- Institut für Landwirtschaftliche Betriebslehre -

A bio-economic model of small-scale farmers' land use decisions and technology choice in the eastern Brazilian Amazon

Inaugural – Dissertation

zur

Erlangung des Grades

Doktor der Agrarwissenschaften
(Dr.agr.)

der

Hohen Landwirtschaftlichen Fakultät

der

Rheinischen-Friedrich-Wilhelms-Universität

zu Bonn

vorgelegt am

22.04.2005

von

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aus

Hamburg (Deutschland)

D 98

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Tag der mündlichen Prüfung: 17.03.2006

Erscheinungsjahr: 2006

Abstract

A bio-economic model of small-scale farmers’ land use decisions and technology choice in the eastern Brazilian Amazon

A great deal of more recent agricultural research in the Brazilian Amazon region has been focusing on the ‘hot spots’ of deforestation at the forest margins. Small-scale agriculturalists represent the largest group of the rural population and, apart from contributing to the high deforestation rates, are among the most affected by the environmental consequences of land use and land cover change in the Amazon region. This study attempts to contribute to the current debate on the sustainability of smallholder agriculture by focusing on one of the oldest colonization areas in the Brazilian Amazon region, the Zona Bragantina.

An additional motivation for the study was the emergence of technological alternatives to the traditional land preparation technique slash-and-burn. Some of these alternatives appear promising in that they could contribute to reducing the social costs of slash-and-burn that accrue mainly in the form of greenhouse gas emissions and material damages from accidental fires.

The study adopts a neo-classical theoretical framework of farm-household behavior that explicitly addresses the links between poverty and the environment. A descriptive analysis of secondary and primary data using standard statistical tools, such as difference of mean tests and regression analysis, provides the background for a formal quantitative analysis that draws on linear and non-linear mathematical programming and accounts for the existence of market and production risks.

It was found that smallholder agriculture in the Bragantina is likely to further contribute to natural resource degradation in the form of greenhouse gas emissions and fallow degradation. However, this does not necessarily imply significant negative effects on household consumption levels, especially in the presence of technological change.

Given that natural resources provide not only private but also social services, policy measures are tested with respect to their effectiveness in improving environmental indicators without halting economic and technological development. Among the typical environmental policy measures, taxes and conservation payments are promising candidates to improve environmental indicators and address regional development heterogeneities in an economically optimal way. In addition, the option of a technology-specific crop yield insurance provides a means to increase the competitiveness of slightly more expensive but ecologically advantageous technologies.

Existing agro-environmental policy measures, such as the upcoming credit program *Proambiente*, were simulated in order to derive recommendations for further fine-tuning. Regarding *Proambiente* it was found that the program regulations are too restrictive with regard to the use of chemical fertilizers. The model suggests that relaxing some of these restrictions will greatly improve the chances for the program to become attractive to smallholders in the Bragantina.

Zusammenfassung

Ein bio-ökonomisches Modell der Landnutzungsentscheidungen und Technologiewahl von Kleinbauern im ostbrasilianischen Amazonasgebiet

Die jüngere landwirtschaftliche Forschung im brasilianischen Amazonasgebiet hat sich vor allem auf Regionen mit hohen Entwaldungsraten konzentriert. Kleinbauern stellen die größte ländliche Bevölkerungsgruppe dar und sind, obwohl mitverantwortlich für die Entwaldung, am stärksten von den ökologischen Folgen der Primärwaldzerstörung und der veränderten Landnutzungsform betroffen. Mit der Untersuchung eines der ältesten Siedlungsgebiete im Amazonasgebiet, der Zona Bragantina, versucht diese Studie einen Beitrag zu der laufenden Debatte über die Nachhaltigkeit der kleinbäuerlichen Landwirtschaft zu leisten.

Das Heranreifen neuartiger technologischer Alternativen zur traditionellen Brandrodungspraxis stellt eine zusätzliche Motivation dieser Arbeit dar. Einiger dieser Alternativen erscheinen viel versprechend, da sie ein Potenzial zur Verringerung der externen Kosten der Brandrodung, z.B. Treibhausgasemissionen und materielle Schäden durch unkontrollierte Feuer, besitzen.

Der methodische Ansatz basiert auf der neo-klassischen Verhaltenstheorie und berücksichtigt den Zusammenhang zwischen Armut und Umweltfaktoren. Einer beschreibenden Analyse von primär und sekundär Daten unter Zuhilfenahme einfacher statistischer Methoden, wie z.B. Mittelwertvergleichstests und Regressionsanalysen, folgt eine formelle quantitative Untersuchung mittels linearer und nicht-linearer mathematischer Programmierung. Die Modellanalyse berücksichtigt insbesondere die Auswirkungen von Markt- und Produktionsrisiken auf die Landnutzungsentscheidungen des einzelnen Haushalts.

