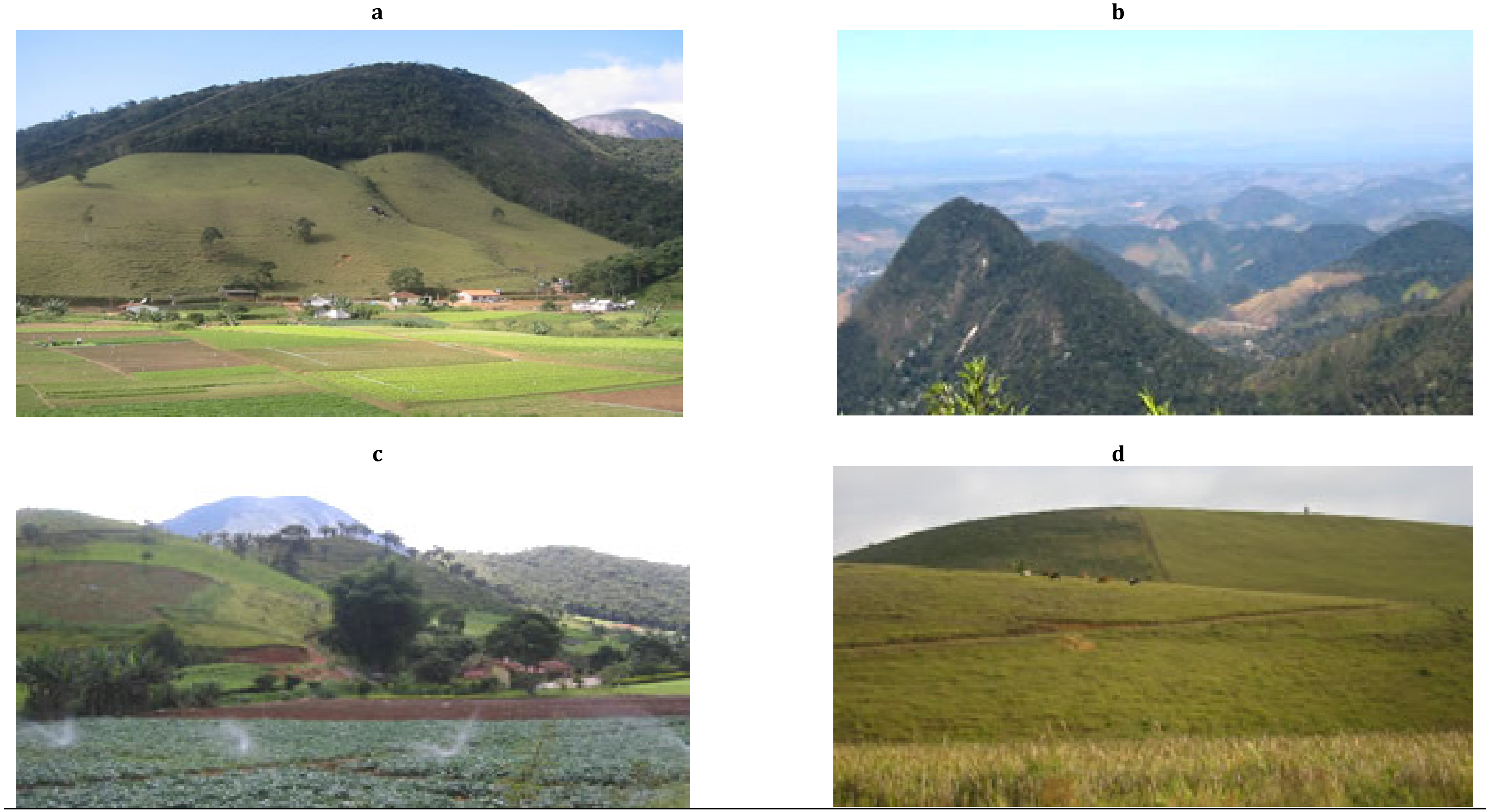


Figure 4.2.1. Landscapes components in the study area. (a) General landscape overview of grass, fragments and crops; (b) mountainous relief; (c) intense horticultural production (d) pastures

The municipality of Teresópolis is characterized by its uneven and mountainous relief. Among the main hilly ones are "*dos Orgaos", "Albuquerque", Paquequer", "Demanda", "Firmamento", "Gamboa", "Capim*". The lowest part of the municipality is at 145 masl and rises up to 2263 masl, that is the highest peak. The mountains are on average from 900 to 1400 masl, they are wavy, covered with vegetation distributed in forest fragments and grassland on the hillsides, whereas agricultural cultivation prevails in the lower parts (Figure 4.2.1.b).

In districts two and three, corresponding to the rural area of Teresópolis (Map 2), the typical landscape combines above three vegetation elements, all three clearly delineated. Very marked limits divide pastures from forests or agriculture from forest, indicating little interaction among these components. The lower parts are dominated by intense horticultural production (Figure 4.2.1.c). Grassland dominates landscape in many regions of the municipality. Brachiaria decumbens is the most common grass species. It was introduced there more than 40 years ago whereas "*capim gordura*" (*Melinis minutiflora*) disseminates with easiness after forest clearing. The grasses are distributed on slopes of 45% up to 55%, sometimes even beyond 65% (Figure 4.2.1.d).

4.2.2. BIODIVERSITY IN FARMING SYSTEMS

During survey of agrobiodiversity of farming systems, only plant diversity was evaluated i.e. crops and plants, herbaceous cover, bush vegetation, and tree species inside the farming systems. The evaluated farming systems in Teresópolis were:

(i) Leaf vegetables systems (LVS);
(ii) Fruit vegetable systems (FVS);
(iii) Mixed Fruit and Leaf Vegetable Systems (MVS);
(iv) Citrus Production systems (CPS);
(v) Ecological Production systems (ECO);
(vi) Cattle Production systems (CPS) and
(vii) Sylvopastoral system (SPS).

In figure 4.2.3 the different systems can be appreciated. The clearly dominant system is cattle raising with 74% of the total agricultural surface of the basin. The horticultural systems are the second more important (24%), of which the leaf-vegetables systems are most important with 14%. The sylvopastoral system occupies only 2% and the ecological and organic cultivations less than 0.4% (Figure 4.2.2).

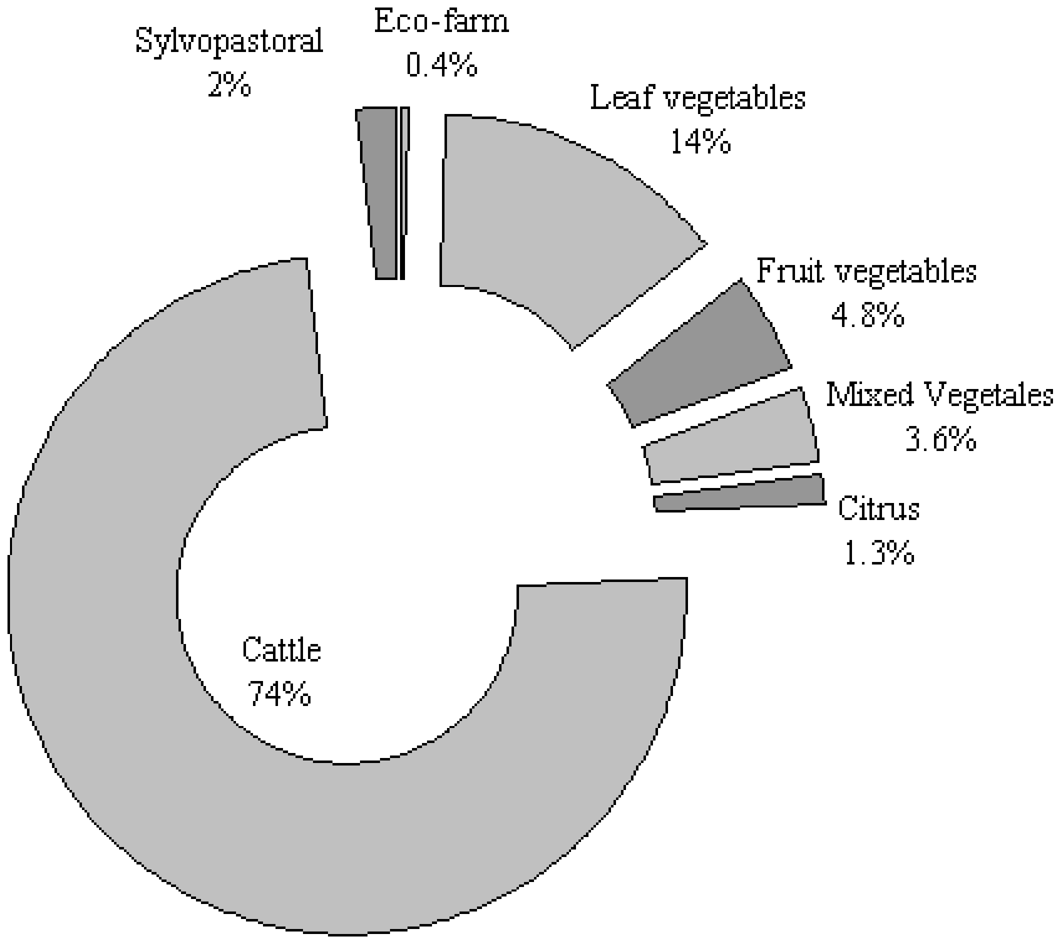


Figure 4.2.2. Relative importance of farming systems

The Cattle or livestock grazing is one of the most widespread land uses in Brazil. In Teresópolis, cattle raising has greatest impact on regional biodiversity. Approximately 74% of land (1327 ha) is currently under pasture and in many areas pasture land is still expanding slowly. The gradual transformation of forest into pasture and agricultural land has had profound ecological impacts in the region, changing the species composition of communities, disrupting ecosystem functions (including nutrient cycling and succession), altering habitat structure, aiding the spread of exotic species, isolating and fragmenting natural habitats, and changing the physical characteristics of both terrestrial and hydrological systems. Similar transformation processes have been reported by Fleischner (1994), Noss (1994), Gomez-Pompa et al. (1993), CCAD (1998). These changes, in turn, have often resulted in the reduction of both local and regional biodiversity.

Figure 4.2.3. Farming systems in Côrrego Sujo: (a) Ecofarm; (b) Fruit Vegetables; (c) Leaf Vegetables; (d) Mixed leaf and fruit vegetables

Figure 4.2.3. Farming systems in Côrrego Sujo: (e) Cattle; (f) Syslvopastoral; (g) Citrus; (h) erosion produced by leaf vegetables systems.

Table 4.2.1. Diversity, richness, dominance and evenness indices compared across different farming systems in Teresópolis

	Diversity (H´)	**Richness** (R_{ch})	**Dominance** (1-D)	**Evenness** (E)
Ecological systems	3.19	96	0.93	0.70
Leaf vegetables	2.18	19	0.86	0.74
Fruit vegetables	2.01	19	0.81	0.68
Mixed vegetables	2.22	21	0.86	0.73
Citrus	0.1	8	0.03	0.05
Cattle	0.01	8	0.00	0.00
Sylvopastoral	0.08	34	0.01	0.03

H´=-(sum Pi*lnPi); Rch=N°sp; D=1-(sum Pi^2); E=H´/lnS
A complete list of the species is enclosed in annexe 8

The lowest dominance indices correspond to the cattle systems (0.00) and to citrus (0.01). It means that a few species dominate, in this case, *Brachiaria decumbens* and *Melinis minutiflor.* Both systems are also characterized by lowest richness, with only 8 species mostly herbaceous (Table 4.2.1).

The implementation of cattle systems is the cause for the fragmentation of landscapes, not only altering its functions but also the behaviour and dynamics of animal and plant populations inside the fragments (Birregard *et al.* 2001). The fragmentation also causes decrease of biomass production, especially on the fragment edge (Laurence *et al.* 1997). For the development of tropical ecosystems, cattle systems are ranked as the major driving force for the next 100 years (Sala *et al.* 2000). Smaller patches contain relatively more edges than larger patches. Abrupt forest edges also affect most ecological variables and indicators of forest dynamics, such as species distribution, tree mortality and regeneration, biomass loss, and community composition of trees. According to some recent estimates of the edge effects of fragments, only the largest forest fragments (>50000 ha) are immune from detectable ecological effects of isolation (Curran *et al.* 1999)

The sylvopastoral system maintains low indices of diversity, still dominated by grasses. The great difference with the cattle systems is the richness of species, being increased fourfold (Table 4.1.1). The most important sylvopastoral species are the folowing (i) pastos: *Melinis minutiflor and Brachiaria decumbens.* Timber: *Lonchocarpus sp, Tibuchina sp, Piptadenia gonoacantha, Cróton floribundus, Machaerium sp*. All species from sylvopastoral systems are listed in appendix 8a from annexe 8.

Thirty four timber species were identified in sylvopastoral systems. It indicates that in these systems a significant portion of the original biodiversity can be maintained within pastures, if they are designed and managed appropriately (Greenberg 1997; Harvey 1999). Pezo & Ibrahim (1998) listed additional positive effects for maintaining and conserving biodiversity e.g. producing timber, forage and fruits, providing shade for cattle, and promoting soil conservation and nutrient recycling.

Sylvopastoral systems provide structures, habitats and resources that may enable the persistence of some plant and animal species within the fragmented landscape, thereby partially mitigating the negative impacts of deforestation and habitat fragmentation. Marten (1986) additionally says that in these systems the species are used for construction materials, firewood, tools, medicine, livestock feed, and human food. Besides providing useful products, the trees in these systems minimize nutrient leaching and soil erosion and restore key nutrients by pumping them form the lower soil strata.

The management of natural regeneration timber species in sylvopastoral systems represents a low cost alternative for the producer. These systems can be applied especially for farmers with small long term investment capacity. *Lonchocarpus sp, Tibuchina sp, Piptadenia gonoacantha, Cróton floribundus, Machaerium sp*. are all species that possess good characteristics for the implementation of systems in the study region. Diverse other native species also possess positive characteristics for sylvopastoral systems and they should be evaluated in future. It is important to highlight that pasture fires are considered as an extremely noxious practice for the propagation of tree species.

Exotic species should be broadly investigated for their implementation like the case of eucalyptus (Andrade 2001). Carvalho (2001) recommends *Acacia mangium, A. auriculiformis* and *Mimosa artemisiana* for use in sylvopatoral systems. The latter three species would also have the capacity to synthesize atmospheric nitrogen.

The most important vegetable and fruit species cultivated in *Côrrego Sujo* are presented in Table 4.2.2. A complete list with more than 60 species is presented in annexe 8: appendix 8b.

The leaf vegetables lettuce, cabbage, broccoli, spinach, watercress and the fruit vegetables chayote, paprika and tomato are the base of the economy and occupy circa 40% of the agricultural area. The farmers manage on average 4 species per hectare (minimum average) up to 12 species per hectare (maximum average). Plots with as much as 18 cultivated species per hectare were also observed.

From 15 cultivated families the *Brassicaceae, Solanaceae, Fabaceae, Asteraceae, Fabaceae* and *Cucurbitaceae* are the most important ones with more than 60 species and 140 varieties of vegetables. This crop diversity is represented by y high diversity index (H´=2.18, 2.01, 2.22) for leaf vegetables, fruit vegetables and mixed vegetables, respectively. It represents a good value for agricultural systems. For the three variants of vegetable systems, dominance is not high (1-D= 0.86, 0.81, 0.86) and the species are equitably distributed. There exists a relative good quantity of species (R_{ch}= 19) in spite of weed control, most of these species being located on the edge of small plots (Table 4.2.3 and annexe 8: appendix 8b).

It is also observed that, little by little the vegetable systems, which few years ago were only located in the alluvial parts, are now invading pastures and forests (Figure 4.2.3 h).

The ecological systems present the best indices of diversity. A dominant crop does not exist, rather, crops are equally distributed in number and area (1-D=0.93; E=0.7; Table 4.2.1). The system houses very high quantity of species (96). Finally, the Shannon diversity index (3.6) indicates clearly that this system combines a high number of cultivated and not cultivated species.

The most important species in the ecological systems are: (i) vegetables and annual crops see table 4.1.2; (ii) trees: *Acnistus arborescens* (marianera) is a plant with great potential for agroforestry systems. It is very fast growing, has easy reproduction and good biomass production, and is a good tutor for other cultivations like chayote. Finally, it produces good quantity of fruits for human consumption and for birds. *Ricinus comunis* is another very fast growing plant, it is important for the recuperation of fertility in fallow plots, and contributes with good quantity of organic matter to fertility restoration of the systems. Their great quantity of terpenes is also used for obtaining of bio-energy. Other important species in the region which can be found in ecological farms and agroforestry systems, are *Vernonia polianthes, Piptadenia gonoacantha, Lonchocarpus sp, , Luehea divaricata;*. (iii) herbaceous: *Cyperus rotundus L* (tiririca), *Melinis minutiflora, Artemisia vulgaris* (Losna), *Eleusine indica* (pê de galinha), *Siegesbeckia orientalis* (botao de ouro), *Amaranthus deflexus* (carurú), *Digitaria horizontalis* (mulambo), *Aristolochia clematitis* (papo de peru) all considered weeds. Some other plants can be found in ecological farms and in recovery areas, such as *Baccharis sp., Vernonia polianthes, Psidium cattleiano, Aeschynomene denticulate, Triunfeta sp., Lantana camara, Cecropia sp., Tibuchina sp.,* and *Euphorbia heterophylla.*

In ecological systems, biodiversity offers ecosystem service beyond the mere production of food, fiber, fuel, and income, by stabilising yield or income in case of incidences of disease and pests or when market prices are fluctuating (Wiersum 1982). This ecosystem service also helps recycling of nutrients (Alesandria *et al*. 2002), controlling of local microclimate, regulating of local hydrological processes, regulating of abundant undesirable organisms, and finally, detoxifying noxious chemicals. Reijntjes *et al*. (1992) states that the main strategy in ecological systems is to exploit the complementarities and synergism that result from various combinations of crops, trees and animals in spatial and temporal arrangements.

The richness and stability in ecological systems make them important sites for in situ conservation within eco-zones, and also offer better positive possibilities through the presence of numerous niches in which agro-diversity can survive. Trinh *et al.* (2003), Michon *et al*. (1983), Fernandes (1986) concluded in a similar way after having studied agro-diversity in home gardens. In concordance with Mac (2001) it was found that managing numerous species in ecological systems could provide a usable framework for maximizing their benefit to biodiversity.

The polycultures and agroforest patterns are characteristic of these systems. The high species richness of all biotic components of traditional and ecological agro-ecosystems is comparable with that of many natural ecosystems (Altieri 1999).

One way to reintroduce biodiversity into large-scale monocultures is by establishing crop diversity by enriching available field margins and hedgerows which may then serve as biological corridors allowing the movement and distribution of useful animals and insects.

There is wide acceptance of the importance of field margins as reservoirs of the natural enemies of crop pests. Many studies have demonstrated increased abundance of natural enemies and more effective biological control where crops are bordered by wild vegetation. These habitats may be important as over wintering sites for natural enemies and may provide increased resources such as alternative host, pollen and nectar for parasitism and predators from flowering plants (Landis 1994, Altieri 1999).

Analyzing biodiversity within this context is an extremely complex task, but one which lies at the heart of all discussions concerning its sustainable use. This complexity arises because of the multitude of different ways and the range of different scales, both in time and space, in which any given resource can be viewed (Serageldin and Steer 1994). In terms of human uses and needs, biodiversity can be looked on as part of the entire capital stock on which development is based. This stock can be divided into: natural capital, living and non-living environmental assets, including biodiversity; fabricated capital, machines, buildings, infrastructure, human capital, human resources, and social capital, the social framework (Groombridge 1996).

In fallow land or forest areas in regeneration, plant diversity and density of individuals and species are influenced by the intensity and frequency of management operations. Vegetation of wild fallows that were not managed was clearly dominated by individuals of C*ecropia spp* (embaúbas), *Lonchocarpus sp* (timbó), *Vernonia polianthes* (Assa peixe), *Tibuchina sp, Piptadenia gonoacantha* (Pau Jacaré), *Croton floribundus* (sange de drago), *Aeschynomene denticulate* (angiquinho), and other early colonizing pioneer species.

The fallow land on agricultural areas include mostly herbaceous and shrub species like *Vernonia polianthes* (assa peixe), *Acnistus arborescens* (marianera). This enriched area normally contains forest species, bananas and varieties of citrus. In these areas more species were found than in the natural fallow areas, in agreement with Anderson (1992) and Pinedo-Vazquez (2000). The latter authors say that despite the assumption that human intervention in fallows lowers the species richness it is still possible that fallow land may contained higher levels of plant diversity. All species are listed in Annex 8.

Despite differences in forest use and in management practiced by farmers, forests in all sites showed high diversity of Shannon's Index (average H' = 2.59). These results were very similar to those reported for forest areas in other regions of Brazil as e.g. in the estuarine floodplains of neotropical forest (Anderson 1992).

In agricultural areas reconverting to secondary forest (about three years of age) the most important families and species were Leguminosae (Papilonoideae) (*Lonchocarpus sp*), Euphorbiaceae (*Croton floribundus*), Anacardiaceae (*Schinus terebinthifolius*), and Sapotaceae. In the bush stratum the most important families and species are Asteraceae (*Baccharis sp, Vernonia polianthes*), Myrtaceae (*Psidium cattleiano*), Melastomataceae (Tibuchina sp).

The ecologically most important families of the woody understory vegetation are Myrtaceae, Lauraceae, Rubiaceae, Melastomataceae, Arecaceae, Nyctaginaceae (BLUMEN, 2006)

Table 4.2.2. Most important crops and varieties in Teresópolis

Common Name	Scientific Name	Varieties
Lady´s finger	*Abelmoschus esculentus*	Gigante, comum curto, chifre de veado
Onion Evergreen	*Allium fistulosum*	Verde comum
Leek	*Allium porrum*	King richard
Celery giant	*Apium graveolens*	
Watercress	*Barbarea verna*	Da água, folha larga
Beet	*Beta vulgaris var. cicla*	Verde comum, crespa comum, talo branco
Mustard Southem	*Brassica juncea*	Lisa, crespa
Cauliflower	*Brassica oleracea*	Bola de neve, gigante
Cabbage	*Brassica oleracea*	Roxo, chato de quintal, coração de boi, louco de verão
Chinese Cabbage	*Brassica pekinensis*	Mineira
Turnip	*Brassica rapa*	Branco, Roxo
Sweet Pepper	*Capsicum annuum*	Dulce, casca dura, allbig, dagmar, magnata
Endive Green	*Cichorium endivia*	Lisa, redonda de coração cheio, Grande, crespa.
Chicory	*Cichorium intybus*	Folha larga, pão de açúcar
Mandarin	*Citrus reticulata*	Casca dura
Coriander	*Coriandrum sativum*	Português
Cucumber W-Indian	*Cucumis anguria*	
Cucumber	*Cucumis sativus*	Caipira verde, record, royal
Pumpkin	*Cucurbita moschata*	Baiana, mineira, jacaré, pescoço, da água, moranga, gila
Carrot	*Daucus carota*	Alvorada, brasília, santana
Rocket	*Eruca sativa*	Cultivada
Lettuce	*Lactuca sativa*	Lisa, crespa comum, crespa, roxa, romana, americana
Tomato	*Lycopersicon esculentum*	
Broccolis	*Matricaria recutita*	
Balm	*Melissa officinalis*	nova Zelândia, verdadeira orelha de rato.

Table 4.2.2. (cont.) Most important crops and varieties in Teresópolis

Common Name	Scientific Name	Varieties
Peppermint	*Mentha piperita*	folha larga
Parsley	*Petroselinum crispum*	Lisa, graúda, portuguesa, salsão Crespa
Green bean	*Phaseolus vulgaris*	Macarrão, atibaia, rasteira, serrano
Radish	*Raphanus sativus*	vermelho de ponta branca, vermelho
Chayote	*Sechium edule*	branco com and sem espinho, verde com and sem espinho
Indian Eggplant	*Solanum gilo*	comprido verde, verde claro, irajá redondo
Eggplant	*Solanum melongena*	Embu, ciça, black – tie
Green been	*Taraxacum offlcinalis*	Anãs, trepadeira, flor roxa
Yam	*Xanthosoma sagittifolium*	Chines
Corn	*Zea Mais*	Vermelho, branco, amarello
Others	Manjerona (*Origanum majorana*), Erva Doce (*Pimpinella anisum*), Espinach chino (*Tetragonia tetragonioides*), Basilicum (*Ocimum basilicum*), Orégano (*Origanum vulgaris*), Pimint (*Capsicum frutescens*), Tomillo (*Thymus vulgaris*).	

Table 4.2.3. Most important tree species in agricultural systems

Family	Scientific Name
Anacardiaceae	Schinus terebinthifolius
Solanaceae	Acnistus arborescens
Sapindaceae	Allophylus sp
Moraceae	Ficus sp
Asteraceae	Siegesbeckia orientalis
Myrsinaceae	Rapanea ferruginea
Myrtaceae	Eugenia sp
Myrtaceae	Myrciaria sp
Leguminosae	Peltophorum dubium
Leguminosae	Senna macranthera
Leguminosae	Senna sp
Euphorbiaceae	Ricinus communis L.
Flacourtiaceae	Casearia sp
Lauraceae	Nectandra sp
Solanaceae	Acnistus arborescens
Myrtaceae	Gomidesia sp
Piperaceae	Piper sp
Euphorbiaceae	Indet
Leguminosae	Indet
Sapindaceae	Indet

Table 4.2.4. Most important herbaceous species in agricultural systems

Family	Scientific Name	Family	Scientific Name
Amaranthaceae	*Amaranthus deflexus*	Leguminosae	*Crotalaria sp1*
Amaranthaceae	*Amaranthus sp*	Leguminosae	*Indigofera hirsuta L.*
Aristolochiaceae	*Aristolochia clematitis* L.	Leguminosae	*Lonchocarpus sp*
Asteraceae	*Artemisia verlotorum*	Leguminosae	*Vigna sp*
Asteraceae	*Bidens pilosa L.*	Malvaceae	*Malvastrum sp*
Asteraceae	*Galinsoga sp*	Malvaceae	*Sida rhombifolia*
Balsaminaceae	*Impatiens sp*	Malvaceae	*Sida sp*
Cecropiaceae	*Cecropia hololeuca*	Melastomataceae	*Tibuchina sp*
Chenopodiaceae	*Chenopodium ambrosioides*	Plantaginaceae	*Plantago tomentosa L.*
Commelinaceae	*Commelina benghalensis l.*	Poaceae	*Digitaria horizontalis*
Convolvulaceae	*Indet*	Poaceae	*Eleusine indica*
Convolvulaceae	*Ipomoea hederifolia L.*	Poaceae	*Melinis minutiflora*
Curcubitaceae	*Momordica charantia L.*	Poaceae	*Panicum maximum*
Cyperaceae	*Cyperus rotundus L*	Poaceae	*Pennisetum clandestinum*
Euphorbiaceae	*Euphorbia heterophylla*	Poaceae	*Pennisetum purpureum*
Gramineae	*Brachiaria decumbens*	Portulacaceae	*Portulaca oleracea*
Gramineae	*Coix lacrima-jobi L.*	Rutaceae	*Zanthoxylum rhoifolium L.*
Gramineae	*Melostack sp*	Solanaceae	*Solanum americanum*
Labiatae	*Hyptis sp*	Tiliaceae	*Luehea sp*
Labiatae	*Leonurus sibiricus L.*	Tiliaceae	*Triunfetta bartramia*
Leguminosae	*Aeschynomene denticulata*	Umbeliferae	*Apium sp*
Leguminosae	*Crotalaria incana*		

Crop Rotations and associations

It is difficult to determine a dominant crop rotation, given the high variety of crop sequences and site conditions. Crop rotations occurring with relative higher frequencies are those starting with lettuce, followed by cabbage, followed by any kind of cultivation of short cycle before another lettuce crop. Broccoli-lettuce, or watercress-lettuce, followed both by two cultivations of any short cycle crop are less frequent rotations (Table 4.2.5).

No fallow periods can be observed, instead fertilizers and soil improvement materials are applied. In a few production units, watercress and lettuce were found to be produced all-year round as a monoculture. Some farmers practice crops associations, the most frequent associations being chayote together with a short cycle crop cultivation, and evergreen onion in intercropped with either coriander or parsley (Table 4.2.6).

Table 4.2.5. Crops Rotation

Frequency	Rotation	Fallow
0.25	**Lettuce**-Chinese Cabbage- LVS -Lettuce	0
0.20	**Chayote**-ccc-x-chayote	0
0.15	**Broccoli**-Lettuce- LVS -Brocoli	0
0.05	**Chinese Cabbage**- LVS - LVS -Chinese Cabbage	0
0.05	**Watercress**-Lettuce- LVS -x-Watercress	0
0.05	**Espinach**-x-Lettuce-x-Espinach	0
0.01	**Paprika** -Yam-Paprika	0
0.24	others	0
1	Total. 100% of the observed rotations	

C = leaf vegetable; x = ad libitum

Table 4.2.6. Crops Association

	LVS	Parsley	Coriander	Corn	Others
Chayote	0.35				
Onion eg		0.25	0.30		
Yam Xanth.				0.05	
Others					0.05

Agricultural Calendar

Leaf crops are cultivated the whole year, whereby lettuce is produced at same quantity during the whole year, whereas broccoli is particularly favoured during winter. The cycle of the vegetables begins in August-September and some vegetables such as tomato, paprika, giló, chayote, etc. are mainly grown in summer (Table 4.2.7).

Table 4.2.7. Agricultural Calendar in Teresópolis

Crop	JAN	FEB	MAR	ABR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Pumpkin	c							SP	spE	sp	C	c
Eggplant									PSHE	C	c	
Chayote								sp	SP			
Green been	C								SPHE	HE	HE	C
Feijao verde									SPH	HE	HC	
Yam	C							SP		H		
Indian Eggplant	C								SP	HE		
Cucumber W- Indian	C									SPH	E	
Corn	c	C								SPH		
Strawberry	c							SP	spE	sp	C	c
Cucumber									SPHE	C	C	
Sweet Pepper	E	CE	C			sphe	e	e	e	ce	c	SPHE
Mandarin					EH	C	Ch	c	c			
Quimbombo									PSE	HEC		
Tomato	C	c				pshe	e	e	PSHEc	Ec	E	C
Perennial cultivations and that are cultivated the whole year.	T	Acelga, Watercress, Celery giant, Lettuce, Leek, Almeirão, Camomila, Carrot, Onion Evergreen, Endive Green, Coriander, Chinese Cabbage, Chinese Cabbage-Flor, Erva Doce, Dente-de-leão, Erva Cidreira, Espinach, Hortelã/Mint, Manjericão, Manjerona, Mustard Southem, Tumip, Orégano, Pimint, Radish, Cabbage, Rocket, Parsley										

P = Land preparation; H = Invasive weeds control; S = Plantation/sowing; E = Plagues and diseases control; C = Harvest; T = the whole year. Capital = bigger intensity and frequency; Lower-case = smaller intensity and frequency

4.2.3. INTERACTIONS AMONG THE LAND-USE SYSTEMS

Fragment-agriculture. In fact, the interaction of the agriculture with the fragments is very low. Certainly, the farming systems will influence the composition of species in the edges, but fragments are hardly used for extraction purposes by farmers. The environmental impact of the agricultural (horticultural) land on the fragment is rather low, since this land use system is usually located below the fragment. Thus, erosion and water quality impacts are rather inflicted on land use systems downstream within the river basins than on forest fragments. Not-quantified nutrients coming from the fragments are deposited on horticultural land, a benefit yet to be quantified.

Specific cultivations like chayote and tomato are examples of direct impact of farming activities on fragments, requiring stakes and posts to serve as tutors in the cultivation. The total area of these cultivations is low, as well as the No. of farmers extracting these materials. The requirements of extraction are about 620 posts of 2.3 m per hectare of chayote. For one hectare of tomato 10500 stakes of bamboo of 1.8 m, and 260 stakes of 2.3 m are extracted.

Fragment - cattle raising. Although at a very low rate, deforestation for pasture land is still going on. The dynamics of land use change could not be analysed, and so it can not be said, what kind of land is being lost, whether valuable old structured forests or recently re-established fragments with *Capoeira* (re-emerging bushland during fallow) characteristics.

A serious impact of beef cattle and horses was observed by accesses to water sources in the forest, where animals go drinking, ruminating and resting in the shadow, and grazing or browsing from what plants can offer there. Doing so, animal faeces contaminate the water sources which are often used as drinking water in the households below.

Cattle raising – agriculture. The agricultural systems and cattle have very little interaction. The manure is not used in the agriculture, it remains in the pasture areas. The agriculture residuals are kept in the cultivation field for organic matter incorporation. Sugarcane and *Capim gigante (Penisetum purpureum)*, as stated before, are the only cultivated forage crops requiring arable land and are thus, directly competing with alternative cropping systems.

Horticulture production requires large amounts of organic matter which is obtained by truckload from other regions, even neighbouring states such as São Paulo and Minas Gerais.

Organic matter is certainly an economically highly significant matter. More interaction among animal husbandry and horticulture systems is assumed to be required for overall agricultural productivity and profitability improvement. Ecologically, it would be highly welcome to substitute long-distance transports of manure with local supply.

Settlements – fragments. For house construction and tools the farmers usually use the wood of the fragments. They also extract some medicinal plants and occasionally eat some animals.

4.2.4. ENVIRONMENTAL PERCEPTION OF FARMERS

The environmental perception of farmers was assessed in individual interviews and a workshop held with the farmers of the study area.

*Farmers observations of landscape***.** 81% of the interviewees stated that during the last 30 - 50 years the landscape has changed a lot. Major changes observed were urbanization – construction of many new houses Forest used to be more dominant in relation to pasture and agriculture (50 years ago). The practice of burning bush land is nowadays more widespread than5-10 years ago. Orchards with citrus have emerged only recently.

Farmers observations of forest fragments. In the past, large and "beautiful" tree species were found in the forests, many of them with great economic value, some of them being scarce and having already disappeared from the fragments as for example: Brauna, Cambota, Garapa, Ipê, Cedar, Maçaranduba, Jacaranda, Peroba, Oricana, candeia, Cinzero, and some others that the farmers were not able to specify.

Conservation attitude. 92% of the interviewees answered that they preserve their fragments. They prevent hunting and deforestation because they are aware that they need the forest to preserve water sources. Reforestation practices are absent. Main reasons for applying conservation measures are: water source, legislation, and emotional value of forest. 72% of the farmers do not know that the agriculture could contaminate and cause damage to the environment and only 13% know that inappropriate agriculture practices can cause damage. The remaining percentage did not answer. One out of each 150 productive units has organic production, 33% have heard about organic agriculture and agro-forestry and are inclined to change but they lack the required know-how. 48% do not want to change the production to organic agriculture, considering such efforts as not necessary. The remaining producers consider such a change not possible because of adverse physical conditions and difficulties.

Fragment value to farmers. The most important value of the fragments is as water source (96 % of the interviewees agreed). The second most important use is the wood extraction for construction timber of low quality. The third use is medicinal plants extraction, although 37% state not knowing the medicinal plants from the forest.

4.2.5. CONCLUSIONS

From the biodiversity point of view, the ecological farming systems, agroforestry- and sylvopastoral systems, and perennial cultivations help to reduce the pressure on the fragments and deforested areas. It improves the cycle of water, and it has also positive influence on the dispersion of fauna and flora. They offer better resources and habitat for the survival of plants and animals than the cattle and horticultural systems. Also, they play an important role as biocorridor and buffering reserves and it also introduces a modest biodiversity level in these depredated areas of the Atlantic forest, where at the moment a single grass (*Brachiaria decumbens*) dominates more than 35% of the surface.

Also, the diversity and structure of ecological, agroforestry, and sylvopastoral systems contribute additional benefits to the local population, microclimate, flow of nutrients, dissipate the dynamics of plagues and diseases, and decrease the effects of fluctuating prices of the market.

The agricultural subsystems, cattle and forest are not very interrelated to each other, giving place mainly to trade-offs rather than providing synergies. The cattle systems do not contribute from any point of view with the conservation of biodiversity. To the contrary, it is the most degenerative practice that threatens biodiversity in the region. It is the main cause for forest fragmentation, also presents bigger soil erosion, and breaks the dispersion of flora and fauna.

In general, farmers appreciate biodiversity positively, but they have no exact knowledge of their benefits. At the moment, the forest fragments represent for the farmers mainly their water source, and are considered very less important as wood source or supply of other by-products like fruits or medicines.

4.3. ENERGY AND BIOMASS IN NATURAL AND AGRICULTURAL SYSTEMS

Since life is basically, an energy transforming process, energy issues are central to sustainability. "Everything is based on energy. Energy is the source and control of all things, all values, and all actions of human beings and nature", according to Odum & Odum (1976) While social and economic sustainability certainly are essential and highly desirable, energy processes and limitations set definite bottom lines (Jansen 2000).

Productivity, i.e. "the output of valued product per unit of resource input", is conventionally, and also according to Conway (1991) standard proposal, calculated regarding the three categories land, labour and capital, with energy aspects in all three production factors. However, Conway also says that for many purposes energy and technology can better be treated as separate production factors.

Two aspects of energy are particularly central to this thesis: one issue is how to quantify energy; the other one is how to understand energy transformations in living systems.

From an energy point of view, the named farming systems (see § 4.2.2) are quite different. The more inefficient one is the cattle system, with an approximate stocking rate of 0.7 ha/TLU. This system requires 461 Joules of inputs (encompassing externalities) to produce one Joule in meat form. Hence, this production system has a poor capacity to accumulate energy in the system in the form of biomass. On the other hand, the ecological systems present a high capacity to store energy (1.80E11 Joules ha^{-1} yr^{-1}), followed by horticultural systems, generally combined with a small forest percentage, and storing energy up to 1.03E11 Joules ha^{-1} yr^{-1}. The sylvo-pastoral systems, contrary to the cattle raising on pure grassland, present a good capacity to store biomass (2.6E10 to 5.56E10 Joules ha^{-1} yr^{-1}), (Fig. 4.3.1)

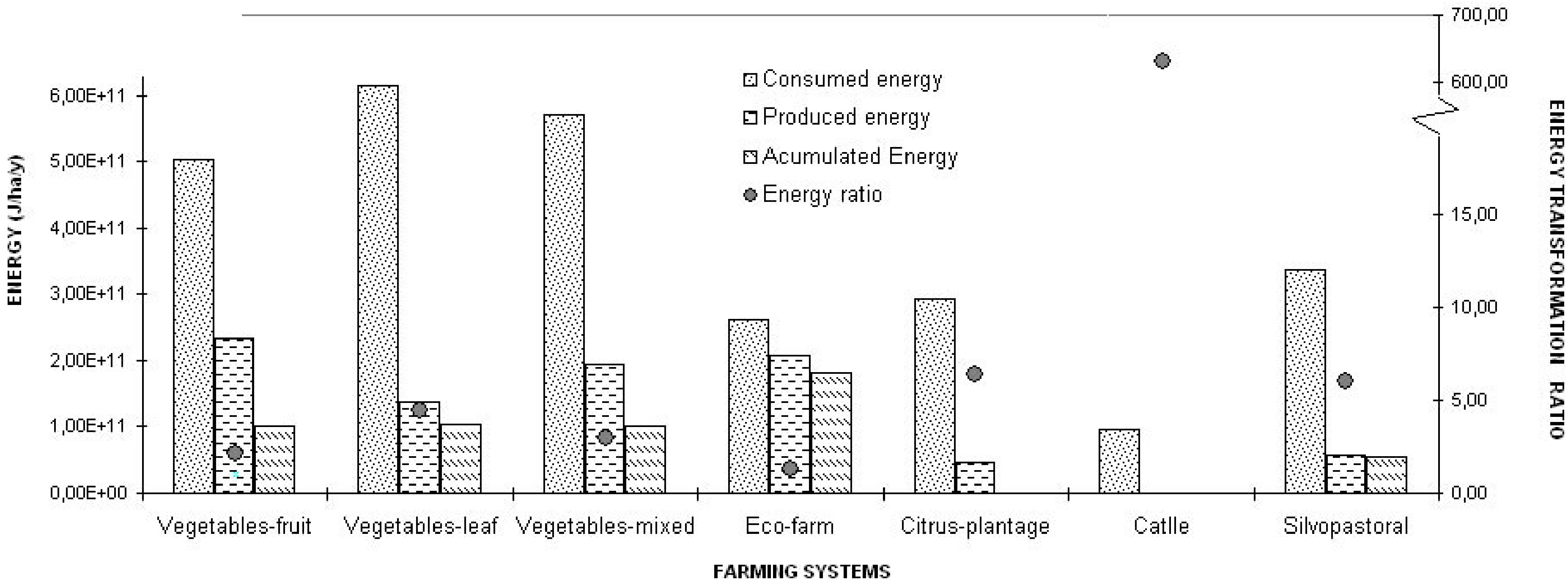


Fig. 4.3.1. Production, consumption, accumulation and energy ratio of different farming systems in RJ-Brazil.