Es konnte gezeigt werden, dass die kleinbäuerliche Landwirtschaft in der Bragantina auch weiterhin zur Emission von Treibhausgasen und zur Degradierung der Sekundärvegetation beitragen wird. Jedoch muss dies nicht notwendigerweise negative Auswirkungen auf die ländliche Einkommensentwicklung haben; insbesondere dann nicht, wenn sich der Trend zum technologischen Wandel weiter fortsetzt. Der Wert der natürlichen Ressourcen der Region ergibt sich nicht allein aus dem privaten Nutzen der Kleinbauern. Es wurden deshalb mögliche Politikmaßnahmen im Hinblick auf ihr Potenzial untersucht, Umweltindikatoren positiv zu beeinflussen, ohne dabei den ökonomischen und technischen Fortschritt zu bremsen. Unter den herkömmlichen Maßnahmen der Agrarumweltpolitik sind vor allem Steuern und Flächenstilllegungsprämien als ökonomisch effiziente Möglichkeiten hervorzuheben, mit denen Umweltindikatoren positiv beeinflusst und regionale Entwicklungsheterogenitäten ausgeglichen werden können. Darüber hinaus erscheint die Option einer technologie-spezifischen Ertragsausfallversicherung als ein wirkungsvolles Instrument zur Förderung von etwas teureren aber ökologisch vorteilhaften technologischen Alternativen.

Existierende agrarumweltpolitische Maßnahmen, wie z.B. das Umweltkreditprogramm *Proambiente*, wurden im Modellversuch umgesetzt, um Optimierungsvorschläge abzuleiten. Hinsichtlich des *Proambiente* Programms wird infolgedessen empfohlen, die strengen Richtlinien zur Nutzung von Düngemitteln zu lockern. Modellsimulationen haben gezeigt, dass dies die Attraktivität des Programms für die kleinbäuerliche Landwirtschaft in der Bragantina deutlich erhöhen würde.

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Acronyms and Abbreviations

AFS	Agro-forestry Systems
ARA	Absolute Risk Aversion
CA	Cluster Analysis
CARA	Constant Absolute Risk Aversion
CE	Certainty Equivalent
CIFOR	Center for International Forestry Research
CMDRS	Conselho Municipal de Desenvolvimento Sustentável
DARA	Decreasing Absolute Risk Aversion
EMATER	Empresa Brasileira de Assistência Técnica
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
E-V	Expected Value – Variance
FAO	Food and Agriculture Organization
FGV	Fundação Getulio Vargas
FNO	Fundo Constitucional de Financiamento do Norte
FUNASA	Fundação Nacional de Saúde
GAMS	General Algebraic Modeling System
GM	Gross Margin
HH	Household
IBGE	Instituto Brasileiro de Geografia e Estatística
LP	Linear Programming
MOTAD	Mean of Total Absolute Deviations
MVP	Marginal Value Product
NAEA	Núcleo de Altos Estudos Amazônicos
NGO	Non-Government Organizations
NPK	Chemical fertilizer that includes nitrogen, phosphorous, and potassium
NPV	Net Present Value
PAM	Produção Agrícola Municipal
PCA	Principal Component Analysis
PDA	Demonstration Project
PIN	Programa de Integração Nacional
PMDRS	Plano Municipal de Desenvolvimento Rural Sustentável
PPG-7	Pilot Program to Conserve the Brazilian Rainforest
PROAGRO	Programa de Garantia da Atividade Agrícola
PRONAF	Programa Nacional de Fortalecimento da Agricultura Familiar
PRORENDA RURAL	Programa de Apoio às Famílias de Agricultores de Base Familiar e Pescadores Artesanais
PRORURAL	Programa de Apoio à Pequena Produção Familiar Rural Organizada
RAP	Risk Aversion Parameter
RHS	Right Hand Side
SAGRI	Secretaria de Agricultura (state level)
SAGRIm	Secretaria de Agricultura (local level)
S&B	Slash-and-burn
SEU	Subjective Expected Utility
SHIFT	Studies on Human Impact on Forests and Floodplains in the Tropics

SIMA	Sistema de Informação de Mercado Agrícola
STR	Sindicato dos Trabalhadores Rurais
WTO	World Trade Organization
ZEF	Zentrum für Entwicklungsforschung

Conversion Rates

November 1, 2002
1 Brazilian Real = 0.27813 Euro
1 Euro (EUR) = 3.59547 Brazilian Reais (R$)
1 Brazilian Real = 0.27525 US Dollar
1 US Dollar (USD) = 3.63300 Brazilian Real (R$)

Acknowledgements

My sincerest gratitude goes to the three academic supervisors who accompanied this study for the last three and a half years. Prof. Dr. Ernst Berg provided most useful guidance especially with regard to the implementation of the model-based analysis of market and production risk. Dr. Stephen A. Vosti was intensively involved in all stages of the research and, apart from contributing plenty of time, effort, and expertise, offered valuable moral support. Prof. Dr. Klaus Frohberg contributed substantial amounts of time and expertise especially in terms of recommendations to improve the model's performance and theoretical foundation.