The natural systems, like the mature forest of the National Park "Serra dos Orgãos" in the Atlantic Forest region, stores 272 Mg C per ha whilst its bordering fragments in a secondary stage only 87.3 Mg C. The latter two biota have the capacity to sequestrate 11.65 and 3.01 Mg C y^{-1} (Table 4.3.2). The aquatic plants, dominated by *Typha domingensis,* are excellent producers of phytomass in the region. Annually they can produce up to 6.3 Mg of C, which is more than a three-year-old regeneration forest with an annual yield of only 2 to 4 Mg C. Surprisingly, horticultural production systems can produce annually as much as 27.8 Mg C ha^{-1} (Table 4.3.1), the larger part of it being exported though.

Table 4.3.1. Average aboveground dry matter (AGDM) stock and yearly phytomass production of different biota in Teresópolis

	Area		**AGDM**	**Phytomass Production**		
	Area (%)	Area (ha)	DM (ton)	DM $ha^{-1}y^{-1}$ (ton)	DM $year^{-1}$ (ton)	Total (J yr^{-1})
Crops	2.6	138	4408	27.8	3833	2.59E13
Grassland	31.1	1654	1488	0.5 – 1.5	827	3.21E12
Forest Fragment	36.2	1925	373511	6.7*	12915*	2.28E14
Forest Regeneration	18.8	1001	7435	2.01-4.42	2902	6.62E13
Others ***	11.4	607	-	-	-	-
Total	*100*	*5324*	*386844*	*3.85***	*20478*	*3,23E14*

Source: Torrico (2004)
AGDM: Above Ground dry matter
* Litter fall; ** See Annex 9 and 10
***Others: corresponds to buildings, streets, rocks, open soils, water, etc

There exists approximately a stock of 386844 ton phytomass dry matter in the studied micro-basin (53 km^2). The same area will produce annually in 20478 tons dry matter representing 2.28*E*14 Joules (Table 4.3.1). The forest fragments and the forest areas in regeneration accumulate more than 92% of biomass in the system, while in agricultural systems 90% of the produced biomass comes out of the system.

Table 4.3.2. Aboveground dry matter (AGDM) stock and yearly phytomass production of different natural systems in Teresópolis compared with selected systems in the world

Natural Systems	AGDM (ton DM ha^{-1})	Phytomass Production (ton DM ha^{-1}y^{-1})	Source
Forest Mata Atlántica (mountain)	606.39	26*	
Forest Mata Atlántica (transition)	617.89	---	
Forest Mata Atlá (high montane forest)	318.38	---	
Fragments Mata Atlântica	194.05	6.71 - 7.1*	
Regeneration 3y	7.43	4.42 - 6.6	
Water plants	11.65	12.7	
Forest fragment Chiapas-Mexico	269.95	---	[1]
Forest Uganda	26.10		[2]

AGFM: Above Ground Fresh Mater; AGDM: Above Ground Dray Mater; * Litter fall [1] Jende (2005), [2]Cleemput (2004)

Table 4.3.3. Aboveground dry matter (AGDM) stock and yearly phytomass production of different farming systems in Brazil, Cameroon and Mexico.

Farming system	AGFM (ton FM ha^{-1})	AGDM (ton DM ha^{-1})	Fytomass Production (ton DM ha^{-1}y^{-1})	Energy Production (J ha^{-1})	Source
Ecological Farm (Mata Atl)	n.a.	n.a.	28.0	1.6.E05	
Leaf Vegetables- Terê-Brasil	30.5	2.89	23.1	2.5.E05	
Fruit Vegetables- Terê-Brasil	132.2	19.42	38.8	9.0.E05	
Coffee Chiapas-Mexico	n.a.	78.2	n.a.	n.a.	[1]
Cocoa Agroforest Cameroon	n.a.	451.0	10.3	8.7.E03	[2]
Leek Bonn-Germany	34.7	6.9	34.7	1.8.E05	
Sugar Cane Chiapas-México	147.3	48.6	48.6	2.7.E06	[3]
Grass Mata Atlántica*	1.1	0.49	1.5	2.0.E03	

AGFM: Above Ground Fresh Mater; AGDM: Above Ground Dray Mater
* Grassland for cattle and 1 year abandoned grasses; [1]Jende (2005), [2]Sonwa (2004), [3]Pohlan (2005)

In the Tables 4.3.3 and 4.3.4 the biggest stock of aboveground biomass per ha was found in the mature mountain forest with an approximative value of 606.39 ton dry matter (DM), on the contrary the pastoral systems present a minimum value 0.49 ton DM ha^{-1}. The agricultural system with the highest capacity for stocking dry matter is the "cocoa agro-forest" with a value of 451 ton DM ha^{-1}.

In general, the agricultural systems in Teresópolis have the capacity to produce around 23.1 to 38.8 ton DM ha^{-1}yr^{-1}, representing high to very high figures. In energy terms the highest value represents 9.0E5 Joules ha^{-1}y^{-1}. The sugar cane system in Chiapas Mexico is the superior production system with a yearly average production of 48.6 ton DM (equivalent to 2.7.E06 J ha^{-1}).

Better combinations of plant, soil, water and nutrient management, with livestock or fish integrated into farming systems and with integrated pest management processes, are frequently achieving production increases of 50 to 100 percent or more in a wide variety of circumstances, including some that are agriculturally quite adverse (CIIFAD 1999). Secondary forests and forest fallows are the most important form of C recovery in tropics due to the extensive area involved (Lugo & Brown 1992). Controlled experiments have showed that primary productivity increases with plant species richness but often saturates at high diversity (Hector et al. 1999, Tilman 2001)

CONCLUSIONS ABOUT ENERGY AND BIOMASS

Energy is a relevant parameter to study the sustainability of systems. It is also, essential to most human activities, including agriculture. Too much energy means wastage, global warming and other environmental threats.

Saving on energy and looking for new production sources will require appropriated production systems, whereby available resources are better preserved by higher efficiency of energy use. Some agricultural systems can end up producing more phytomass than neighbouring natural systems as was the case with horticulture in the municipality of Teresópolis. However, the same horticultural systems use much more energy to produce the same quantity of energy as that produced by ecological systems, indicating a lower efficiency for energy conversion. Increasing energy use, climate change and the expected increases in the cost of energy underline the need to improve energy use efficiency.

The primary agricultural production can be directly a good energy producer through conversion of natural energy sources like sun and rain into biomass and indirectly it can save great quantities of energy through its efficient use.

In concordance with Nonhebel (2002) fossil energy use efficiency is higher in ecological (low-input) crop production systems than in vegetables (high-input), and cattle systems. This is caused by the fact that in low-input systems, a relatively large amount of the used phosphor, nitrogen originates from non-fossil resources.

High attention should be paid to the forest in regeneration state; from the energy point of view it was proven that these increase the biomass stocks considerably in the micro-basin. Also it was observed that the pastoral systems are those which store and produce less energy. From that point of view the sylvopastoral systems increase considerably the stock of carbon without reducing the forage production which is not the case with the cattle system, also Houghton *et al*. (1993) and Richter *et al*. (1999) showed similar appreciation.

The choice of a particular production system will thus have significant consequences for the energy yields that can be obtained. Improved energy efficiency reduces the vulnerability of producers and consumers to energy price shocks (Outlaw 2005), reduces the adverse impacts of long-term real energy price increase and reduces potential environmental impacts of fossil fuel consumption.

4.4. ENVIRONMENTAL AND ECONOMIC EVALUATION

Emergy analysis was accomplished to compare the main Farming systems in the Corrego Sujo basin in Teresópolis. Emergy synthesis integrates all flows within a system of coupled economic and environmental work in common biophysical units (embodied solar energy or solar energy or solar emjoules (sej); (see also § 2.4), facilitating direct comparisons between natural and financial capital assets. The studied systems were (a) Ecological farm, (b) Cattle systems, (c) Fruit Vegetables, (d) Leaf Vegetables, (e) Vegetables mixed systems and (f) Citrus plantation. The emergy flows have been calculated taking into account the amounts of natural resources, material inputs and services involved in each type of production. To evaluate the impact on the basin level, the input data and average yields of 42 crops and 6 production systems were extrapolated. As materials we consider: seeds, limestone, fertilizers, pesticides, herbicide, fuels, and machinery (the latter one considered as depreciation of capital investment); as services we consider: manpower, administration, transport, taxes, insurance, and social security. The manpower data have been expressed in terms of working days of 8 hours $ha^{-1}year^{-1}$ i.e. md $ha^{-1}y^{-1}$.

4.4.1. MANPOWER

The agricultural systems that use more manpower are those based on horticulture, either this for fruit, leaves or mixed production, using in total 118 workers/100 hectares, corresponding to 80% of the available household manpower. The vegetable systems that conserve a fragment (60% of the area) in the production unit use considerably less manpower, approximately 45 workers/100 ha, of which 65% correspond to family manpower. The ecological systems use low quantity of manpower per production unit, since usually the areas dedicated to the agricultural production do not surpass 10% of the total area (Fig. 4.4.1)

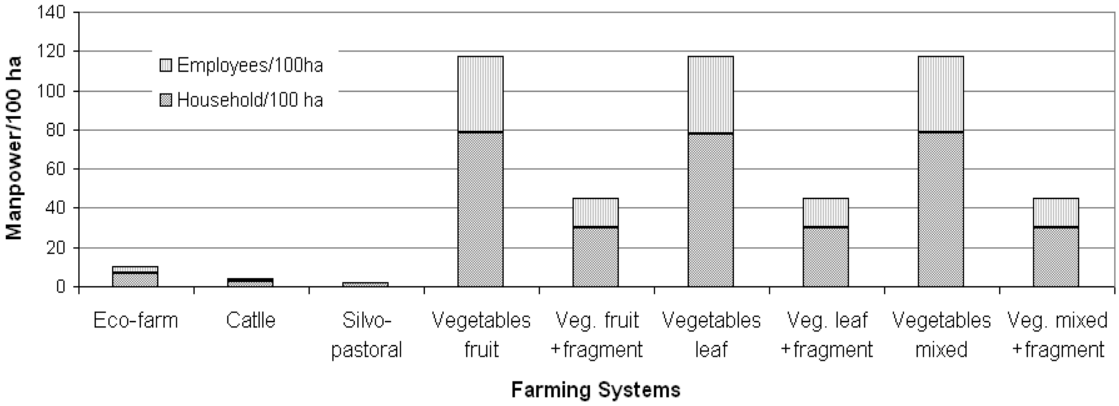


Figure 4.4.1. Family and employed Manpower in different farming systems.

Table. 4.4.1. Relationship of necessary manpower (md) per year for the main cultivation

	Watercress	Tomato	Onion Evergreen	Chicory	Chayote	Chinese Cabbage	Coriander	Spinach	Lettuce	Paprika	Carrot	Zucchini	Almeirao	Beet	Cabbage	Mint	Leek	Rocket
Preparation of nurseries	4	2		7	1	5	1	13	6	3				13	7			
Maintenance		2								2								
Transplanting and seeding	15	8	50	10	3	20	12	17	6	8	7	5	38	26	7	27	69	4
Fertilization	3	9	20	4	6	15	3	3	4	10	2	5	3	4	1	4	17	1
Watering	7	4	38	5	26	10	7	13	1	3	2	1	1	16	2	1		2
Weeding	8	28	58	22	9	19	27	84	21	18	23	9	75	77	14	66		16
Pest Control	3	19	40	3	5	11	5	5	13	30	4	11			7	7	17	3
Harvest	44	42	68	19	118	96	204	94	3	113	28	42	118	16	31	164	65	253
Tying		49			12					32								
Placing posts	6	8			48					3								
Staking		8			8					9								
TOTAL	88	177	273	70	237	176	259	229	53	231	66	73	235	152	69	269	237	279

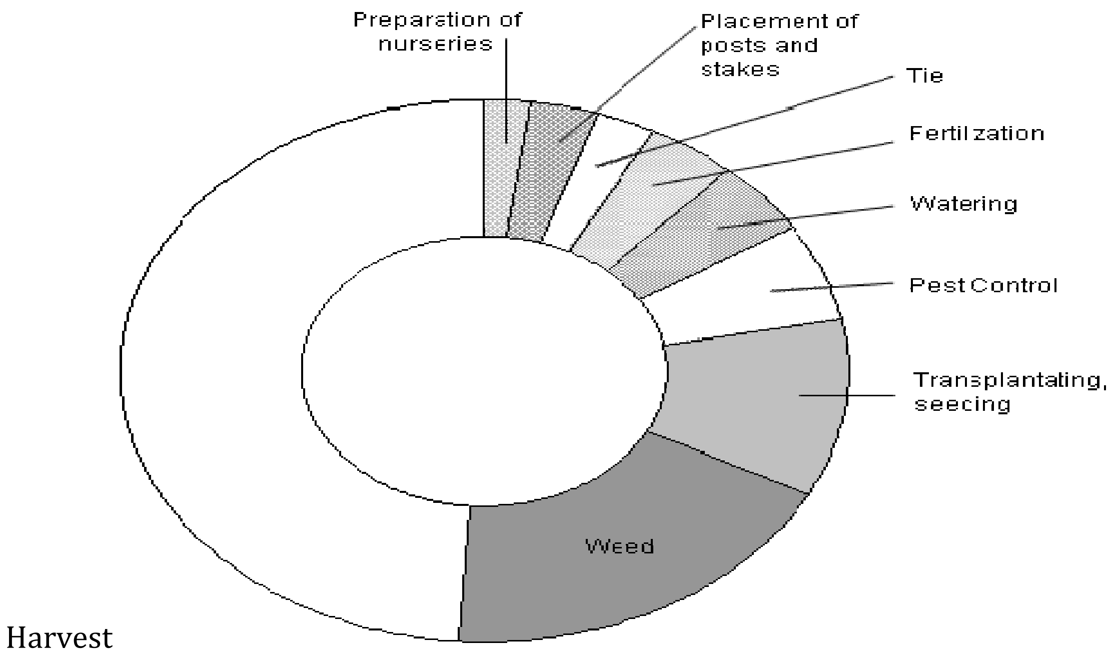


Figura 4.4.2. General distribution (%) of manpower in horticultural systems

Harvest, weeding, and transplanting are the activities that use the most quantity of manpower. The harvest alone uses circa 50 % of the total manpower whilst 39% are needed for weeding and transplanting (Figure 4.4.2). The crops that use bigger quantity of manpower a year are rocket (279), mint (269), coriander (259), leek (237), whereas the crops that use smaller quantity of manpower are lettuce (53), carrot (66), cabbage (69) and chicory (70) (Table 4.3.1).

4.4.2. ECONOMIC INDEXES

Positive economic indices were recorded for all crops cultivated as a monoculture system. The relationship costs benefit indicates that all crops recover more money than the amount invested. The cultivations with more values are: Onion Evergreen (9.87), Paprika (3.7), and Tomato (2.99). The cultivations that present smaller relations of benefit cost are: Cabbage (1.12), almeirao (1.18), beet (1.22) (Table 4.4.2).

Because the crop cycle is always smaller than 1 year the recovery of capital is quick. From that point of view the Net Present Value as well as the Internal Rate of Return are highly positive (77), whereas the average net income per hectare and per year is 15500 $ R for average production costs amounting to 8200 $ R per ha and year (Table 4.4.2).

Table 4.4.2. Calculation of economic indicators of the most important crops (as monoculture)

Crop	Production		Production Cost ($R ha^{-1})	Bruto income ($R ha^{-1} y^{-1})	Indicators	
	unit	u/ha			IRR	B/C
Lettuce	box	4239	4869	8478	35	1.74
Water cress	bund	83720	6201	16744	54	2.70
Broccoli	bund	41025	10255	20513	15	2.00
Onion	bund	48760	12350	121900	71	9.87
Evergreen						
Chicory	box	6370	7061	19110	83	2.71
Lady finger	box	4672	12652	23360	29	1.85
China col	bund	237553	14833	35633	47	2.40
Cilantro	bund	12863	6236	19295	164	3.09
Spinach	bund	121813	6883	18272	135	2.65
Paprika	box	5002	10826	40016	74	3.70
Tomato	box	2467	14004	41939	111	2.99
Carrot	box	720	2433	5760	28	2.37
Zucchini	box	1048	3758	7336	38	1.95
Almeirão	bund	37500	5743	6750	33	1.18
Beet	box	638	5223	6380	41	1.22
Col	box	3034	5427	15170	102	2.80
Mint	bund	26200	8435	2620	88	1.50
Leek	Bund	12040	12067	42140	79	3.49
Rocket	Bund	50630	5728	15189	54	2.65
Cabbage	Box	2950	13200	14750	62	1.12
Rocket	bund	48000	5728	9600	65	1.68

Table 4.4.3. Average Net Income of the most important farming systems in Côrrejo Sujo

Farming system	Range of Net Income ($US $ha^{-1}y^{-1}$)	Average income ($US $ha^{-1}y^{-1}$)
Eco-farm	120 to 2450	899
Cattle	66 to 98	78
Sylvopastoral	66 to 102	84
Fruit Vegetables	4440 to 10220	6760
Leaf Vegetables	3600 to 12780	4770
Mixed Vegetables	4800 to 13480	5110
Citrus	130 to 189	146

The intensive horticultural systems for fruits, leaves or mixed are presenting big economic returns, varying according to the fluctuating market prices (see annex 7). The revenues can reach 3600 up to 13480 $US ha^{-1}$. On average, revenues for the horticultural systems based on fruit, leaf or mixed production amount to 6760, 4770 and 5110 $US ha^{-1}$ respectively. From the economic point of view, large differences exist with the less intensive systems, like the ecological systems with 2 to 6 months fallow and having a net annual income of 899 $US ha^{-1}$ on average. Finally, the systems that present very low income per hectare and per year are the Cattle, Sylvopastoral and Citrus systems with 78, 84, and 146 $US ha^{-1}y^{-1}$, respectively.

4.4.3. FARMING SYSTEMS

The horticultural systems of the region are highly intensive, especially the horticultural systems based on either fruit, leaf or mixed that make high use of inputs like nitrogen fertilizers, pesticides and herbicides. These systems are also the most common ones in the region. The ecological system hardly makes use of external inputs. The cattle system occupies notably the biggest territorial extension (83.7% of the total agricultural area) and it uses low external inputs as is also the case for the sylvopastoral and citrus systems. A general overview of the Farming systems is presented in the Table 4.4.4.

All physical, biological and monetary inputs of the studied agricultural systems were converted into emergy flows and are aggregated as shown in Figure 4.4.3 (details in annex 3).

Table 4.4.4. General Overview

	Eco-farm	Cattle	Sylvopas-toral	Fruit Vegetables	Leaf Vegetables	Mixed Vegetables	Citrus
Area (%)*	0.1	83.7	2.3	2.9	5.8	2.2	2.8
Seeds quality	good	any	any	good	very good	very good	Good
Fertilizers	any	any	any	High	high	high	Low
Pesticides	any	any	any	High	high	high	Any
Herbicides	any	any	any	middle	middle	middle	Any
Anti-parasites	any	middle	middle	Any	any	any	Any
% Forest (average)	80	5	15	33	32	32	15
% Crops Area (average)	18	0	0	66	66	66	84
Fallow (months/yr)	2 to 6	0	0	0	0	0	0
Production Losses (%)	18	0	0	14	11	11	10
Market destination (%)	20	100	100	99	100	100	98
Irrigation	low	any	any	high	high	high	Any
Principal product	diversified	meat	meat	Chayote, tomato	salad, cabbage	Chayote, salad	Mandarin

* Percent of the total agricultural area in Teresópolis

4.4.4. ENERGY FLOW

The ecological system consumes big quantities of renewable emergy (1.79E16 sej $ha^{-1}yr^{-1}$), representing more than 80% of the total emergy (Fig. 4.4.4), and this input comes mainly from rain and river water, from solar energy as well as from the silts being deposited through the rivers in the system. The horticultural systems have an average consumption of 1.10E16 sej $ha^{-1}yr^{-1}$. Both these values represent the used emergy coming from natural resources, approaching 15% of their total consumption.

While efforts to internalize the external costs of the system (soil erosion) in monetary units are available in the literature, we offer an alternative approach based on emergy synthesis, which enumerates the value of soil based on the environmental work required to produce it rather than based on surveys or derived pricing techniques.

The cattle system on the hillsides loses 7.04E15 sej $ha^{-1}yr^{-1}$ (120330 kg soil with 1.8 to 4.2% OM content), this quantity corresponds to 40% of the emergy used by the system (fig. 4.3.4), representing 4.6 times more than the ecological system and 2 times more in comparison to the other systems (Figure 4.4.3).

It was observed clearly that to the exception of horticulture, the other systems hardly have entrances of materials. The most important inputs of emergy are materials (33%), nitrogen (19%), organic matter (16%) and electricity (14%) from a material total (M) of 4.61E16 sej $ha^{-1}yr^{-1}$ (Figure 4.4.3).

In the same way the used quantity of services in the system is 3.1E16 for horticultural systems, while the other systems make very little use of services. For all the other systems circa 80% of services correspond to manpower that normally comes from the family, the second place of the services corresponds to the maintenance of infrastructure (7%) and finally 5% corresponds to communication.

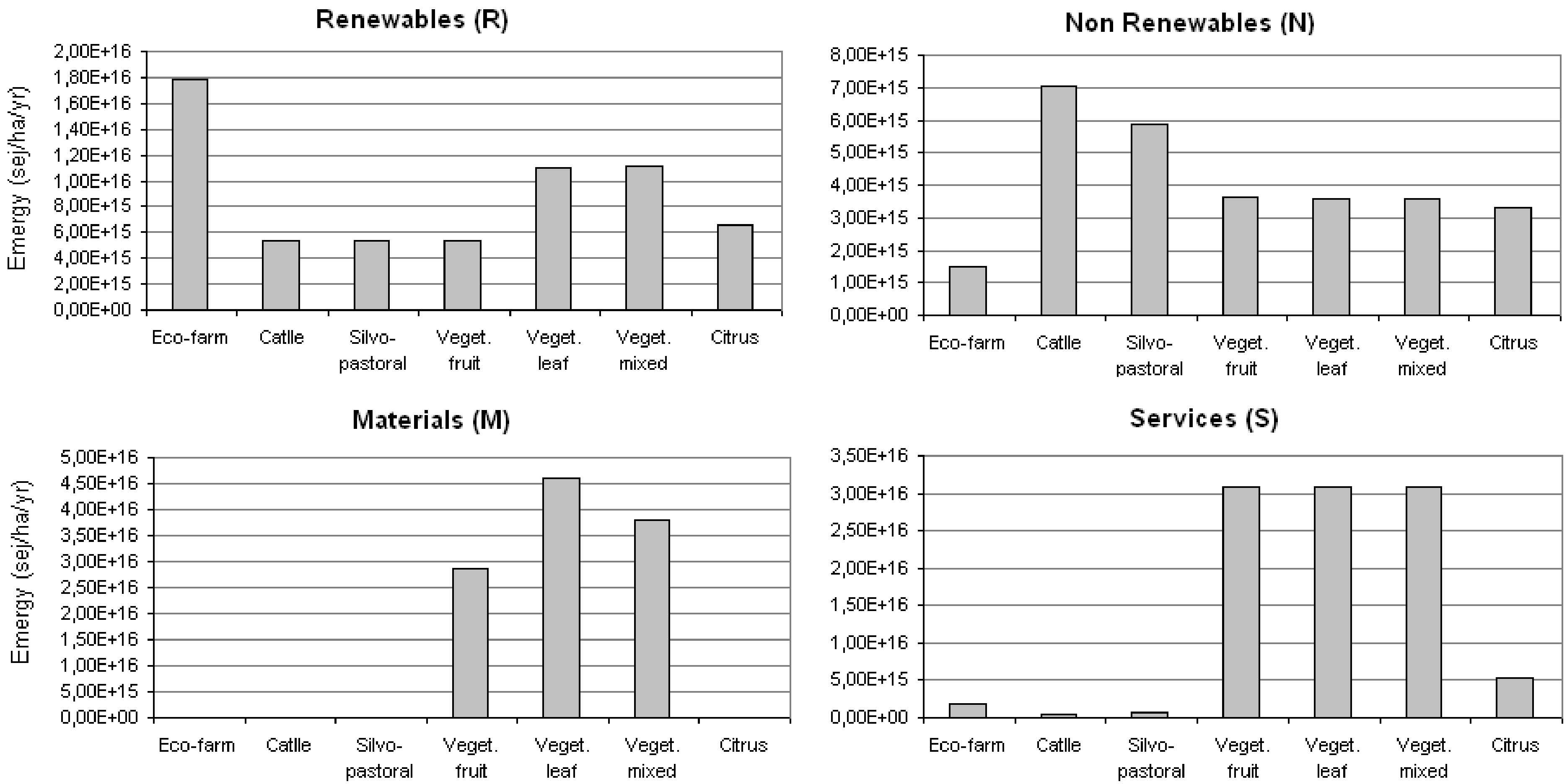


Figure 4.4.3. Energy flow for energy sources and production systems

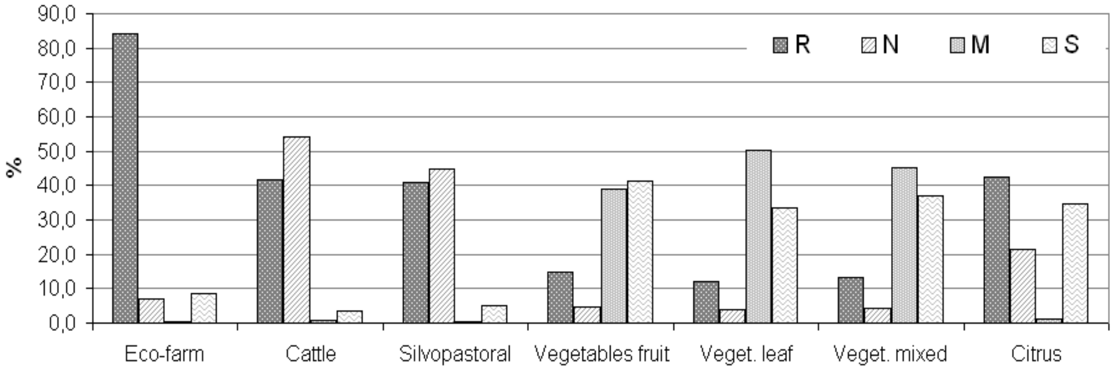


Figure 4.4.4. Percentage of energy flow for energy sources and production systems

4.4.5. EMERGY SYNTHESIS OF THE FARMING SYSTEMS

A farming system is a natural resource management unit operated by a farm household, and includes the entire range of economic activities of the family members (on-farm, off-farm agricultural as well as off-farm non-agricultural activities) to ensure their physical survival as well as their social and economic well-being.

Emergy synthesis for each farming system is summarized in the Table 4.4.5. Fig. 4.4.3 shows aggregated flows (details in annex 3). The long-term sustainability of human economic production and its basis in natural capital stocks is achieved via a suite of emergy-based indices. These indices, which relate flows from the economy to flows to the environment, were used to compare net yields and environmental loading, and to identify more sustainable agricultural methods. The fraction renewability (%R) (Table 4.4.5) quantifies the reliance of each system on renewable energies. The emergy yield ratio (EYR) compares units of exported energy with emergy invested. For agriculture, an investment of emergy (EIR) from the economy is made in order to capture renewable emergy from the environment. This ratio quantifies the effectiveness of non-renewable resources to capture renewable resources. The environmental loading ratio (ELR) is the ratio of purchased and non-renewable resources to renewable resources.

Table 4.4.5. Computed transformities and emergy indices for 7 farming systems in teresópolis

	Eco-farm	Cattle	Sylvo-pastoral	Fruit Vegetables	Leaf Vegetables	Mixed Vegetables	Citrus
Transformity (Tr, sej J^{-1})	4.8E4	6.3E7	2.3E5	3.1E5	6.7E5	4.3E5	3.4E5
Renewability (%R)	66	41	41	15	12	13	43
Net emergy yield ratio (EYR)	5.34	22.56	19.16	1.25	1.19	1.21	2.78
Emergy investment ratio (EIR)	0.23	0.05	0.06	4.02	5.26	4.68	0.56
Environmental loading rate (ELR)	0.51	1.41	1.44	5.66	7.28	6.52	1.35
Emergy exchange ratio (EER)	1.23	0.47	0.43	0.61	0.92	0.61	1.91

Transformity (Tr).

Is the inverse value of the system efficiency for a specific product, the solar transformity for an item is the solar emergy per unit available energy (sej J^{-1}). Tr = (Emergy used) / energy of products. That index evaluates the quality of the flow of energy and it allows to do comparisons with other forms of energy of other systems.

Transformity values vary from 4.88E4 to 6.30E7 sej J^{-1}. The transformity values of ecological systems (4.88E4 sej J^{-1}) are lower than that of the systems like cattle (6.30E7 sej J^{-1}), Silvo-pastoral (2.35E5 sej J^{-1}), Vegetables on average (4.5E5 sej J^{-1}), and citrus (3.3E5 sej J^{-1}). This means that ecological systems are more efficient, whereas cattle systems are most inefficient.

Other agricultural transformities are reported by Brandt-Williams (2001) in Florida for corn (1.26E5 sej J^{-1}) and tomatoes (8.6E5 sej J^{-1}), by Cohen (2005) for maize in Kenya (1.11E5 sej J^{-1}), by Ortega (2001) in Brazil for Ecological soybean (8.8E4 sej J^{-1}), for Chemical soybean (1.0E5 sej J^{-1}), and by (Haden 2003) in Denmark for crops and animal husbandry (2.59E5 sej J^{-1}).

Renewability (%R).

Is the percentage of the total energy driving a process that is derived from renewable sources (%R = R/Y). In the long rung, only processes with high %R are sustainable. As renewable resources we consider: rain, uptake of nutrients like nitrogen, minerals from soil rocks, products and services obtained from the farm area under preservation (according to Brazilian law at least 20% of total area).

Because of the large amount of non-renewable inputs relative to renewable inputs, the vegetable system had the lowest fraction of renewable inputs (12%) compared to the citrus system (43%) and to the ecological system (66%). This indicates that the ecological system depended on renewable resources for over 66% of its inputs meaning that from an ecological point of view it is the most sustainable. Other renewability ratios for agricultural systems are presented in Table 4.4.6.

The EIR, ELR and EYR offer additional information about the ability of each land use to be related to the larger economic system.

***Emergy Yield Ratio (EYR)*.**

Expresses the net benefit to society from energy sources (Brown 2003), in other words the ratio is a measure of how much a process will contribute to the economy.

Because the cattle and silvopastoral systems are based almost exclusively on natural inputs, the EYR ratios are as high as 22.6 and 19.2, respectively, as would be expected. This indicates that these systems incorporate high free resources from nature in to the society or economy systems, but with a high loss of non renewable resources (erosion). The ecological system has strong internal recycling which renders economic benefit to the farmer and ecological benefit to environment. The ecological system value is 5.4. The EYR typical values for agricultural products vary from 1 to 5. The lowest value is one, which happens when nature inputs are null (RN = 0). The difference above the minimum value measures the cost-free contribution of the environment to production.

The value of EYR for the vegetable systems is closest to unity (1.19, 1.21, 1.25); it means that the nature contribution is low when compared to resources from economy; so, this system is not able to deliver too much net emergy to consumer systems because most parts of inputs are not renewable (e.g.: herbicide, fuel, fertilizers, pesticides, etc.). For the citrus system the value is slightly higher (2.78), this system do not have high economy inputs, and natural resources are bigger. The ecological system has strong internal recycling which renders economic benefit to the farmer and ecological benefit to environment.

Bastianoni (2000) found an EYR value of 1.96 for farms with six different crops and livestock in Italy. Other emergy yield ratios for agricultural systems are presented in the Table 4.4.6

Emergy Investment ratio (EIR).

It evaluates if a process is a good user of the emergy that is invested, in comparison with alternatives. This ratio measures the society's effort to produce a given product in relation with nature's contribution; it evaluates if the system uses the investment adequately. A low value means that the environment has a relatively larger contribution than the economy (goods and services), having lower costs and being more competitive. This ratio gives a clear vision of the difference between the systems in relation to the investment needed for production.

The intensive vegetable systems values are high (4.02 to 5.26), thus demonstrating an economically fragile agriculture due to its dependence on purchased inputs from foreign regions. The citrus system has good value (0.56). Livestock production, sylvopastoral systems and the Ecological farm show the lowest values, 0.05, 0.06 and 0.23 respectively. Those three systems use nature resources (free) instead of economy resources (expensive) having lower need of external investment and lower production costs. The ecological option demands more economy inputs (services) than the cattle systems. More emergy investment ratios for agricultural systems are presented in the Table 4.3.6

Emergy Load Ratio (ELR)

This ratio is directly related to the fraction of renewable resources, and is considered a measure of ecosystem stress due to production (Ulgiati 1998). The environmental loading ratio is a direct inverse function of the renewable fraction.

Vegetables leaf, fruit and mixed systems (7.28, 5.66 and 6.52) produce great environmental damage. Also the Catlle systems, silvopastoral systems and citrus systems (1.41, 1.44 and 1.35) generate high environmental impact. Ecological agriculture instead has lower value (0.51), which confirms greater use of natural renewable resources by ecological and organic production techniques. The greater environmental loading ratios for the intensive vegetable systems and cattle systems compared to the ecological system reflect the environmental cost of using more purchased resources.

Other emergy load ratios for agricultural systems are presented in the Table 4.4.6

Emergy exchange Ratio (EER)

The emergy exchange ratio is the ratio of emergy exchanged in a trade or purchase (what is received to what is given). The ratio is always expressed relative to one or the other trading partners and is a measure of the relative trade advantage of one partner over the other. The emergy exchange ratio (EER) is the ratio of emergy received to the emergy given in any economic transaction, *i.e.*, a trade or sale. The trading partner that receives more emergy will receive greater real wealth, and therefore, greater economic stimulation due to the trade.

The emergy exchange ratio shows that the transaction of the ecological production systems (1.23) and citrus (1.91) do not receive a fair price. The received emergy by the transaction demonstrates that the systems export more emergy that the one received through the payment of the products. The cattle (0.47), Sylvopastoral (0.43), vegetables fruit (0.61), leaf (0.92) mixed (0.61) give less energy to the buying system than to the producing system.

Table 4.4.6. Comparison of emergy indicator for different faming systems

Farming System	Y	Tr	% R	EYR	EIR	ELR	EER
Ecological soybean (1)	2.57E15	8.8E4	92	1.09	1.19	0.46	1.45
Organic Soybean (1)	2.39E15	8.1E4	78	1.27	1.40	0.42	1.35
Chemical Soybean (1)	3.54E15	1.0E5	74	1.35	3.40	0.23	2.51
Herbicide Soybean (1)	3.80E15	1.1E5	31	3.25	3.70	0.21	2.69
Ecological farming system (2)	4.77E15	2.0E5	69	3.36	0.4	0.82	0.02
Eco farm integrated system (5)	-	2.8E5	75	11.90	0.09	-	5.52
Sitio santa Helena (5)	-	8.5E5	27	2.52	0.66	-	2.33
Sitio tres lagos (5)	-	2.3E6	25	7.82	0.15	-	9.91
Bovine meat (sej kg^{-1}) (4)	9.90E13	2.1E12*	8	7.83	-	11.0	-
Danish agriculture (6)	-	-	-	1.17	5.91	9.67	-

(1) Ortega (2001); (2) Unicamp (2004); (4) Serrano (2001); (5) Roosevelt-Agostino (2001); (6) Haden (2003)
* sej kg^{-1}

4.4.6. EMERGY SYNTHESIS OF THE WATER BASIN CORREGO SUJO

The added data for the Corrego Sujo basin show in general that the consumption of materials and services expressed in emergy terms are very low in comparison to the total emergy used in the basin. This is justified given the minimum area, approx. 1.8% occupied by crops under intensive use of inputs coming from human economy. The biggest quantity of emergy is from natural renewable and not renewable sources, mainly in form of water, minerals and organic matter (Table 4.4.7). The basin has high capacity to store biomass and in emergy terms its value is 2.1E18 sej.

Table 4.4.7. Summary Table of the yearly emergy flows for Côrrego Sujo agriculture, 2005.

Name of flow	**Quantity (E+17 sej)**
Local renewable sources (R)	318
Local non-renewable sources (N)	238
Purchased resources (M)	0.41
Services and labor (S)	0.04
Emergy Yield (Y)	556
Feedback from economy (F = M S)	0.45
Biomass saved in system	21.7

The loss of organic matter (3.5% average soil content) through the soil erosion for the whole basin is of 2.38E19 sej, in economic terms this would represent between 1.7 and 4.9 million dollars per year.

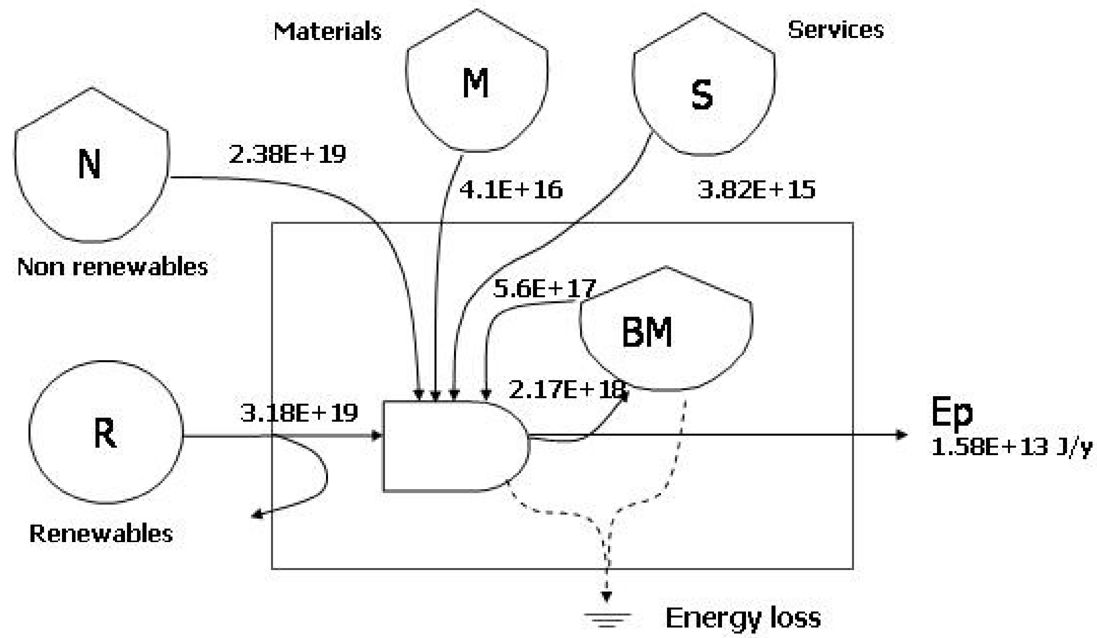


Figure 4.4.3. Overview diagram showing the main pathways of emergy flows in Côrrego Sujo agriculture, 2005.

The principal renewable flows are sunlight, rainfall and minerals. Purchased goods, fertilizers, fuels, and services are also shown. Internal production systems include forests and forest in regeneration (1 to 3 years old), citrus orchards, intensive and ecological farming; livestock are shown in Fig. 4.4.4.