Heartfelt thanks go not only to my tutor Dr. Bettina-Hedden-Dunkhorst and my colleague Dr. Arisbe Mendoza-Escalante, but also to all other members of the SHIFT-project, who contributed to this study – Prof. Thomas Hurtienne, Prof. Francisco de Assis Costa, Dr. Tatiana de Abreu Sá, Dr. Osvaldo and Dr. Maria de Socorro Kato, Dr. Manfred Denich, Dr. Milton Kanashiro, Dr. Konrad Vielhauer and the rest of the Embrapa/NAEA field team, who provided much more than valuable research support and scientific guidance. I am also indebted to many other fellow students and colleagues at ZEF, NAEA, and Embrapa for technical assistance as well as scientific and moral support.

For the extraordinary logistical support, I am especially grateful to the *Sindicatos dos Trabalhadores Rurais*, *Emater*, and the local *SAGRIs* in Bragança und Igarapé-Açu, and Castanhal. Special appreciation goes also the German-Brazilian research project *Madam*, the *Escola Agrotécnica de Castanhal,* the *Fundação Nacional de Saúde*, and the *Universidade Federal Rural da Amazônia* for their assistance and provision of infrastructure.

Special thanks go to Rozilda Henrique, Gregor Lotz, Stefan Krüger, Gisela Michel, Christina Schierlitz, Maik Rose, Anke Teubner, Sven Anemüller, Juan Ramirez, Claudia Kahwage, Dörte Segbart, Frank Krämer, Jochen Redlin, Nils Meyer-Abich, Boris Hoffmann, Joana Katte, Patricia Lazaro, Malte Puttfarken, Marc Müller, Holger Seebens, and Henrich Brunke for their priceless logistical and moral support.

I dedicate this effort to my parents Gabriele and Dirk Börner, who made it possible.

Funding for research and follow-up activities was generously provided by the *Bundesministerium für Bildung und Forschung* (BMBF).

1.0 Introduction

1.1 Background and Motivation of the Study

The deforestation of the world's primary forests is one of the key challenges faced by the global community, not only because of the associated emissions of greenhouse gases and the loss of biodiversity (United Nations Millennium Declaration 2000). Especially in tropical areas deforestation often comes with the degradation and pollution of natural resources, such as soils and river streams, which usually affects the rural poor more than other society members. A recent FAO study highlights the 'hotspots' of deforestation in the world and shows that about 25% of the world's forest cover change between 1990 and 2000 has taken place in Brazil (table 1.1).

Table 1.1: Forest area and area change

	Land area in km^2	Forest area in 2000 in km^2	Average annual change 1990-2000 in km^2
Africa	29783940	6498660	-52620
Asia	30847640	5477930	-3640
Europe	22599570	10392510	8810
North and Central America	21369660	5493040	-5700
Oceania	8490960	1976230	-3650
South America	17547410	8856180	-37110
Brazil	***8456510***	***5439050***	***-23090***
World	**130639000**	**38694550**	**-93190**

Source: FAO (2004)

The main driving forces of deforestation in the Brazilian Amazon[1] are usually divided into six categories, namely, cattle ranching, commercial and large-scale agriculture, small-scale agriculture, logging, mining, and large infrastructure projects (OED 2000, Andersen et al. 2002, Alencar et al. 2004, Margulis 2004). According to Alencar et al. between 18 and 30% of the deforestation in the Brazilian Amazon is caused by small-scale[2] or family agriculture.

Recent agricultural research in the Amazon has predominantly focused on agricultural frontier areas, i.e. areas where agriculture is directly or indirectly involved in the clearing of primary forests (see for example Walker et al. 2000 or Vosti et al. 2002).

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[1] Defined here as the North Region of Brazil plus northern Mato Grosso and western Maranhão.

[2] The terms small-scale farmer, smallholder, or family farmer are used here interchangeably. This study defines small-scale farm-households as operational holdings smaller than 100 ha. The implications of this definition are discussed in the introduction to chapter 2.

Nonetheless, deforestation rates across the Amazon are still dramatically high and increasing, which is why understanding the causes and dynamics of deforestation remains among the priorities on the research agenda.

The officially promoted colonization of the Amazon dates back to the end of the 19th century. Today, some of the early colonized areas are almost completely deforested and despite rather pessimistic predictions, small-scale agriculture continues to sustain rural livelihoods and contributes a substantial share to the value of the regional domestic product. Using the example of settlements in the states Acre and Rondônia, Vosti et. al (2002) have shown that it is realistic to expect that today's agricultural frontiers may follow similar development paths, at least as far as the elimination of primary forest cover is concerned. Some important questions that these findings imply for further policy research are the following:

1. What kind of land use systems are likely to emerge on agricultural frontier areas twenty years from now?
2. How does economic and agricultural change affect rural livelihoods in the absence of a valuable natural resource, such as primary forests?
3. Can small-scale agriculture in the Amazon be sustainable without expansion into virgin forests?
4. If yes, what policy mix is required to create the necessary socio-economic and institutional environment to maintain and increase rural welfare and environmental sustainability in a changing economic environment?
5. If no, can policies and technological change be combined in a way to make smallholder agriculture more sustainable?

Starting with Vosti and Reardon (1997), sustainability[3] in agro-ecological policy research has increasingly become associated with the three cornerstones of a 'critical triangle' of development goals. The notion that sustainable development requires poverty alleviation, environmental sustainability, and economic growth to be addressed simultaneously, spurred further research efforts. Many of these have focused on assessing potential tradeoffs and synergies between the three development

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[3] In this context sustainability is understood according to its most general definition given by the World Commission on Environment and Development (1987): Sustainable development is development that meets the needs of future generations without compromising the ability of future generations to meet their own needs. Depending on the analytical framework, more specific or restricted definitions can be adopted as discussed in section 3.3.7.

goals in the context of agricultural intensification, i.e. increasing input (or output) use per hectare, and technological change, i.e. a change in total factor productivity (Lee and Barret 2001, Angelsen and Kaimowitz 2001). This literature provides a broad set of methodologies for the analysis of land use decisions and technology choice at the farm-household level. Understanding why some farmers adopt certain land use systems in combination with certain technologies and other farmers not, is found to be crucial to providing policy makers[4] with the information necessary to use policy instruments more effectively.

Even though they have developed under different economic and political circumstances than more recent settlement areas, looking at the old Amazonian colonization regions can help answer the five questions posed above. It is a more recent phenomenon that the importance of smallholder agriculture for the design of sustainable development strategies begins to be recognized by decision-makers at the regional and national level. Smallholder agriculture certainly contributes to deforestation on agricultural frontiers; however, in contrast to large-scale cattle holdings and soybean plantations, it has shown its ability to sustain itself over several decades without continuous expansion even under conditions of comparatively high population density.

This study attempts to apply research approaches that have proven useful in the analysis of smallholder agriculture in agricultural frontier areas to the case of an old colonization region in the eastern Brazilian Amazon. By focusing on the socio-economic and bio-physical determinants of land use and land cover change at the farm-household level, it seeks policy scenarios that minimize tradeoffs and enhance complementarities between the three development goals of the ‘critical triangle’. Key findings may prove useful in designing agricultural and environmental policies for old colonization areas and provide hints for decision-makers concerned with sustainable development at the forest margins.

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[4] The term ‘policy maker’ is used here as a collective term for technical and executive staff, i.e. stakeholders, in public and private institutions, such as government offices, banks, donor agencies, trade unions etc.

An important part of the knowledge from which this research has developed was generated in the course of the SHIFT-Program[5] carried out in the Northeast of the Brazilian state Pará. Until 2001, the Program had a strong focus on the ecological aspects of the fallow-based farming system in the Zona Bragantina close to the state capital Belém. Natural scientists found fallows[6] to be of vital importance for the traditional slash-and-burn system[7], apart from their contribution to biodiversity conservation and carbon sequestration (Denich 1989, Hoelscher 1994). Yet it was shown that repeated slash-and-burn cycles reduce fallow re-growth capacity as well as organic matter and nutrient content of agricultural soils (Sommer 2000). Without technological alternatives, it was argued, soil and fallow degradation would compromise the natural resource base for future generations. As a result, it was proposed to substitute the traditional slash-and-burn system by a mechanical chop-and-mulch[8] approach (Denich et al. 2004). Apart from agronomic advantages, it was hoped that such a technology could contribute to reducing the external costs of using fire for land preparation, i.e. greenhouse gas emissions[9], health effects, and material damages.

Today, mechanical mulching is one among several fire-free technological alternatives in the region. Yet smallholders are often reluctant to adopt them for reasons that are not always obvious. Some of these reasons are particularly explored in this study, e.g. the fact that production decisions have to be made in an uncertain environment of unstable agricultural yields and fluctuating market prices. Moreover, farm-household resource endowments tend to vary over time and space, thereby shifting the farm-level determinants of land use and technology choice. Policy makers, on the other hand, face the difficult task of deciding whether or not to promote a given technology without having sufficient information about:

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[5] Studies on the Human Impact on Forests and Floodplains in the Tropics.

[6] The terms fallow and secondary forests are used interchangeably.

[7] Slash-and-burn is defined here as a semi-continuous agricultural production system. A productive period of 1 to 2 years (annual crops) or more (perennial crops) is followed by a fallow period. The length of the fallow period depends on various factors. For example, very short fallow periods (1 to 3 years) have been observed shortly after the clearing of primary forests. As soil fertility reduces, fallow periods extend and then depend on the intensity of the production system. In the Bragantina, farmers typically started off with a 25 ha plot, of which between 2 and 5 ha are cultivated every year (Penteado 1967).

[8] For a detailed technology description see chapter 5.