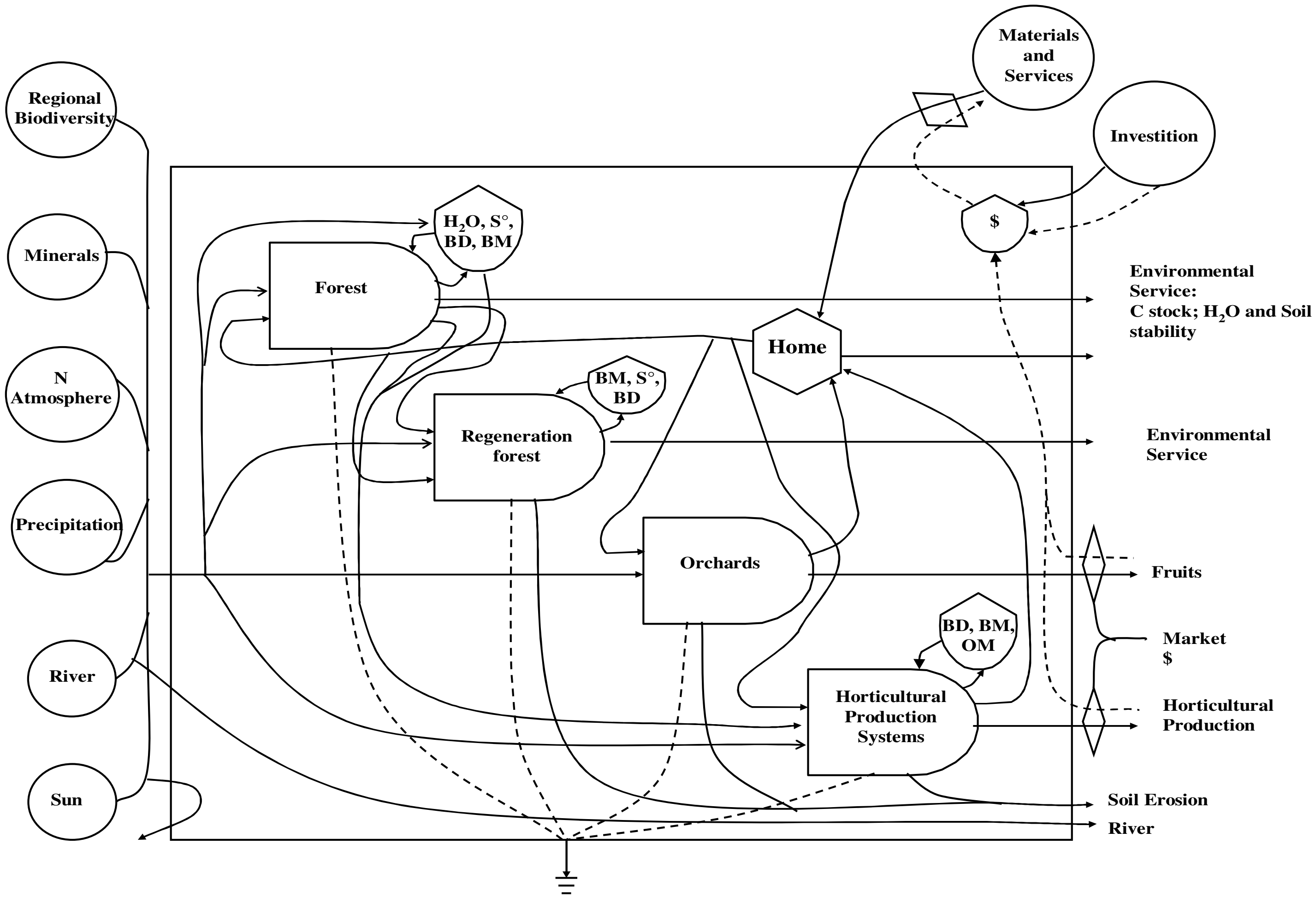


Figure 4.4.4. Teresopolitan environmental/economic system depicting resource flows entering the system and the organization of major internal components that utilize those resources

Table 4.4.8. Computed transformities and emergy indices for the Corrego Sujo Basin.

Emergy indices	**Parameter**	**Value**
Transformity (Tr, sej J^{-1})	Y/Ep	1.8E5
Net emergy yiel ratio (EYR)	Y/F	1234
Emergy investiment ratio (EIR)	F/I	0.001
Enviromental loading rate (ELR)	(NF)/R	0.75
Renewability (% R)	100(R/Y)	57
Emergy exchange ratio (EER)	Y/income*3.18E12	3.05

From Table 4.4.8 it can be deduced that in general the basin does not have dependence of purchased resources (EIR 0.001). The sources from the economy (material and services) increase the environmental load indirectly because it used a great quantity of non renewable sources to manufacture them. The environmental impact is moderate (ELR 0.75) as the system makes high use of renewable resources. The efficiency of the basin as a system is highly positive (EYR 1234) indicating that it takes more emergy than that it takes from the economic system in form of materials and services. It represents a positive contribution to the economy. The EER of 3.05 indicates that there exists a certain decapitalization of the system, because it exports emergy to the urban systems at a moderate to average level. In general, the basin considered as a system is characterised by a half rate renewability (% R = 57) indicating again that the biggest contributions come from natural sources, and showing that the ecological sustainability is moderate to good.

Table 4.4.9. Sensitivity analysis for the water-basin Côrrego Sujo

Alternative systems to actual cattle production	Variable Change	
	Economic	Ecologic
Sivopastoral	o	+
Ecological or organic systems	+	+++
Intensive Vegetable systems	+++	o
Citrus	+	+
Forestry	++	+++
Follow	-	++

(+) low positive impact; (++) middle positive impact; (+++) high positive impact; (-) low negative impact; (o) neutral

The biggest positive impact in terms of emergy indices was achieved through the substitution of the cattle production by ecological systems. In this case the use of non renewable energies decreased considerably up to a value of 1.17E15 sej $ha^{-1}yr^{-1}$. This value was obtained from the soil erosion at 3.5% of organic matter. In economic terms this means 0.3 to 0.8 million dollars/year is spent for non-renewable energy in the whole basin, which is a quite considerable quantity for such a small area, representing about 50% of the annual investment in the basin. Substituting these cattle systems for ecological or organic systems will convey clear advantages in all aspects, e.g. from an economic aspect the revenues are multiplied 4 to 12 times, ecologically the negative impact decreases, and the stock of carbon and biomass increases considerably.

In Teresópolis, annual agricultural crops and short rotation perennials (mixed systems) tend to give the greatest economic productivity per hectare per annum but have marginal or even negative returns on emergy due to inputs for soil preparation, fertilizing and harvesting in accordance with Holgrem (2003) who studied crop rotation and its effect on the emergy ratios. Long rotations and low input plantation and natural forestry (eco-farm) have lower economic productivity per hectare per annum but can more easily be managed in a sustainable way and finally, can be grown on marginal land too poor for food production. These advantages show up as high emergy yield ratios

Farmers that organize their operations by drawing on high yield emergy sources (vegetable systems) are able to displace their fellow farmers who continue to organize their farming systems around local renewable emergy flows - a process observed in Teresópolis as a fairly rapid shift from annual farming systems to intensive chemical use farming and inefficient livestock.

The results from the vegetable systems demonstrated the increased yield per area resulting from the investments in high energy resources (e.g. fertilizers, services). However, the dependence on these inputs reduces the fraction of renewable energy and increases environmental degradation, making these systems less sustainable relative to systems more dependent on renewable energies.

Dependence on non-renewable energies for larger yields may be a good strategy when non-renewable energies are readily available. However, when non-renewable energy sources are no longer available, or environmental degradation prohibits their use, agriculture will need to be reorganized to rely on the limited flow of renewable resources.

4.4.7. CONCLUSIONS ECONOMIC AND ENVIRONMENTAL EVALUATION

By quantifying the inputs to agricultural system on a common basis emergy analysis comparisons across agricultural systems are facilitated and activities or sceneries to achieve greater sustainability can be identified. The studied systems were the vegetables (leaf, fruit and mixed), ecological, cattle production, syslvopastoral, and citrus systems.

The horticultural systems use more manpower in comparison to the other systems, the ones that uses less are the cattle systems. Due to the forest handling and agroforestry inside the same property, the ecological systems in general, make low use of manpower per hectare. But if it takes exclusively into account the agricultural area this option uses more manpower than that of all other studied systems. The horticultural intensive systems in general obtain better net income, they are also the most dependent in inputs coming from the economy and for this reason more unstable. They contribute also less to the economy of the region, because of their low use of renewable resources.

Cattle production is one of the most important components of agriculture in Teresópolis, being the main consumer of natural resources all together. Cattle production contributes to the degradation of resources, namely, land degradation, water scarcity and pollution, global warming, and diminishing biodiversity.

In general terms the cattle systems cause bigger environmental damage and they have the smallest yield per hectare in economic and energy terms. Although these do not depend on resources coming from the economy they use many non-renewable resources. The erosion is the most important factor in terms of non-renewable resources. In economic terms this soil loss represents a very high value.

The vegetable systems had large amounts of energy invested in irrigation, fertilizers and fuels, and the cattle systems use great quantities of non-renewable resources, leading to a loss of autonomy of producers in relation to technology and prices fixed abroad. The ecological systems demonstrated potential gains in sustainability by reducing the energy devoted to these inputs. Because large amounts of non-renewable energies are required to supply water and nutrients to fields, finding methods to reduce these inputs has great potential to increase the sustainability and decrease the environmental loading of agricultural production.

The substitution of the cattle systems for any other agricultural or forest system represents economic and environmental clear gains. The best options were the ecological, agroforestry and forest systems.

The largest value of sustainability corresponds to the ecological systems in ecological terms and also it is the only one that has the capacity to save capital in form of biomass in the system. These systems use fewer resources from economy and more natural renewable resources, which guarantee its sustainability. They ensure the survival of the producer throughout the time and the preservation of the biodiversity.

Emergy evaluation with similar findings for other agricultural systems were published by Pimentel (1993), Cohen (2006), Martin (2006), Ortega (2001), Serrano (2001), Roosevelt-Agostino (2001) and Haden (2003).

4.5. ECO-VOLUME AND RESILIENCE INDEX

4.5.1. ECO-VOLUME

Eco-volume (V_eco), is the aboveground quantifiable space or volume limited by a uniform vegetation stand and its height, within which coexist wide interactions among biotic and abiotic components. Eco-volume is the product of the area occupied by a uniform type of vegetation and its eco-height[5].

The forest systems have the highest values of eco-volume, varying between 44500 m^3 ha^{-1} for semi-arid forests in northeast Brazil up to 250000 m^3 ha^{-1} for primary mountain rain forests in the Atlantic region. The aquatic plants dominated by *Typha domingensis* present 9500 m^3 ha^{-1} of eco-volume. The highest values of eco-volume in agricultural systems (average: 90000 m^3 ha^{-1}) correspond to agroforestry systems (coffee and cocoa), and ecological systems. The horticultural systems and grassland have reduced values averaging 24000 m^3 ha^{-1} (Figure 4.5.1).

The importance of the eco-volume concept is its emphasis on the interrelationships between species living within the boundaries of a space or volume (area x eco-height). These interactions are as important as the physical factors to which each species is adapted and responding. Each eco-volume encompasses a biological community (or biocoenosis defined by Möbius 1877) adapted to specific conditions in a given place (Tansley 1935).

The functionality of the eco-volume tended to be overlooked. Janssens *et al.* (2004a) indicates that the eco-volume has an effect on precipitations (additional precipitations also coined as eco-precipitations[6] are generated), as well as on regulation of other ecological functions like microclimate and water cycles. Eco-volume leads directly into such areas as water cycling, Gross Primary Productivity (GPP), Net Primary Productivity (NPP), and energy flow. Eco-volume is related too with the landscape ecology concept proposed by Troll (1939), whereby interactions between environment and vegetation are investigated.

[5] *Eco-height renders a weighed average over time and across the different vegetation community fractions. In this case, a vegetation reaches community status as from canopy closure onwards and its height will be given by the domineering (upper layer) plants.*

[6] *Eco-precipitations are complementary rains generated by ecological sound management of a watershed basin.*

Inside each eco-volume one can distinguish a vertical structure, for example in forests one can recognize different strata like an herbaceous stratum, a bush stratum and a tree stratum. The eco-volume is subject to either periodic or abrupt changes based on climatic cycles or due to man-made disruptions, like deforestation or extraction of plant material. These changes can also be natural through phytosociological succession.

Bio-volume (V_{bio}), is the total volume of plants (trees, bushes, herbaceous, etc) taken by their corresponding biomass. Hence, bio-volume of a plant is its biomass divided by its corresponding specific weight. The concept is based on the hypothesis that plants mainly compete for space, Janssens *et al.* (2005), Diaz *et al.* (2004), CIID (1998), Kolnaar (2006), Hansen (1999). The competition is not only aboveground but also belowground where occupation of soil space is of primary importance (Casper 1997).

The natural systems with a bigger value of V_{bio} are the mature Atlantic rainforest 1575 m^3 ha^{-1}, and to a lesser extent its fragments with 912 m^3 ha^{-1}. The systems with less V_{bio} are the water plants, *caatinga*[7] and the forest in regeneration (65, 129 and 221 m^3 ha^{-1} respectively). The ecological cropping of coffee in the Northeast Brazil has a great bio-volume value of 739 m^3 ha^{-1}. Other agricultural systems with a very good value of V_{bio} are the cocoa agroforests in Cameroon (396 m^3 ha^{-1}). The agricultural systems with less V_{bio} are the grass systems, Horticultural system and the sylvopastoral system (13, 32 and 74 m^3 ha^{-1} respectively) (Figure 4.5.1)

The potential eco-volume *(V_{pot})* is the state of full maturity of a forest sometimes called "climax". This stage shows a structured functional unit in equilibrium of energy and matter flows between its constituent elements, attaining maximal interactions between organisms (plant, animal and other living organisms—also referred to as a biotic community or biocoenosis) living together with their environment (biotope), functioning as a limit concept. Therefore, we calculate $V_{pot}=V_{loss}+V_{eco}$.

The V_{pot} for the region of Teresópolis is given by the mature forest of the National Park "Serra dos Ôrgaos" (250000 m^3 ha^{-1}). For the waterlogged areas where only aquatic plants may thrive V_{eco} amounts to 120000 m^3 ha^{-1}, whereas for the coffee producing region in the northeast in, we took an average of 180000 m^3 ha^{-1}.

The Volume-loss (V_{loss}), equals V_{pot}-V_{eco}, and represents the regression of an ecosystem in terms of V_{eco}. The bigger the V_{loss}, the bigger be the ecosystem losses in quality, function, and services (Figure 4.5.1).

[7] *forest of stunted trees and spiky scrub in the regions of small rainfall in Brazil*

The V_{loss} can be connected with the yield per hectare expressed in dry matter (ton), energy (MJ) or money (€) to determinate the attrition or conversely the efficiency of the systems as a function of V_{eco}. For example to generate a ton of dry matter in the grass and citrus systems it was necessary to sacrifice 166067 m^3, and 145397 m^3 of V_{eco} respectively. That represents roughly the volume of an average middle football stadium. That high attrition is due to the very low productivity of these systems.

The most efficient system in Teresópolis is the Fruit-vegetables system with an average value of 3451 m^3 * ton DM^{-1} * ha^{-1}. If we divide the V_{loss} by yield expressed in Euros it follows that to generate hundred Euros it is necessary to sacrifice an eco-volume equivalent to the volume of a stadium (Figure 4.5.2)

From this point of view the cattle, sylvopastoral and citrus systems are the less efficient systems and the more destructive of the ecosystems.

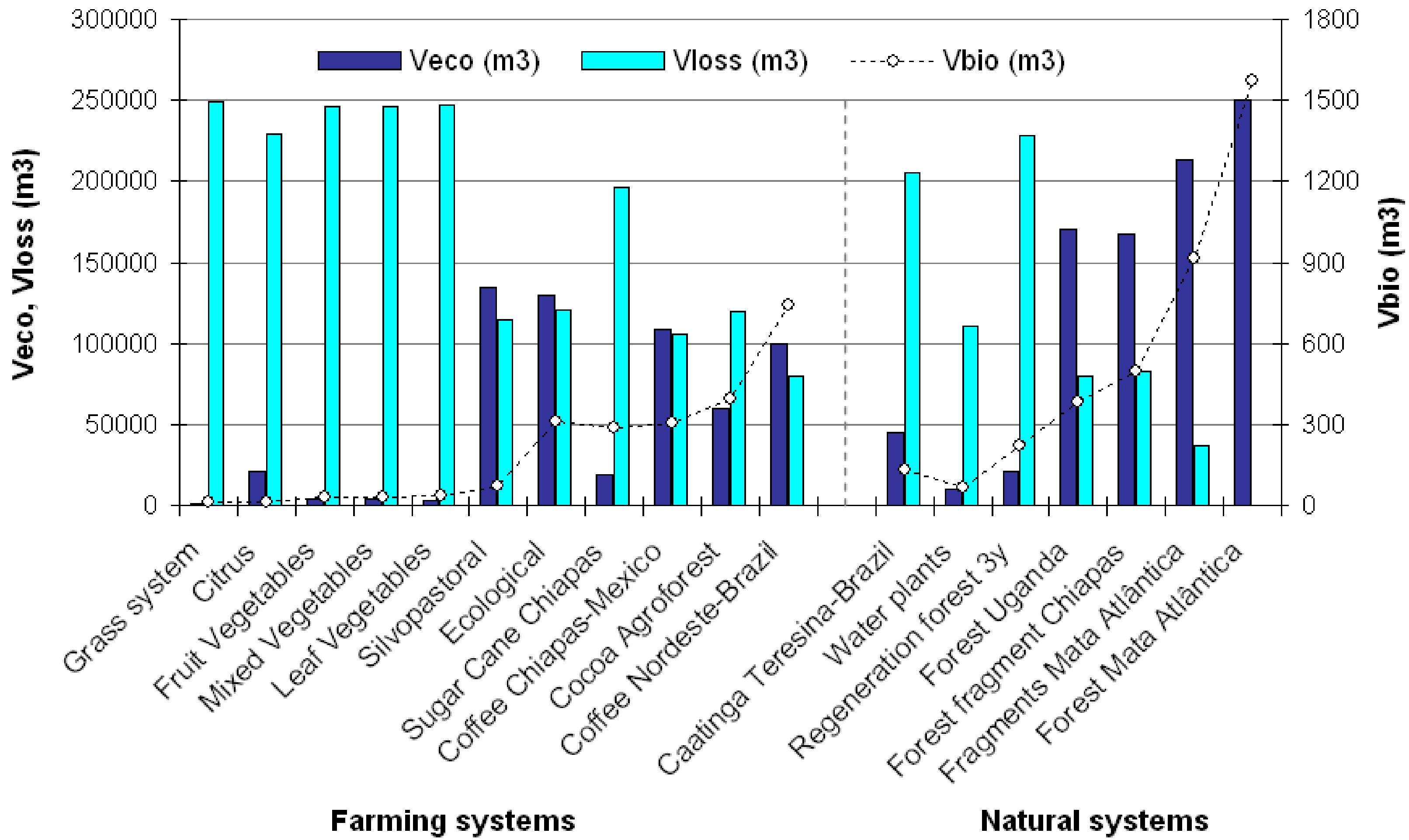


Figure 4.5.1. Eco-volume (V_{eco}), bio-volume (V_{bio}) and volume-loss (V_{loss}) of agricultural and natural systems

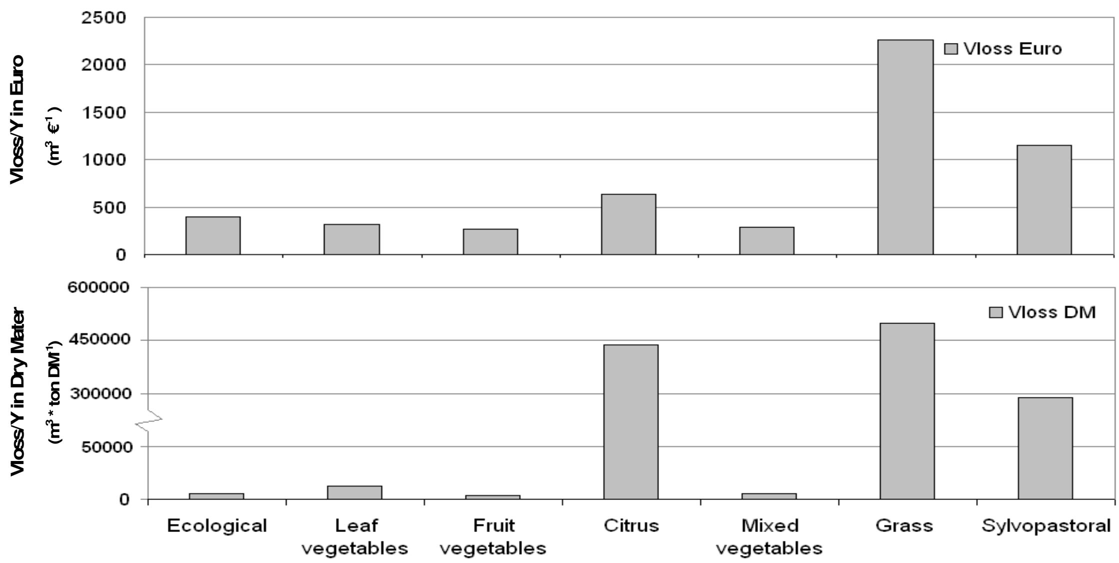


Figure 4.5.2. Eco-volume attrition. Volume loss (V_{loss}) needed to produce dry matter (V_{loss} $Y^{-1}ton^{-1}$ dry matter^{-1} ha^{-1}) and monetary units (V_{loss}/Y €$^{-1}$ ha^{-1})

The plants compete for space to have mainly bigger access to light, the aggressive plants develop volume quickly and not necessarily dry matter. The plants that do not have the capacity to develop volume quickly, they have adapted making low energy use in the respiration or increasing their photosynthetic capacity. The plants that not were able to adapt (most of the crops) usually die or decrease their yield. Vitta (n.a.) indicates that the loss of yield of a crop is more sensitive to morphological parameters (increase of volume) than to physiologic parameters related to the photosynthesis.