[9] This refers not so much to CO_2, but to CO, CH_4, and NO_x, which are emitted in large quantities during vegetation fires.

1. The target groups for technology dissemination
2. The potential impact of technology dissemination and related policy instruments on socio-economic and environmental indicators.

It is an additional objective of this study to shed some light on these two issues using a dynamic quantitative tool for evaluating selected technologies and policy instruments in the face of risk at the farm level.

In summary, this study tries to accomplish two interrelated tasks. **First**, it contributes to the ongoing debate with respect to sustainable agricultural development in the Amazon region. It does this by examining the case of an old Amazonian colonization region, where small-scale agriculture has shown the potential to sustain - albeit on a low welfare level - rural livelihoods over more than a century. **Second**, it builds on ten years of agronomic research on the fallow-based land use system of the study region. This research has led to the development of concrete technological options to address the negative environmental and economic consequences of the traditional slash-and-burn system practiced by smallholders in the area. To date, this and other technical innovations have not yet been evaluated using a quantitative framework at the farm-household level that takes both socio-economic and biophysical research results into account.

The two tasks are complementary in addressing the five key policy research questions that have evolved from previous research efforts in agricultural frontier areas (page 2). Evaluating technological alternatives at the farm-household level provides decision-makers with information that assists in deciding on how to promote a given type of technology. A dynamic perspective of smallholder behavior can then help to explore whether the existing or potential policy environments are likely to condition paths of agricultural intensification and technological change in favor of the three cornerstones of the ‘critical triangle’.

1.2 Objectives, Research Questions and Hypotheses

General objective

Identifying trade-offs and synergies involved in policy options for targeting rural poverty and environmental degradation in the presence of technology and economic change in the Zona Bragantina.

Specific objectives

1. Provide a socio-economic characterization of the fallow-based smallholder production system in light of the most recent findings of local ecological and agronomic research.
2. Identify and evaluate actual and potential trends in land use and technology change on representative small-scale farms under alternative policy settings.
3. Identify major farm-level constraints to favorable trends in technology and land use change.
4. Provide guidance as to how existing and alternative policy instruments can address these constraints in order to achieve sustainable development goals more efficiently.

Introductory research questions and related working hypotheses

1. What are the major ecological and socio-economic peculiarities of smallholder development in the Bragantina

    H: The Bragantina region differs from more recent settlement projects mainly through its proximity to the urban center Belém and the low degree of general development in the Amazon during its colonization phase (e.g. very poor infrastructure and low market integration in the first half of the twentieth century were not as favorable for large scale investments and agricultural expansion as afterwards). Nevertheless, parallels exist to the development at some of today's agricultural frontiers, such that the Bragantina can serve as a reference case.

2. What is the role of fallow in a production system without primary forests?

    H: The ecological functions of fallow have been identified by natural scientists. In the economics of smallholder production fallow represents a production factor that has the characteristics of a renewable resource. Farmers therefore try to optimize fallow length, such that today's benefits from burning fallow equal the benefits of maintaining the fallow for an additional year.

3. Do some smallholders exploit their resource base more than others? If yes, why?

   H: Farmers fully internalize the private costs of using fallow. Hence, overexploitation can only be a consequence of economic hardship or technological change in combination with imperfect knowledge about its impact on fallow regeneration.

4. What are the external costs of using fire for land preparation?

   H: Burning fallow vegetation for land preparation involves costs that are external to the farm-household. Due to the absence of primary forests (with high bio-diversity and (eventually) amenity values) in the Bragantina, these costs are much lower when compared to agricultural frontier areas.

5. What type of policy action has proven successful in conditioning land use decisions and technology choice?

   H: Due to the geographical dimensions of the Amazon, infrastructure development and policies based on market mechanisms, such as roads and credit schemes, are more effective (in a negative and positive sense as they enhance both economic development and natural resource exploitation) than policies that require extensive monitoring and enforcement at the micro level, e.g. environmental standards.

Main research questions and hypotheses to be tested

Some of the research questions below have an explorative character, and hence, were formulated without specific hypotheses.

1. Is the existing dominant land use system environmentally and economically sustainable?

   H: Contrary to smallholdings in recently settled agricultural frontiers, the average farm-household is in a steady-state type of situation, where quality and quantity of natural resources, e.g. acreage and average age of fallows, is relatively stable. Nevertheless, technological and economic change is taking place that is likely to alter the steady-state towards reducing natural resource quality.

2. What are the major constraints on current land use and intensification strategies?

   H: In comparison to agricultural frontiers, labor is more abundant and land scarcer in the Bragantina. Nevertheless, labor can become scarce in peak seasons, e.g. during land preparation.

3. To what extent do these constraints play a role in the adoption of alternatives to slash-and-burn such as conventional mechanical land preparation or mulching?
   - 3.1. H1: Both technologies are labor saving and cash intensive as they require upfront investments for machine service and fertilizer. Since labor is relatively scarce during land preparation, increasing wage rates can have a positive impact on adoption. At least during the main slash-and-burn season in October, cash is less constrained for farms that dispose of perennial cash crops that are harvest prior and parallel to land preparation.
   - 3.2. H2: Both technologies provide essentially the same benefits for farmers. In the short-run, farmers will prefer the one that can be provided at lower service costs.
   - 3.3. H3: The adoption of mechanical land preparation frees labor during the slash-and-burn season. Hence, the average cultivated area per farm will increase at the expense of fallow area.
4. What is the impact of risk aversion on product mix?
   - 4.1. H: Prices for cash crops tend to fluctuate more between years than those for regionally traded staple crops. Farmers who are more risk averse will tend to increase the share of staple crops, such as cassava and beans, in the crop mix.
5. What is the impact of risk aversion on technology choice?
   - 5.1. H: If a technology increases both expected return and the variance of return of a given agricultural activity, a risk averse farmer will choose lower activity levels than a risk neutral farmer.
6. If a technology is not privately, but socially profitable, what types of incentives are necessary to induce a given level of its adoption?
   - 6.1. H: Policy incentives, such as taxes and subsidies, are likely to be successful in inducing technology adoption. However, additional measures, such as standards and related institutional innovations might be necessary to reduce undesired side effects, such as increasing pressure on secondary forests.
7. Do policy-technology combinations exist that can simultaneously reduce environmental degradation and poverty in the region?

8. What is the effect of policy instruments aimed at reducing market and production risk?
9. What are the impacts of nationally and/or internationally induced shifts in prices and/or production costs on land use and technology choice and the performance of policy instruments?
10. To what extent are the results valid beyond the borders of the study region?

1.3 Conceptual Framework

Most of the policy and research questions raised in the two sections above directly target poverty and environment links in the context of household decisions with regard to land use and technology choice. Research aiming at giving policy advice should establish a practical link to the instruments available to decision makers and other factors conditioning farm-household decisions and their impact on environmental indicators.

Vosti and Reardon (1997) propose a conceptual framework that relates both household and village behavior and environmental consequences to policy relevant conditioning factors, such as prices, markets, interest rates, infrastructure, and technology. A slightly adapted version of this framework is depicted in figure 1.1.