The distribution of plants, its structure and the performance of the community in the ecosystems (eco-volume) are determined by the distribution of resources or better use of these through some species with large competing capacity for space (bio-volume and bio-surface[8]).

Crowding intensity *(C_i)*, represent the relationship between Bio-volume with its actual Eco-volume (percentage of V_{eco} occupied by V_{bio}) ($C_i=100*(V_{bio}/V_{eco})$. Its assessment is very diverse, and it will be mainly differentiate for natural and agricultural systems. In natural systems, in general, the bigger the C_i, the better will be the V_{eco} quality. In agricultural systems the spacing or density and weed control play a very important role to reduce the competence, and this activities impact in the reduction of C_i. That means, the lower the C_i, the better will be the ventilation, bigger

[8] Bio-surface is the total surface of a living plant i.e. of leaves, twigs, stems, branches and roots

the CO_2 availability, and lower the plague and illnesses incidence, especially fungous. The crowded systems stands, at the population level, delay the development of size between neighbours, plant weight, increase mortality rate (Ballare *et al* 94; Weiner 1990). Among the best characterized population responses to increased plant density (number of plants per unit area) are: (i) reduction in individual plant size (weight), (ii) increase in mortality rate, and (iii) development of size inequalities among neighbours (Myers 1996).

Difficultly *Ci* surpasses 1% so for natural systems as for agricultural systems, e.g. the plants in grass system are very crowded, reaching a value of 1.41%. The forests in regeneration on the same way has a high density of plants and a high bio-volume (C_i=1.04%). The lower values were for the sylvopastoral system (0.03%) and citrus (0.07%), this is justified because the formation of big spaces between trees (6 to 12 m), and in citrus systems (each 6 m); and also because exists a big weed control and pruning.

C_i is bounded also to the competition concept, in this case the competition for a limited space. The competition is the interaction among individuals, provoked by the demand common of a limited resource, and that it drives to the reduction of the performance of those individuals Clements *et al.* (1929), they concluded also that, competition is purely a physical process such crowding. On the contrary for Went (1973) the competition is an overrated factor in the plant world. Direct competition for space and light between plants does not start before the available surface is covered and plants are large enough to withhold light from their neighbours. Therefore competition for light and space will start earlier in high density populations, with plants growing close to each other, than in low density populations Kolnaar (2006).

In the contrary sense of C_i the Wesenberg factor (W_f), is introduced in order to better appreciate the ability of a community plants to colonise an environmental space (= V_{eco} / V_{bio} *or* $1/C_i$).

The citrus system with low V_{bio} colonizes bigger space (1466), sylvopastoral (1837). The grasses and vegetables have less capacity to colonizing. In natural systems the forest in regeneration presents the lowest W_f value (96), the biggest forest Uganda (442) (figure 4.5.3).

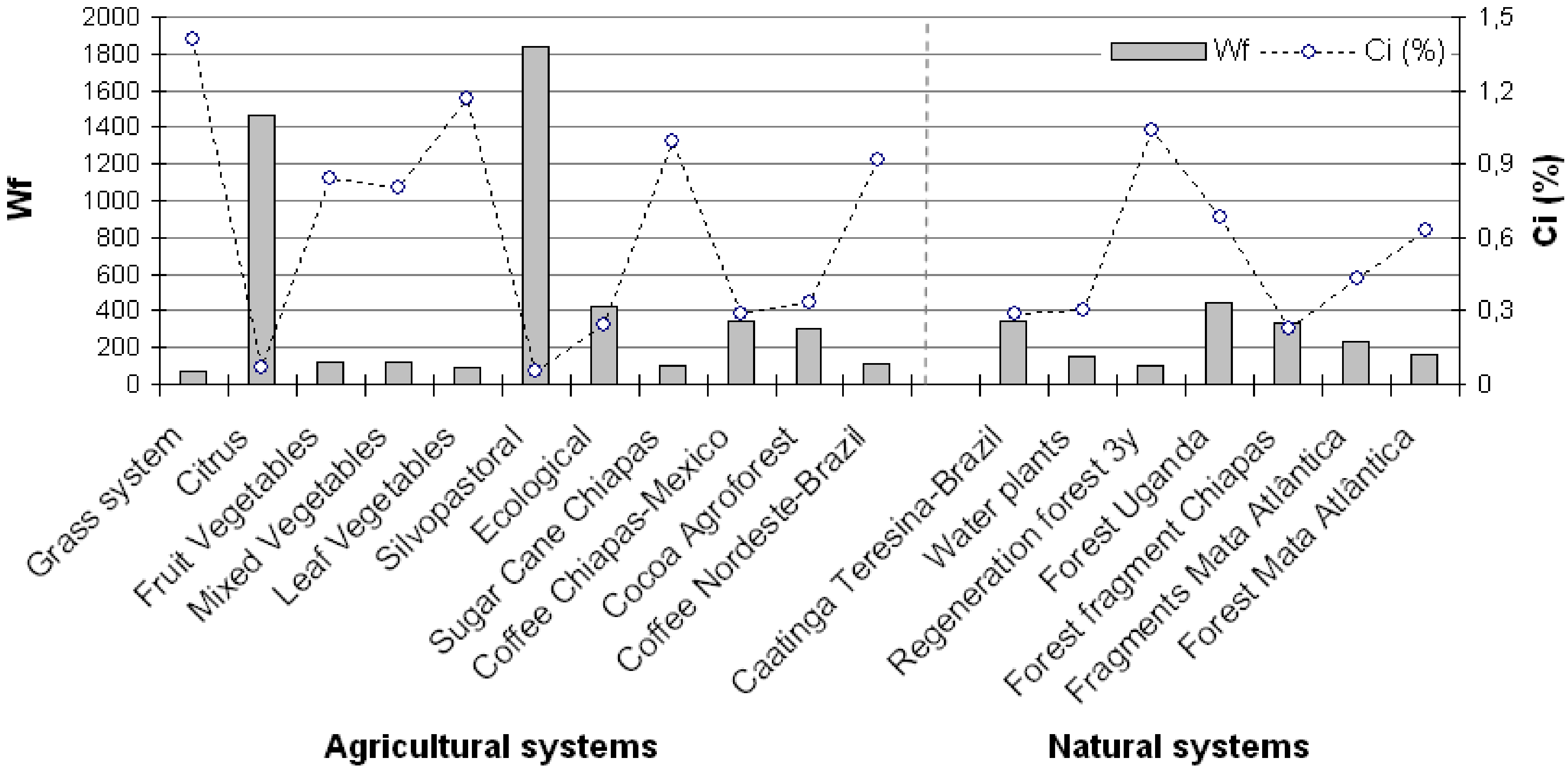


Figure 4.5.3. Wesenberg factor (W_f) and crowding intensity (Ci) of agricultural and natural systems

4.5.2. RESILIENCE INDEX

The *Ri* index measures the resilience of the systems by comparing bio-volume (V_{bio}) with the potential eco-volume (V_{pot}). Bio-volume represents the current state of the systems and V_{pot} represents the state in equilibrium of the ecosystems.

Resilience is not a new term, it has found application in many different fields, and from its origin is considered the capacity to return to a previous good condition (equilibrium). Pimm (1991) defines it as a measure of how fast (time) a system returns to an equilibrium state after a disturbance. Holling (1973) defined it as a measure of how far the system could be perturbed without shifting to a different regime (persistence). Schulze (1994), Ehrlich (1986), Walker (1992) defined resilience as the ability of ecosystems to resist stresses and shocks, to absorb disturbance, and to recover from disruptive change. Resilience is a buffer against environmental changes or disturbances (Vergano 2006).

> For us *resilience relates to the continuity of ecosystems and their ability to endure changes, disturbances, stresses as well as to its capacity to rebuild itself until an equilibrium level, at which it is capable of achieving its ecosystems functions, and providing goods and services.*
>
> *The more resilient the ecosystem, the faster is the returning process to the original long lasting equilibrium state, the bigger the ability to tolerate changes, disturbances and stresses, and the higher is the probability of maintaining the efficiency of ecosystems' functioning.*

The systems with indices between 0.3 and 0.5 possess high resilience capacity. Above 0.5 the systems are approaching climax stage. Indices between 0.1 and 0.2 represent systems with average resilience capability, those smaller than 0.1 are indicative of low resilience.

The agricultural systems with bigger resilience index (R_i) were Coffee Nordeste in Brazil (0.41), Cocoa in Cameroon (0.22), Coffee in Chiapas Mexico (0.14) and ecological horticulture in the Mata Atlântica (0.12), all four agroforestry systems. The lowest indices correspond to the grass systems (0.005), citrus (0.006), vegetables (0.013 on average) and sylvopastoral (0.029) (Fig. 4.5.4).

The forest systems present middle to high resilience. The Atlantic rain forest is near the climax level. The aquatic plant systems and the forest in regeneration (3 year old) present a low resilience index (0.054 and 0.088 respectively). The lowest index corresponds to a young Caatinga with only 0.052 (Fig. 4.5.4).

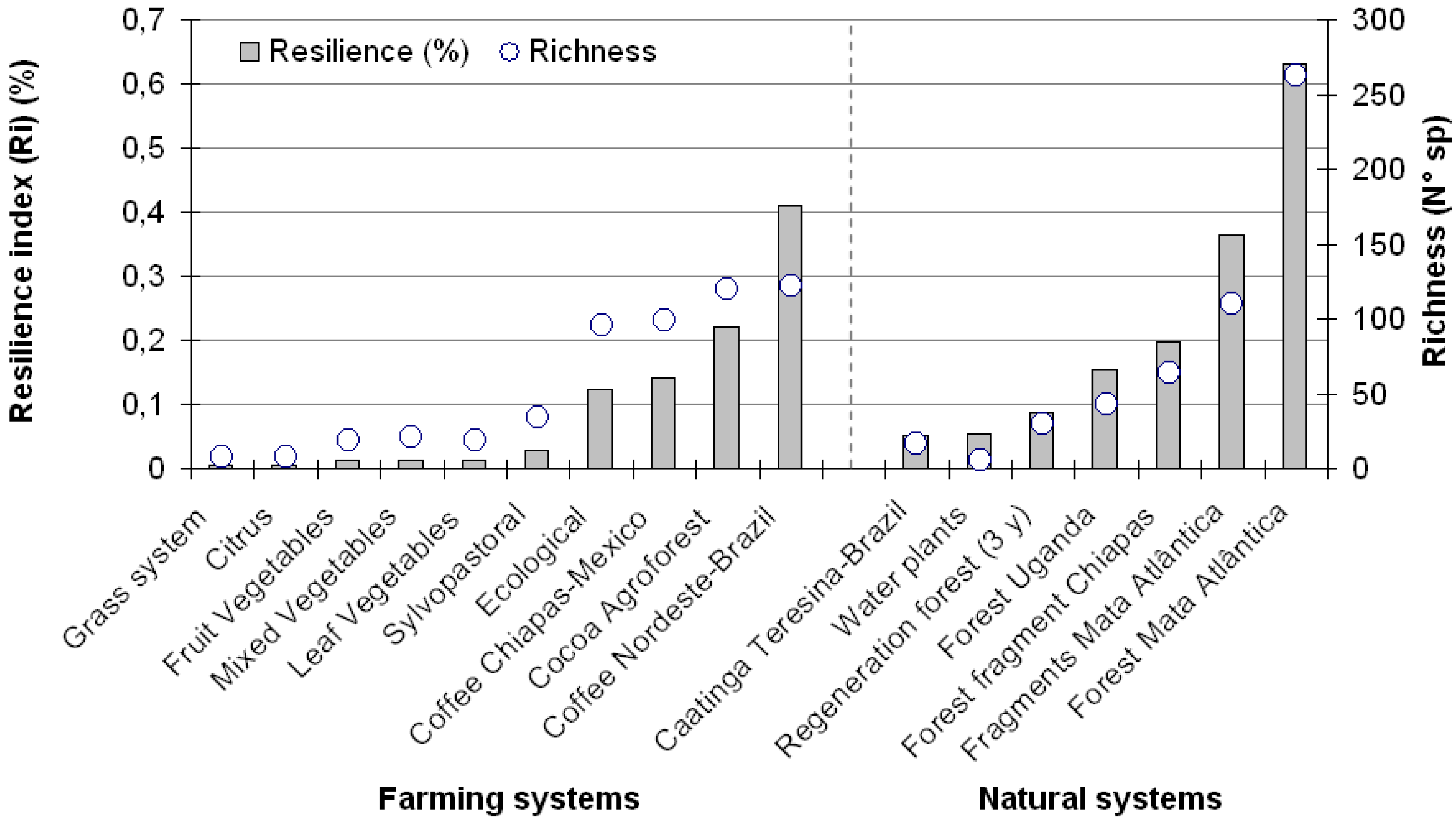


Figure 4.5.4. Resilience index for natural and agricultural systems

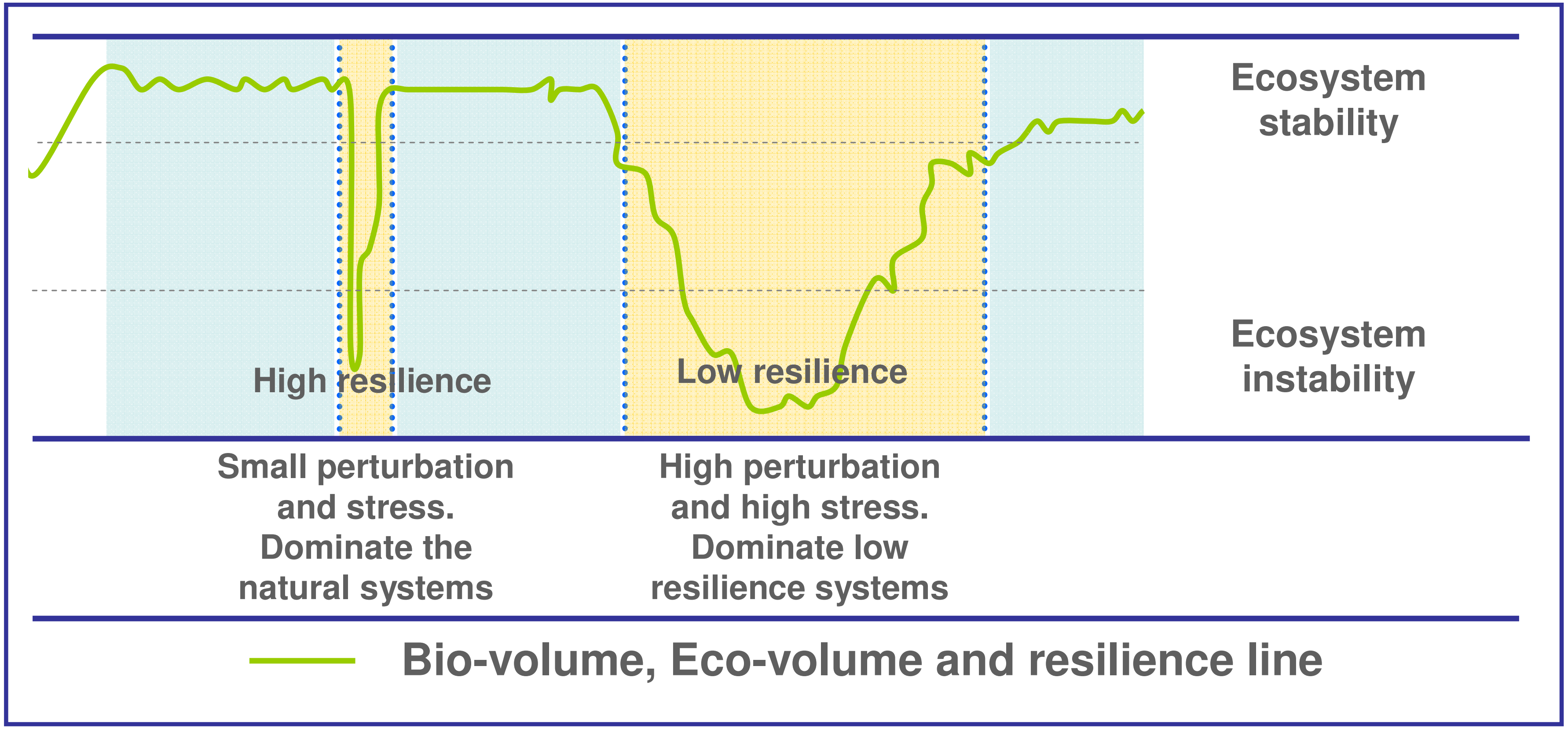


Figure 4.5.5. Bio-volume, eco-volume and resilience line, ecosystem stability in small perturbed and low stressed natural systems, and in high perturbed and high stressed low resilience systems. Ecosystem stability as a function of recovery time

When agricultural systems like cattle and vegetable systems are predominant in the landscape, the natural system can not guarantee the provision of the same goods and benefits as in the previous equilibrium state, and thus have a very low resilience. The lower the natural system's capacity to adapt to changes, the higher is the risk to decline (Fig. 4.5.5).

The graph shows situations in relation to the stability and resilience of ecosystems. The left part of the graph, or high resilience prevails when a system generally approaches stability (or climax). The latter stage can suffer small types of perturbations or stresses, the impact of which can be reverted quickly and easily to the stable equilibrium state e.g. small deforested areas in the rain forest. The second situation to the right, - low resilience -, occurs when stress and perturbations are bigger. Consequently, the ecosystem presents difficulties returning to the stability stage or needs a long time and large resources e.g. current agricultural systems and cattle systems that dominate the landscapes in the Atlantic rain forest region (Fig. 4.5.5).

4.5.3. RESILIENCE AND BIODIVERSITY

The environmental services of biodiversity are certainly significant, probably much more so than the direct benefits of biodiversity in the form of material goods (Myers 1996). Biological diversity appears to enhance the resilience of desirable ecosystem states, which is required to secure the production of essential ecosystem services (Elmqvist *et al.* 2003). Species that directly or indirectly influence the ability of the ecosystem to function will enhance resilience, to the contrary of sets of species that do not have a significant role in altering the states of the ecosystem (Walker 1992).

We found a statistically significant correlation of 0.93 (+/- 0.06) between Resilience index and Richness at 99% of confidence level. The model based on the resilience index explained 87.3% of the variability. The Atlantic rain forest has the biggest number of species (263[9]), while surprisingly the cocoa agroforestry in Cameroon and the coffee agroforestry system in North-East Brazil have a larger number of species (120 and 122 respectively) (Fig. 4.5.6).

[9] Species with DBH bigger than 5 cm on 0.8 hectare. Thier (2006); Seele (2005); Wesenberg (personal communication)

Agricultural systems	Resilience (%)	Richness
Grass system	0,005	8
Citrus	0,006	8
Fruit Vegetables	0,012	19
Mixed Vegetables	0,013	21
Leaf Vegetables	0,014	19
Sylvopastoral	0,029	34[10]
Ecological	0,124	96
Coffee Chiapas-Mexico	0,142	99
Cocoa Agro-forest	0,220	120
Coffee Nordeste-Brazil	0,411	122
Caatinga Teresina-Brazil	0,052	16
Water plants	0,054	6
Regeneration forest (3 y)	0,088	30
Forest Uganda	0,154	43
Forest fragment Chiapas	0,198	64
Fragments Mata Atlântica	0,365	110[4]
Forest Mata Atlântica	0,630	263[4]

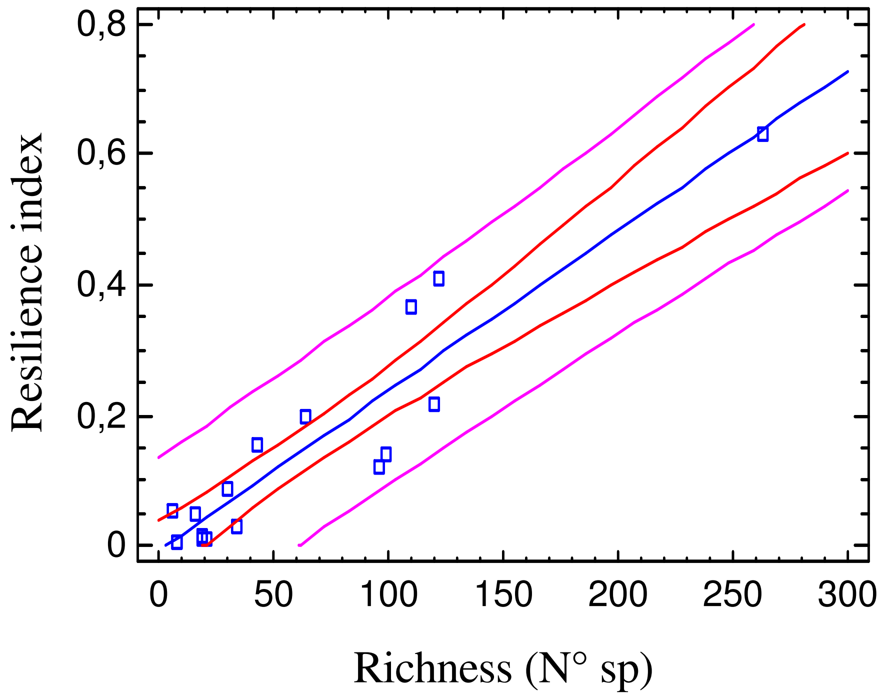


Figure 4.5.6. Simple Regression - Resilience index vs. Richness. The output shows the results of fitting a linear model to describe the relationship between Resilience index and Richness. The equation of the fitted model is Resilience index = -0,0075 + 0,0024*Richness. Correlation Coefficient = 0,934. R-squared = 87,295 percent

[10] Gibson 2000

Jones (1995) affirms that some connections exist between resilience and biodiversity. Biodiversity can make an important and positive contribution to ecosystem resilience. For Ricklefs (1993) and Perrings (1995) biodiversity could supply the most important service in natural systems. However, many authors are uncertain as to the exact contribution of species composition and richness to the ecosystem dynamics (Perrings 1994b; Solbrig 1991, Schulze, 1994). Johnson *et al.* (1996) says that no pattern or deterministic relationship needs to exist between species diversity and the stability of ecosystems. Ecosystem processes often appear to be quite resilient to biodiversity decline as they can keep on supplying environmental services after loosing a good number of species and large numbers of populations (Lawton 1994 cited Myers 1996).

It is incorrect to say that we can loose lots of species with impunity. A cut-off stage would (eventually) arrive when there would be simply too few species to maintain basic ecosystem functions (Myers 1996). The same author find that biodiversity contributes an environmental service of semi-absolute value in the sense of reducing severe risk but that it plays only a relatively minor role in supplying many other services. Paine (1969), Holling *et al.* (1995) affirm that resilience may be linked to the prevalence of a rather limited number of organisms and groups of organisms (*keystone species).*

4.5.4. CONCLUSIONS ECO-VOLUME AND RESILIENCE

Given the difficulty to determine interactions between biotic and abiotic components in ecosystems, and considering the ecological importance of the vertical structure in vegetation communities, eco-volume is an important parameter to measure the ecological function and quality of natural systems, and their interactions with agricultural systems.

Increasing eco-volume is important to the long-term health of ecosystems. Fragmentation and perturbation of forest ecosystems (reduction of eco-volume) represent interruptions and/or destructions of both the horizontal and vertical connectivity, as they impact negatively on the ecosystem functionality. Hence, provision of goods and services for the human well-being as well as for wildlife and plants cannot be supplied any longer.

In agricultural systems bio-volume (V_{bio}) is controlled by the farmers with different purposes, like weed control, pruning for yield achievement, adaptation to machinery, etc. Depending on the system, V_{bio} and biomass production usually remain constant, as illustrated by most systems (grasses, horticultural, cane of sugar, citrus). The ecological and agroforestry systems tend to increase their V_{bio} at a slow rate until they remain almost constant. This stage for these agroforestry systems is to be considered as "equilibrium point" between agricultural and natural systems, where resilience index, eco-volume, bio-volume, biodiversity and energy flow are all larger and more efficient.

An alternative measure (index) of resilience was proposed by considering the actual V_{bio} as a function of the potential eco-volume. By means of this method it is possible to measure very easily resilience and its evolution in time. This method allows comparing natural and agricultural systems with the same units. It also enables integrating other variables like biodiversity, energy flow, accumulation of carbon, etc. to obtain a better scenario likelihood of the ecosystems capacity to return to their original climax equilibrium state. It was showed that there does exist a high positive correlation between resilience index, biomass, energy efficiency and biodiversity.

CHAPTER V

GENERAL CONCLUSIONS

In this thesis, we define agroclimax as the equilibrium point between the natural systems and the agricultural systems. The previous chapters analysed characteristics of agricultural and natural systems in terms of bio-diversity, energy, ecosystems function, and resilience. At the same time, ways in which the agricultural systems can interact positively with the natural systems, were analyzed. The evaluated systems for this purposes were: (i) Leaf vegetables systems; (ii) Fruit vegetable systems; (iii) Mixed Fruit and Leaf Vegetable Systems; (iv) Citrus Production systems; (v) Ecological Production systems; (vi) Cattle Production systems, (vii) Sylvopastoral system, (viii) Forest fragment and (ix) Forest in regeneration stage (1, 2 and 3 years old).

In the introduction 6 hypotheses were proposed on how we can evaluate agricultural and natural systems such as to find equilibrium between them. In these conclusions, we review and conclude about above mentioned hypotheses.

HYPOTHESIS 1. CONTRIBUTION OF THE AGRICULTURAL SYSTEMS (AS) TO THE BIODIVERSITY CONSERVATION

> *Agricultural systems can reduce the pressure on the fragments and deforested areas, they can improve the cycle of water, influencing on the dispersion of fauna and flora, offer better resources and habitat for the survival of plants and animals, and; also play an important role as bio-corridor and buffering reserves.*

It seems contradictory to say that Agricultural Systems (AS) can influence biodiversity, at times even positively, although they are the main responsible for imbalances of natural systems, and hence, for loss of biodiversity. As starting hypothesis, we assumed that present natural systems are deteriorated. Topics like management and conservation activities of genetic resources were analyzed. From this point of view, and starting from a deteriorated current state of the natural systems we conclude that AS can have great influence on the management and conservation of the biodiversity in the Municipality of Teresópolis.

Ecological farming systems, agroforestry- and sylvopastoral systems, as well as perennial crops help reducing pressure away from the fragments and deforested areas.

It improves the cycle of water, and it has also positive influence on the dispersion of fauna and flora. They offer better resources and habitat for the survival of plants and animals than the cattle and horticultural systems. Also, they play an important role as bio-corridor and as buffer and finally, it also introduces a modest biodiversity level in these degraded areas of the Atlantic forest, where at the moment a single grass dominates more than 31.1% of the surface.

In ecological systems, the spatial and temporal combinations of crops, trees and animals are the main strategy in order to distribute crops equally in number and area. The system houses very high quantity of species, up to 99 in the study region. There exists a high combination of cultivated and not cultivated species. The richness and stability in ecological systems make them important sites for in situ conservation and provide a usable framework for maximizing their benefit to biodiversity.

Forest and cattle present strong trade-offs, threatening the conservation of biodiversity. Cattle are the main cause for forest fragmentation, rupturing dispersion of flora and fauna, and also favoring bigger soil erosion.

The sylvopastoral system (SPS) maintains low indices of diversity and is widely dominated by grasses. The great difference with the cattle systems is the richness of species, being increased fourfold. Significant portion of the original biodiversity can be maintained within pastures. In Côrrego Sujo thirty four timber species were identified in SPS, providing structures, habitats and resources that may enable the persistence of some plant and animal species within the fragmented landscape, thereby partially mitigating the negative impacts of deforestation and habitat fragmentation. Other additional positive effects are the production of timber, forage and fruits, providing shade for cattle, and promoting soil conservation and nutrient recycling. The management of natural regeneration timber species in SPS and its implementation represents a low cost alternative for the producer. These systems can be applied especially for farmers with small long term investment capacity. The native species with positive characteristics for these systems were identified.

Ecological and sylvopastoral systems contribute additional benefits to the local population, microclimate, flow of nutrients, whilst dissipating the dynamics of plagues and diseases, and decreasing the effects of fluctuating prices of the market. The vegetable system has a good crop diversity index, and a good quantity of species is equitably distributed. Eight from more than fifty commercial crops are the base of the economy and occupy circa 40% of the agricultural area. The farmers manage on average 6 species per hectare, with a tendency to reduce it.

Forest areas in regeneration present high plant diversity and density of individuals. If fallow land is left idle then vegetation is dominated by few individuals of fast development. All studied forest fragments showed high diversity, despite different management and use.

Biodiversity can be considered as part of the entire capital stock on which development is based, in spite of farmers not appreciating biodiversity positively. However, they have no exact knowledge of their benefits. At the moment, the forest fragments represent for the farmers mainly their water source, and are considered very less important as wood source or supply of other by-products like fruits or medicines.

HYPOTHESIS 2. THE AGRICULTURAL AND NATURAL MOSAIC IN THE LANDSCAPE

Economic, geographical and environmental positive conditions for the agriculture make that crop monoculture systems increase and dominate the landscape. In these landscapes that are mosaics of agricultural systems and natural vegetation the ecological function of the natural systems (fragments) are affected by the surrounding agricultural systems.

The production conditions are very favourable for the agriculture, especially for vegetable production systems and some fruits like citrus. The good conditions are determined by physical factors like climate or water availability. Also the region is very close to a big market with a favourable demand for agricultural products. The manpower is cheap and abundant, whereas soil is said to be available at a fair price. These good production characteristics are threatened by deforestation to the point that even not suitable soils is considered for cultivation. Further, the intensive production systems themselves impair the quality of water resources. In many areas erosion threats the sustainability of the production systems.

The landscape is dominated by forests (fragments, 36.2%), grasses (31.1%) and forest regeneration (18.8%). The cropped area is only 2.6% (1793 ha) of the total available land. From this 1793 ha under agricultural production, 74% (1327 ha) correspond to cattle production 24% is occupied mainly by horticultural systems, and the rest (2%) are sylvopastoral systems.

The cattle raising is the biggest agricultural system in surface terms, and unfortunately, it also causes most fragmentation, not only altering the ecological functions of the forest but also the behaviour and the dynamics of animal and plant populations inside the remaining forest fragments.

Extensive forests areas were replaced by grasses, leaving small forests fragments not larger than 16 ha on average. Hence, isolation of these fragments is constantly growing as are the edge effects too. This landscape tends to change little by little, replacing pastures either by horticulture in places with steeper slope (biggest tendency), by fallow to a lesser extent or by regeneration forest.

The primary agricultural production can be directly a good energy and carbon producer through conversion of natural energy sources like sun and rain into biomass and indirectly, it can save great quantities of energy through its efficient use.

Energy evaluation has great relevance to study the sustainability of agricultural systems (AS), not only because energy is a fundamental part of human activities but also because it plays an important role in agriculture and in the global economy. The growing dependence on non renewable energy of the AS results in ecological and economic uncertainty, whereas waste and overuse of these non renewable resources threat the global environmental balance.

The main primary agricultural production in Teresópolis is not a good energy producer. Its energy conversion from natural resources into biomass is small. Hence, agriculture around Teresópolis can not save great quantities of energy, neither directly nor through efficient use of energy. Cattle system, that occupies the largest area in the landscape is the most inefficient one in terms of energy, requiring 461 Joules of inputs to produce one Joule in meat form. It has a poor capacity to accumulate biomass in the system (energy). Horticultural systems, generally combined with a small forest, are storing energy up to 1.03E11 Joules ha^{-1} yr^{-1}. But some AS like ecological and sylvopastoral systems produce great quantities of energy and at the same time can save large amounts of energy through its efficient use. The ecological systems present high capacity to store energy (1.80E11 Joules ha^{-1} yr^{-1}). Sylvo-pastoral systems, contrary to the cattle raising, present better capacity to store biomass, with a positive difference of 2.6E10 to 5.56E10 Joules ha^{-1} yr^{-1}.

The actual increasing cost of energy, high greenhouse gas emissions, and the increasing energy use in the agriculture underline the need to improve energy use efficiency. Saving on energy and looking for new production sources will require appropriated production systems, whereby available resources are better preserved by higher efficiency of energy use. Fossil energy use efficiency is higher in ecological crop production systems than in vegetables and cattle systems. This is caused by the fact that in low-input (ecological) systems, a relatively large amount of the used phosphor or nitrogen originates from non-fossil resources and that a larger amount of energy comes from renewable sources. Integrated agricultural systems that combine better crops, soil, trees, water and nutrient management in the system, increase frequently the energy efficiency by 100 to 200 percent or by even more, although circumstances may vary widely, sometimes even affecting agriculture quite adversely.

An important alternative in this region is the development of carbon projects, as ecological measure to preserve and increase the forest area and income. It is demonstrated that the natural systems have a good potential to sequestrate carbon, the mature forest of the National Park "Serra dos Orgãos" (Atlantic Forest), stores 272 Mg C ha^{-1} , the secondary forest fragments 87.3 Mg C ha^{-1}. Total dry phytomass in Côrrego Sujo (53 km2) amounts to . a stock of 386844 ton. The same area will produce annually 20478 tons dry matter representing 2.28E14 Joules. The forest fragments and the forest areas in regeneration accumulate more than 92% of biomass in the system. Horticulture can end up producing more phytomass (27.8 Mg C ha^{-1}) than neighbouring natural systems were it not that 93% of it is exported from the system. Hence, this situation disables these systems for carbon sequestration. Secondary forests and forest fallows are the most important forms of C recovery in Teresópolis. The pastoral systems are those which store and produce less C and energy and, because this system is the principal factor for the fragmentation, it also causes decrease of biomass production on the fragment edges.

HYPOTHESIS 4. ENVIRONMENTAL IMPACTS, QUALITY OF INPUTS, AND SUSTAINABILITY

> *By quantifying inputs of agricultural systems on a common basis using emergy analysis, facilitate comparisons across agricultural systems and its environmental impacts, as well as, make possible the identification of scenarios to achieve greater sustainability.*

The environmental impact caused by the AS in Côrrego Sujo is moderate as the system makes high use of renewable resources. The ecological sustainability is moderate to good. The basin as a system contributes positively to the economy; it gives more emergy than that it takes from the economic system in form of materials and services. However, this fact represents also a loss of capital.

The material and services increase the environmental load indirectly because great quantitiesof non renewable sources to manufacture them, were used.

Positive economic indices were recorded for all crops except cattle. The most positive impact was achieved through the substitution of cattle production by ecological systems. The revenues are multiplied 4 to 12 times, the negative ecological impact decreases considerably (0.3 to 0.8 million $US ha^{-1}, for erosion concept), and the stock of carbon and biomass increases significant. Vegetable systems tend to give the greatest economic productivity per hectare per annuum. The vegetable systems demonstrate an increase of yield per area to which high inputs like fertilizers and services, did contribute. The dependence on these inputs reduces the fraction of renewable energy and increases environmental degradation, making these systems less sustainable relative to systems more dependent on renewable energies. Finally, they contribute also less to the economy of the region, because of their low use of renewable resources.

The ecological system, presents the largest value of sustainability in ecological terms, and poses the capacity to save great quantity of biomass in the system, uses fewer resources from the economy as opposed to more natural renewable resources, which eventually guarantee its sustainability. They ensure the survival of the producer on a long term basis and the preservation of biodiversity. The cattle system on the hillside loses the biggest quantity of soil representing 5 fold that of the ecological system and twice that of the other systems.

Cattle production is the main consumer of natural resources all together. Cattle systems cause bigger environmental damage and they have the smallest yield per hectare in economic and energy terms. The erosion is the most important factor in terms of use of non-renewable resources. The approach of soil erosion based on emergy synthesis enumerates the value of soil based on the environmental work required to produce it, rather than based on surveys or derived pricing techniques. The loss of organic matter through soil erosion for the whole basin represents in economic terms between 1.7 and 4.9 million dollars per year.

To increase sustainability of the AS it is necessary to reduce its dependence on external inputs. In Teresópolis the AS showed great invested quantities of energy in irrigation, fertilization and fuels. Among the studied systems, the less sustainable one is the cattle, followed by citrus and sylvopastoral. The horticultural systems also cause environmental damages but they offer the biggest economic revenues. The most sustainable systems are the ecological ones. The implementation of sylvopastoral systems in the study region is not only a cheap, simple alternative, but by the same token it also possesses a high positive ecological impact.

HYPOTHESIS 5. ECO-VOLUME (V_{ECO}) AS PARAMETER TO MEASURE ECOLOGICAL FUNCTIONS

> *Eco-volume is an effective and important parameter to measure the ecological function and quality of natural systems, and their interactions with agricultural systems.*

Eco-volume is an important parameter to measure both the ecological function and the quality of natural systems, as well as their interactions with agricultural systems. This importance could be bigger when eco-volume concept determines the interactions between biotic and abiotic components in ecosystems, and considers the ecological importance of the vertical structure in vegetation communities.

The eco-volume concept is important because it integrates the interrelationships between species living within the boundaries of a space or volume. These interactions are as important as the physical factors to which each community is adapted and responding. Each eco-volume encompasses a biological community adapted to specific conditions in a given place. The eco-volume is subject to either periodic or abrupt changes based on climatic cycles or due to man-made disruptions, like deforestation or extraction of plant material. These changes can also be natural through phytosociological succession.

Reduction of eco-volume (fragmentation and perturbation of forest ecosystems) represents a negative impact on the ecosystem functionality, resulting in ecosystems not being able to provide goods and services for the human well-being as well as for wildlife. Increasing eco-volume i.e. increasing the horizontal and vertical connectivity is important to the long-term health of ecosystems. The grass system, vegetables, and fruits in Teresópolis lose a great deal of eco-volume. To the contrary, sylvopastoral and ecological systems present low losses.

Different indices like W_i, C_i and the biomass pools show that plants mainly compete for space and light (limited resources). This competition is not only aboveground but also belowground where occupation of soil space is of primary importance. Most of the crops do not have this capacity and usually decrease considerably the yield. The plants that dominate in a community are usually those that have bigger capacity to develop and to conserve bio-volume.

The ecological and agroforestry systems tend to increase their V_{bio} and biomass at slow rate until they remain almost constant. This stage for these agroforestry systems is to be considered near to the "equilibrium point" between agricultural and natural systems, where resilience index, eco-volume, bio-volume, biodiversity and energy flow are all larger and more efficient.

HYPOTHESIS 6. THE MEASUREMENT OF RESILIENCE IN NATURAL AND AGRICULTURAL SYSTEMS

Eco-volume makes possible the measure of the resilience of agricultural and natural systems, whereby comparisons between both systems are made possible and the evolution in time can be monitored.

Resilience relates to the continuity of ecosystems and their ability to endure changes, disturbances, stresses as well as to its capacity to rebuild itself until an equilibrium level, at which it is capable of achieving its ecosystems functions, and providing goods and services.

The alternative method to measure resilience considers the actual V_{bio} as a function of the potential eco-volume. By means of this method it is possible to measure very easily resilience and its evolution in time. This method allows comparing natural and agricultural systems with the same units. It also enables integrating other variables like biodiversity, energy flow, accumulation of carbon, etc. to obtain a better scenario likelihood of the ecosystems capacity to return to their original climax equilibrium state. It was showed that there does exist a high positive correlation between resilience index, biomass, energy efficiency and biodiversity.

Through the evaluation of resiliency it was concluded that the dominant agricultural systems in Teresópolis and, more particularly, in the water basin of Côrrego Sujo (cattle and vegetable) have reduced resiliency index, whilst the less important systems (Ecological and Sylvopastoral) achieve the greatest resilience.