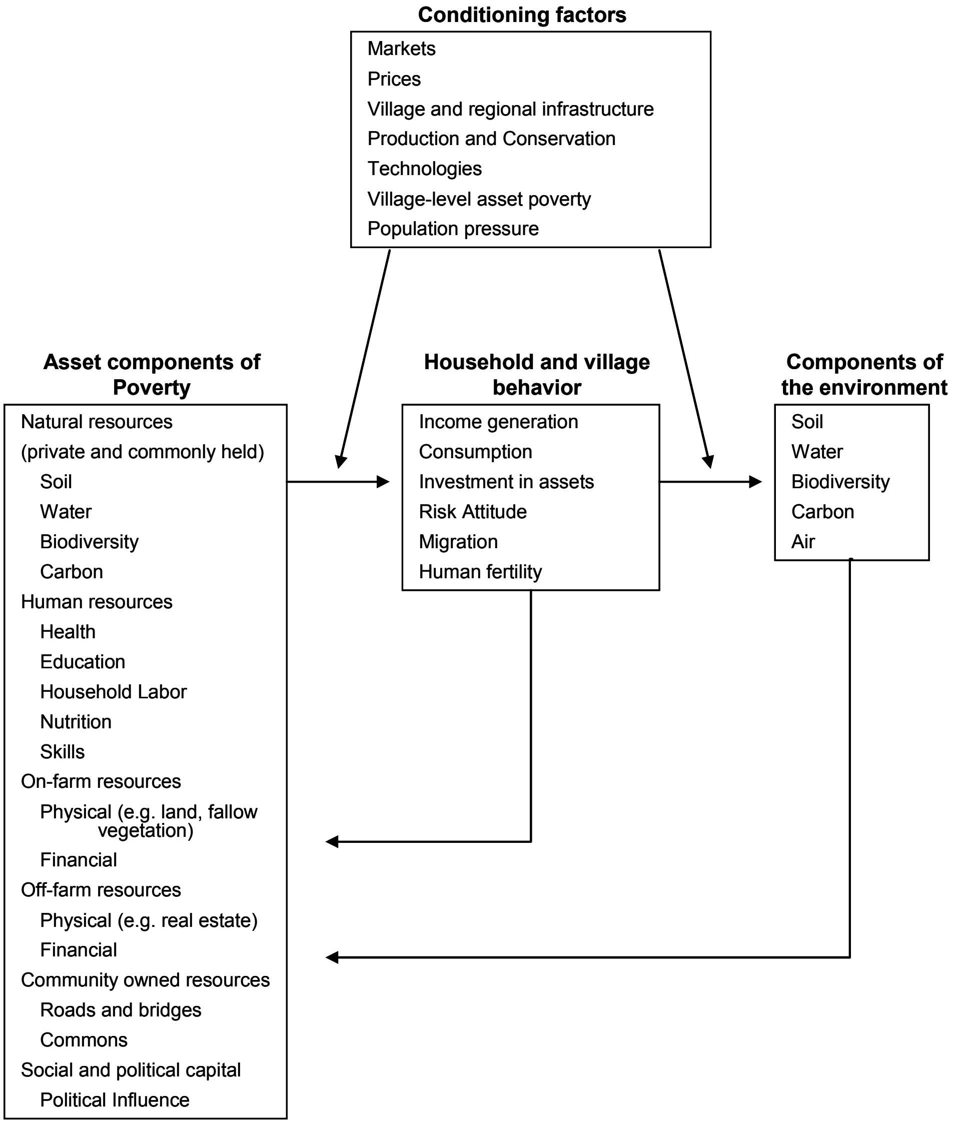

Figure 1.1: Conceptual framework for the analysis of poverty and environment links at the household level

Household behavior, e.g. investment and consumption, is shown here to depend on the availability of *asset components of poverty*, such as natural, physical, and human resources among others. Assessing poverty in this way has proven useful as it differentiates between different types of poverty, and hence, the number of ways in which poverty can be linked to the environment. Of particular interest for this study is the term ‘conservation-investment poverty’, i.e. the “cutoff point defined as the ability to make minimum investments in resource improvements to maintain or enhance the quantity and quality of the natural resource base” (Vosti and Reardon 1997, p. 52). This is different from pure welfare measures of poverty in that it is a site-specific function of socio-economic and environmental conditions. For instance, a farmer might appear wealthy in terms of per capita household income, but still be unable to invest in labor intensive conservation technologies due to labor market imperfections.

According to figure 1.1, policy can influence environment and poverty links at two points, first by conditioning the way farm-households make use of their resources, e.g. through the imposition of forest conservation standards, or second by providing access to technologies that reduce the impact of agriculture on soil erosion, e.g. mulching or agro-forestry systems. Farm-household decision-making is assumed here to be determined by the desire to maximize household utility. Most quantitative approaches use a proxy, e.g. household income, to represent utility (see chapter 3 for a discussion).

The information necessary to apply such policies is often quantitative in nature as they require the specification of a minimum or maximum number of hectares to be conserved or cultivated, a minimum price, or an optimal subsidy. Implementing such policies, however, requires a great deal of local knowledge and practical experience as the success of agricultural and environmental policies finally depends on the interplay of local and regional institutions and organizations and the provision of services, such as agricultural extension. This study attempts to provide scientific guidance with respect to the likely impact of agricultural and environmental policy options assuming that they are successfully implemented. Yet, potential options for policy action will be evaluated based on extensive field experience and qualitative observations. As a consequence, a given policy option might appear optimal from an analytical point of view, but judged inappropriate in view of the institutional set up in the study area.

1.4 Structure of the Study

The study is divided into three parts. Part I consists of the chapters 2 and 3 that provide a short overview of the data used and a detailed theoretical discussion of the methodological steps adopted for this research. Part II presents the results of a descriptive analysis of primary and secondary data and some preliminary conclusions in chapter 4. Subsequently, chapter 5 shows the results of the analytical steps to prepare the main model inputs. Finally, Part III presents the results of the farm-household modeling exercise and the conclusions of the study. Chapter 6, 7, 8 show the results of the baseline simulation, the technology evaluation, and the policy scenarios, respectively. Chapter 9 relates the results to the research questions and hypotheses presented in section 1.2 and derives the main implications for policy-makers. A final section, critically reviews selected model assumptions and their implications for the interpretation of results and potential future research.

Part I Theory, Methodology and Data

This part first provides an overview of the secondary data sources and the collection of primary data in chapter 2. Chapter 3 outlines the reasoning behind the choice of methodology that addresses the research questions listed in chapter 1. Then a discussion of critical issues in bio-economic modeling serves as a framework, in which the general model and important model components are developed in the specific context of the study. The discussion is divided into pre-modeling issues, such as the identification of representative households (section 3.3.2), bio-physical processes (section 3.3.5), and socio-economic processes (3.3.6). Finally, section 3.3.7 provides deliberations on how the approach chosen can serve to addressing questions regarding the sustainability of agricultural change in the study area.

2.0 Data Base and Data Collection

The research activities of the earlier SHIFT phases had primarily focused on the district Igarapé-Açu in the center of the study region. Detailed bio-physical and agronomic information had been collected with respect to the traditional slash & burn technology and the proposed alternatives, i.e. mechanical mulching and fallow enrichment. Especially economic and agronomic characteristics of cattle holding, but also some general institutional and socio-economic aspects of smallholder production were addressed during various project phases. But in order to evaluate the technological innovations on a broader scale, it was necessary to account for the socio-economic (and quite likely ecological) diversity, under which smallholders operate in the study area.