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ANNEXES

ANNEXE 1. GLOSSARY OF TERMS AND DEFINITIONS

Abundance (5)	Percentual importance of given vegetation structure. All components add to 100% for a given vegetation type along the thinking of Braun-Blanquet.
Agrobiodiversity (2)	"The dynamic variation in farming systems that occurs within and between agro-ecosystems and natural systems. It arises from the many and changing ways in which farmers manage diverse genetic resources in dynamic ecological and socio- economic contexts".
Agroclimax (2)	"The state of agricultural systems in which sustainability components reach a balance, in function of a production system combining environmental and socio-economic factors within a region". The energy balance inside the system reaches high levels of efficiency, renovability and transformation. These systems have high capacity to harbor, to use and to manage Agrobiodiversity and finally they present a wide elasticity to pass to natural systems. This balance is a function of the production system, environmental and socioeconomic factors of each region.
Basal area (1)	Stem cross section of a tree at breast height = πr^2 Normally summed over all trees in one ha
Biomass (2)	Total animal and plant organic material on a dry matter basis and normally on 1 ha.
Bio-surface (1)	To be determined as sum of Sbiostem + Sbioleaf + S biofruit + Sbioroot Again surface of roots Sbioroot will normally not been considered. The Sbiostem includes the surface of the actual stem but allso all ohter woody parts i.e. branches and twigs.
Biovolume (1)	It is the volume of stem, branches, roots, rootlets, twigs and leaves. It can be done by direct measurement of water displacement in water. It is tedious exercise. Sampling of each of the plant components will reduce the work load. Nevertheless, allometric relations are preferred and the root system is generally not considered. A very quick approach is to assume that a plant is an assembly of tubes and that all parts could be squeeze within a cylinder formed by: Vbio = Basal area x heco
Carbon sequestration (1)	Total biomass, expressed in Carbon weight, as it is stored in the phytomass and the necromass.
Climax vegetation	Is the vegetation which establishes itself on a given site for given climatic conditions in the absence of anthropic action after a long time (it is the asymptotic or quasi-equilibrium state of the local ecosystem).
Coverage Index for each Species (CIi) (1)	Is the sum of Relative Dominance and Relative Density. Cli = RDoi + RDi . crown closure = crown basal area either in m^2/ha or in % of surface.
Crown closure (1)	In GIS corresponds to tree crown projection or tree cover or cover index of a vegetation.
Crown volume (1)	Crown volume is calculated in a similar way to crown surface area. Crown volume (Cv) is estimated from the crown width (D) and crown depth (L) after assuming one of three regular geometric shapes.
Crown basal area (1)	Basal area of crown projection on ha basis.
Crown diameter (width) (1)	Average of widest and smallest crown diameter = K
Crown height (depth) (1)	Distance between lower branch insertion and tree top.
Crown surface area (1)	Surface directly exposed to sun light i.e. normally the upper cone. Different simulations according to tree shape: Cone, Paraboloid, Hemisphere.
DBH	Diameter at breast height (1.3 m) = d

Diameter at soil level[1] — It renders a better idea of the actual competition between roots systems. In some cases though, it is awkward to measure it e.g. in the case of buttresses (flutes).

Dominance [1] — Degree of crown coverage of a given species in m^2/ha

Eco-capacity [1] — Eco-volume x Eco-vitality index.

Ecoclimax — Final and sustainable stage reached by a vegetation at the end of a normal succession.

Ecoheight [1] — Weighted average height of given phytocenose or agricultural system. Corresponds to average height in a mono-specific forest stand. Weighting will be performed according to the abundance of each vegetation component.

Ecorain [1] — The eco-rain is this supplementary fraction of annual rains due to better ecological management of a watershed. The following factors are contributing to the eco-rains:
- the eco-height of the eco-volume leading to a temperature reduction,
- the evaporative cooling of the actively transpiring vegetation,
- the recycling of rains within the ecologically managed watershed basin,
- a reduction of the wind in connection with the eco-volume of a vegetation, decreasing the wind factor and hence the evapo-transpiration in the Penman-Monteith formula, and finally the amount of dew daily collected by the bio-volume of a vegetation.

Eco-vitality index [1] — To be defined. It could combine e.g. LAI, K_{Olsen}, Litter fall, Basal area. For the time being EVI = LAI x K_{Olsen} x BA/25. The eco-vitality index would be equal to 1 when LAI = 1, K_{Olsen} = 1 und BA=25 m². To be improved

Eco-volume [1] — Surface of given phytocenose or agricultural system multiplied by the eco-height. Eco-Volume normally to be expressed on ha basis.

Eco-volume [2]

Emergy (4, 6) — Emergy can be defined as the total solar equivalent available energy of one form that was used up directly and indirectly in the work of making a product or service. Emergy expresses the cost of a process or a product in solar energy equivalents. The basic idea is that solar energy is our ultimate energy source and by expressing the value of products in emergy units, it becomes possible to compare apples and pears.

Empower density [2] — "The ratio of total emergy use in the economy of a region or nation to the total area of the region or nation. Renewable and non-renewable emergy density are also calculated separately by dividing the total renewable emergy by area and the total non-renewable emergy by area, respectively."

Emergy exchange ratio [2] — "The ratio of emergy exchanged in a trade or purchase (what is received to what is given). The ratio is always expressed relative to one or the other trading partners and is a measure of the relative trade advantage of one partner over the other."

Emergy investment ratio [3] — "The ratio of emergy fed back from outside a system to the indigenous emergy inputs (both renewable and non-renewable). It evaluates if a process is a good user of the emergy that is invested, in comparison with alternatives."

Environmental loading ratio (ELR) [3] — "The ratio of non-renewable and imported emergy use to renewable emergy use." "At the scale of biosphere, it is the ratio of non-renewable (N) and slowly-renewable emergy (SR) to renewable emergy (R) - [(N+SR)/R]. The ELR is an indicator of the load on the environmental and might be considered a measure o stress due to economic activity."

Emergy per capita [3] — "The ration of total emergy use in the economy of a region or nation to the total population. Emergy per capita can be used as a measure of potential, average standard of living of the population."

Emergy Sustainability Index (ESI) [3] — "the ratio of the Emergy Yield Ratio to the Environmental Loading Ratio. It measures the contribution of a resource or process to the economy per unit of

	environmental loading." "An index that accounts for yield, renewability, and environment load. It is the incremental emergy yield compared to the environmental load and is calculated as the ratio of emergy yield to environmental load (EYR/ELR)."
Emergy yield ratio (EYR) [(3)]	"At the scale of the biosphere, the EYR is the ratio of the emergy of the output (Y=R+SR+N) divided by the emergy of non-renewable inputs (N) that are used. (BROWN & ULGIATI, 1999). "The ratio of the emergy yield from a process to the emergy costs. The ratio is a measure of how much a process will contribute to the economy."
Emjoule	The unit of measure of emergy, "emergy joule." It is expressed in the units energy previously used to generate the product; for instance the solar emergy wood is expressed as joules of solar energy that were required to produce tl wood.
Emergy investment ratio [(4)]	The ratio between the emergy invested from society (economy, services and other resources) and the emergy invested from the environment. This ratio measures the intensity of the economic development and the loading of the environment
Energy	The same as motion or ability to move. There are different forms of energy, e.g. potential energy, kinetic energy, pressure energy etc. and they are all measured in joule (J).
Enthalpy	The amount of energy a system releases if the system's temperature drops (assuming the pressure is constant) to 0 K. Heat content is therefore another word for enthalpy.
Entropy	A measurement of the disorder in the motion, and it is measured in Joules per Kelvin (J/K).
Exergy	A part of the energy that can be used as an energy source, thus each process implies that exergy is consumed and it is therefore always related to the surroundings. A maximum amount of work (mechanical energy) that can be obtained from a system in a process leading to the system reaching equilibrium with its surroundings.
Externality	Side effects of an action of the agricultural system that influence the well-being of nonconsenting parties or other systems. The nonconsenting parties may be either helped (by external benefits) or harmed (by external costs). For example, the water contamination caused for the agricultural activities.
Factor to convert DM to C	0.45 * DM
Frequency	Of a species being present or absent in a plot): normally alloted to 5 frequency classes (0-20; 20-40 etc)
Gross Primary Productivity (GPP)	The rate at which it accumulates biomass, including the energy it uses for the process of respiration (measured in $kg/m^2/year$).
Joule (J)	The metric unit of energy and work. One joule is defined as the amount of energy exerted when a force of 1 newton is applied over a displacement of 1 metre.
K/d ratio	Ratio of crown width (K) over diameter at breast height d. Normally K is expressed in m and d in cm. This ratio is known to be species specific and independent of age or stand.
LAI	Leaf Area Index (Blattflächen Index) or leaf to ground surface ratio. Can also be approximated by LAI = 10 x R_f/P_{fs} Where R_f = leaf part of litter in t (DM)/ha R_{fs}= specific weight of leaf surface (mg DM/cm^2)

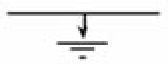
Heat	A transient form of energy. It quantifies the spontaneous transfer of thermal energy due to a temperature gradient. The SI unit for heat is the joule.
Hysteretic	Hysteresis phenomena are widely spread in nature, whereby a decay process follows another curve as a reconstruction process to reach the initial starting point. Hysteresis phenomena are widely spread in nature, whereby a decay process follows another curve as a reconstruction process to reach the initial starting point.
Litter fall [(2)]	All organic debris falling on the ground in a vegetation, phytocenose or agricultural system expressed on a dry matter and hectare basis. The total litter fall (Lt) encompasses leaf fall (Lf), fruit and bloom fall (Lb) as well as branches and bark fall (Lr).
Net emergy yield ratio [(4)]	The ratio between the emergy yield and the emergy invested from society (economy, services, and other resources). The emergy yield ratio of each system output is a measure of its net contribution to society beyond its own operation.
Net Primary Productivity (NPP)	The rate at which an ecosystem accumulates biomass minus the energy used for the process of respiration (measured in $kg/m^2/year$).
Non-Renewable Emergy [(4)]	"The emergy of energy and material storages like fossil fuels, mineral ores, and soils that are consumed at rates that far exceed the rates at which they are produced by geologic processes."
Nye-Greenland equation	It's an index to assess relative space occupation and is estimated by the relative basal area of all individuals belonging to one species or family. RDoi = (BAi x 100)/ ΣBan The basal area is calculate by converting perimeter to basal area in cm^2
Olson coefficient	$K_{Olsen} = Lt/Ls$
Rain Use Efficiency	The rate at which a system returns to a single steady or cyclic state following a perturbation.
Relative Dominance (RDo)	It is an index to assess relative space occupation and is estimated by the relative basal area of all individuals belonging to one species or family. RDoi = (BAi x 100)/ ΣB an The basal area is calculate by converting perimeter to basal area in cm^2
Relative Density (RDi)	It is an index to assess the species relative distribution. RDi = (Ni x 100)/Nm
Percent renewable emergy (%Ren) [(4)]	"The percent of the total energy driving a process that is derived from renewable sources (R/(R+SR+N)). In the long rung, only processes with high %REN are sustainable . "
Renewable Emergy [(4)]	"The emergy of energy flows of the biosphere that are more or less constant and reoccurring, and that ultimately drive the biological and chemical processes of the earth and contribute to geologic processes."
Renewable carrying capacity [(4)]	"The environment's ability to support economic development based solely on its renewable emergy sources. Calculated by dividing the sum of non-renewable and purchase emergy inputs to a region or economic process by the average renewable emergy flows per unit area of the region. The result is the area required to "sequester" the equivalent emergy required for the population or process from renewable sources."
Soil litter	Amount of organic material laying on soil surface at a given moment of the year, on a dry matter and hectare basis. This is the main source of material undergoing the humification process.
Solar transformity [(4)]	"The ratio of the solar emergy that is required to generate a product or service to the actual energy in that product or service. Transformities have the

	dimensions of emergy/energy (sej/J). A transformity for a product is calculated by summing all the emergy inflows to the process and dividing by the energy of the product. Transformities are used to convert resources of different types to emergy of the same type. The transformity is a measure of the "value" with the assumption that systems operating under the constraints of the maximum emergy principle generate products that simulate productive process at least as much as they cost."
Specific weight	The proportion of biomass to bio-volume gives the specific weight of a vegetation, crop or agricultural system
Sinergy	The effect of two or more subcomponents working together to produce an effect that is greater than the sum of the parts. Refers to the phenomenon of two or more discrete influences or agents acting in common to create an effect which is greater than the sum of the effects each is able to create independently.
Stem volume	Is a world wide applied parameter by foresters. The easiest formula is the one by Krueger:Vstem = height of bole x cross sectional area at mid-bole.
Trade-off	A trade-off refers to losing one quality or aspect of something in return for gaining another quality or aspect. It implies a decision to be made with full comprehension of both the upside and downside of a particular choice.
Transformity	The ratio obtained by dividing the total emergy that was used in a process by the energy yielded by the process. Transformities have the dimensions of emergy/energy (sej/J). A transformity for a product is calculated by summing all of the emergy inflows to the process and dividing by the energy of the product. Transformities are used to convert energies of different forms to emergy of the same form.
Work	May be defined as organized motion and is measured in Joules (J). Work can be mechanical, electrical, magnetic, or of other origin.

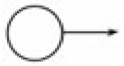
(1) Janssens *et al.* (2004a)
(2) Torrico (2006)
(3) Brown & Ulgiati (1999)
(4) Odum H.T. (1996), Odum E.C. (2000)
(5) Magurran (1988)
(6) Jorgensen (2001)

ANNEXE 2. SYMBOLS OF THE ENERGY SYSTEMS LANGUAGE

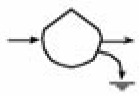
Energy circuit: A pathway whose flow is proportional to the quantity in the storage or source upstream.



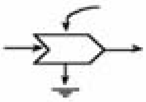
Heat sink: Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.



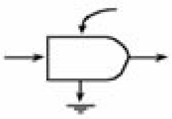
Source: Outside source of energy delivering forces according to a program controlled from outside; a forcing function.



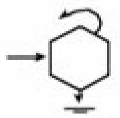
Tank: A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.



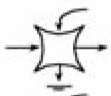
Interaction: Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both;control action of one flow on another; limiting factor action;work gate.



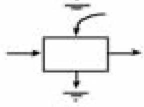
Producer: Unit that collects and transforms low-quality energy under control interactions of high-quality flows.



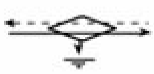
Consumer: Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.



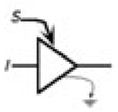
Switching action: A symbol that indicates one or more switching actions.



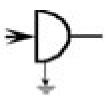
Box: Miscellaneous symbol to use for whatever unit or function is labeled.



Transaction: A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source.



Constant-gain amplifier: A unit that delivers an output in proportion to the input *I* but is changed by a constant factor as long as the energy source *S* is sufficient.



Self-limiting energy receiver: A unit that has a self-limiting output when input drives are high because there is a limiting constant quality of material reacting on a circular pathway within.

Symbols redrawn after Odum (1971, 1994, 1996).

ANNEXE 3. DETAILS OF ENERGY AND EMERGY CALCULATIONS

APPENDIX 3A. NATURAL AND ECONOMIC EMERGY CONTRIBUTIONS ECO-FARM

Note	Flows	Value	Units	Transformity (sej/kg), (sej/J), (sej/$US)	Emergy Flow (sej/ha y)
	Renewable Natural resources "R"				
1	Sun	1,296E+11	J/ha/y	1,00E+00	1,30E+11
2	Rain	1,08E+11	J/ha/y	4,70E+04	5,07E+15
3	Wind	3,06E+09	J/ha/y	2,45E+03	7,49E+12
4	Underground water	3,44E+08	J/ha/y	1,76E+05	6,06E+13
5	River Water	0,00E+00	J/ha/y	1,76E+05	0,00E+00
6	Forest Biomass	5,00E+01	kg/ha/y	3,69E+11	1,85E+13
7	N (atmosphere)	1,73E+02	kg/ha/y	7,73E+12	1,34E+15
8	P (rocks)	2,43E+00	kg/ha/y	2,99E+13	7,27E+13
9	K (rocks)	2,15E+01	kg/ha/y	2,92E+12	6,27E+13
10	Ca (system)	2,87E+00	kg/ha/y	1,68E+12	4,83E+12
11	Other minerals	2,97E+01	kg/ha/y	1,71E+12	5,08E+13
12	Sediments rivers	1,52E+11	J/ha/y	7,40E+04	1,12E+16
					1,79E+16
	Renewable Natural resources "N"				
13	Soil loss	2,06E+10	J/ha/y	7,40E+04	1,52E+15
					1,52E+15
	Services (Econ. Resources) "S"				
14	Man power (hard)	0,00E+00	$US/ha/y	3,18E+12	0,00E+00
15	Man power (family)	4,91E+02	$US/ha/y	3,18E+12	1,56E+15
16	Maintenance (infrastructure)	2,18E+01	$US/ha/y	3,18E+12	6,93E+13
17	Insurance cost	2,18E+01	$US/ha/y	3,18E+12	6,93E+13
18	Communications cost	3,49E+01	$US/ha/y	3,18E+12	1,11E+14
19	Taxes	1,45E+00	$US/ha/y	3,18E+12	4,62E+12
20	Other services	8,72E+00	$US/ha/y	3,18E+12	2,77E+13
					1,82E+15
	Materials (Econ. Resources) "M"				
21	Fungicides	0,00E+00	J/ha/y	1,48E+13	0,00E+00
22	Herbicides	0,00E+00	J/ha/y	1,31E+15	0,00E+00
23	Insecticides	0,00E+00	J/ha/y	2,40E+12	0,00E+00
24	Nitrogen fertilizer	0,00E+00	kg/ha/y	7,73E+12	0,00E+00
25	Phosphate fertilizer	0,00E+00	kg/ha/y	2,99E+13	0,00E+00
26	Potash fertilizer	0,00E+00	kg/ha/y	2,92E+12	0,00E+00
27	Cilium	0,00E+00	kg/ha/y	2,08E+12	0,00E+00
28	Other minerals	0,00E+00	kg/ha/y	1,71E+12	0,00E+00
29	Manure	0,00E+00	J/ha/y	2,69E+04	0,00E+00
30	Electricity	5,04E+07	J/ha/y	3,36E+05	1,69E+13
31	Petroleum fuels	4,63E+07	J/ha/y	1,11E+05	5,13E+12
32	Materials for maintenance	3,06E+00	$US/ha/y	3,18E+12	9,72E+12
33	Vaccines and medicament	0,00E+00	$US/ha/y	3,18E+12	0,00E+00
34	Depreciation	1,47E+01	$US/ha/y	3,18E+12	4,68E+13
					7,9E+13

No.	Item	Value	Unit	Ref.	Energy	Transfor-mity	Emergy
1	**Sun**				1,296E+11	1	1,30E+11
	Solar radiation=	4,5	kWh/m^2.y	[6]			
	albedo (a) =	0,2		[7]			
	energy =	(radiation)*(1-albedo)					
	(kWh/m^2.y)*(3,6E6J/1kWh)*(1E4m^2/ha)*(1-a)						
		1,296E+11	J/ha.y				
	Transformity =	1	sej/J				
2	**Rain + ETP**				1,08E+11	4,70E+04	5,07E+15
	precipitation =	1600	mm.y	[8]			
	ETP	557,3	mm.y	[9]			
	water energy =	5000	J/kg	[10]			
	Water density=	1000	kg/m^3	[10]			
	energy =						
	(kg/m^3)*(J/kg)*(1E4m^2/ha)						
		1,08E+11	J/ha.y				
	Transformiy =	4,70E+04	sej/J	[11]			
3	**Wind**				3,06E+09	2,45E+03	7,49E+12
	air density =	0,8	kg/m^3	[8, 9]			
	anual average velocity =	2,3	m/s	[8, 9]			
	geotropic wind =	3,33	m/s 60% de 5,55	[12]			
	haulage coefficient =	0,001	adimensional	[12]			
	energy = (area m^2/áreaha)*(kg/m^3)*(m/s)^3*(0,001)*(3,14E7s/y)						
		3,06E+09	J/ha.y				
	transformity =	2,45E+03	sej/J	[11]			
4	**Undergroud water**				3,44E+08	1,76E+05	6,06E+13
	flow of the nascent =	1,27E+03	m^3/y	[1]			
	used water in the system =	8,00E+02	m^3/y	[1]			
	energy = (m^3/y)*(1/área total ha)*(1000kg/m3)* (5000J/kg)						
		3,44E+08	J/ha.y				
	transformity =	1,76E+05	sej/J	[13]			
5	**River water**				0,00E+00	1,76E+05	0,00E+00
	time of use of the pump =	0	h/d	[15]			
	pumped flow =	0	litro/s	[15]			
	pumped flow =	0,00E+00	m^3/y				
	energy = (m^3/y)*(1/área total ha)*(1000kg/m3)* (5000J/kg)						
		0,00E+00	J/ha.y				
	transformity =	1,76E+05	sej/J	[13]			
6	**Forest BM**				9,50E+08	3,69E+11	1,05E+13
	Forest Biomass	50	kgDM/y	[1]			
		28,3	kg DM/ha/y				
		9,50E+08	J/ha.y	[26]			
		3,69E+11	sej/kg				
7	**N (Atmosphere)**				8,7E+09	7,73E+12	1,34E+15
	consumption =	172,9	kg/ha.y				
	energy=	8,7E+09	J/ha.y	[16]			
	transformity =	7,73E+12	sej/kg	[14]			
8	**P (rocks)**				4,0E+07	2,99E+13	7,27E+13
	consumption =	2,43	kg/ha.y	[1]			
		4,0E+07	J/ha.y	[17]			
	transformity =	2,99E+13	sej/kg	[14]			
9	**K sistema**				1,1E+08	2,92E+12	6,27E+13
	consumption =	21,46	kg/ha.y	[1]			
		1,1E+08	J/ha.y	[17]			