2.1 Towards a Working Definition of Smallholders

A vast body of literature exists that is concerned with defining and characterizing smallholder agriculture in different economic and environmental settings (see Wolf 1966, Mintz 1974, and Friedmann 1980 on basic definitions). Ellis (1988), in line with this literature, uses the term ‘peasant’ to describe farm-household units with access to land and ‘limitations in the operation of market principles’ (Friedmann 1980, p. 164). Moreover, the reliance on family labor is considered a defining economic characteristic.

Chayanov (1928) was among the first to recognize that the economic concept of the private firm fails, when - as in the case of subsistence and semi-subsistence farm-households – consumption and production decisions are made simultaneously, e.g. due to market imperfections.

The more recent Brazilian discussion uses the term 'family agriculture' (Abromovay 1992, Costa 2000/1995) to stress that smallholder production follows a different logic than commercial farming enterprises. Depending on the degree of market dependence, it is argued, family farms produce surplus only to the extent necessary to guaranty reproduction. The result is a relatively inelastic supply response to changes in product prices. As far as annual consumption and cash crops are concerned, this has recently been confirmed by Mendoza (2005) for a representative set of farm-households from the study region.

For the empirical analysis of this study, which is related to Mendoza (2005), primary data had to be collected. A useful working definition for this purpose should not be too restrictive as far as criteria are concerned that are likely to fluctuate over time. The share of hired labor per farm, for example, can easily surpass a given threshold with the adoption of a labor intensive cash crop. However, due to fluctuating product prices and/or pests, it is possible that a farmer returns to his old, less labor intensive, land use system in a relatively short period of time[10]. The same applies to market integration if measured as the share of commercialized production value. Farm size has shown to be relatively stable over time, although with a tendency to reduce as a result of splitting at generations, which is why it was finally used as a decision criterion for the selection of survey districts. Unless otherwise indicated, farms smaller than 100 ha were considered smallholdings. According to the agricultural census of 1995/6, 97% of farms in the Micro-regions Bragantina and Castanhal[11] fall into this category. Although this may seem a very high upper bound if compared to the size of smallholder farms in Africa or Asia, it makes sense in the context of the Amazon, where family farms of this size are not unusual. The identification and

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[10] In the study region, this has been observed for the case of passion fruit during the 90ies and for pepper in the 80ies (Wander 1998, Duarte 2003).

[11] The geographical definition of the region has changed various times in the last 50 years. The micro-regions Bragantina and Castanhal (as defined by the IBGE) roughly correspond to the region defined in the sample frame and will henceforth be called "Zona Bragantina".

classification of 'typical' smallholder farms within this universe was then part of the empirical analysis, and hence, will be presented in Part III of the thesis.

2.3 Secondary Data Sources

Table 2.1 summarizes and described the secondary data sources consulted for this study.

Table 2.1: Secondary data sources

Source	Description
SHIFT-reports	- general overview and main research findings
SHIFT-Ph.D. and M.Sc. theses	- general and detailed bio-physical and agronomic information at the micro level - socio-economic information at the regional and micro-level
EMBRAPA/NAEA (scientists)	- bio-physical, agronomic, and socio-economic background information
EMATER (agronomists)	- bio-physical, agronomic, and socio-economic background information
IBGE Censo agropecuário 1970-1995/6	- socio-economic and agronomic information at the district, regional, and national level
IBGE Censo demográfico 1996 and 2000	- demographic information at the district, regional, and national level
IBGE PAM 1974-2002	- agricultural production (i.e. quantity and value of production, average yields) at the district level
SIMA 1997-2002	- product prices at the regional level
IBGE/FGV various years	- macro-economic information
FUNASA	- village level demographics

2.4 Primary Data Collection

Since various subprojects of the last SHIFT-phase depended on primary data, it was decided to use a common sampling frame for the study area. Based on expert knowledge 13 districts were selected to represent the study region, which are assumed to represent the micro-regions Castanhal and Bragantina as defined by the IBGE (table 2.2). One of the main reasons for the selection was that the study focused on the *terra firme* areas of the study region. Hence, districts with a substantial amount of frequently flooded (*varzea)* areas were excluded. In addition, it was sought to capture the whole range of agricultural diversity that is assumed to be partly determined by the distribution of rather exogenous factors, such as soil types, rainfall distribution and institutional frame conditions.

Table 2.2: District level sampling frame

	Microregions Castanhal and Bragantina	Selected districts
1.	Augusto Corrêa	Bonito
2.	Bonito	Bragança
3.	Bragança	Capanema
4.	Capanema	Igarapé-Açu
5.	Igarapé-Açu	Nova Timboteua
6.	Nova Timboteua	Peixe-Boi
7.	Peixe-Boi	Capião Poço
8.	Primavera	São Miguel do Guamá
9.	Quatipuru	Santa Maria do Pará
10.	Santa Maria do Pará	Ourém
11.	Santarém Novo	São Francisco do Pará
12.	São Francisco do Pará	Castanhal
13.	Tracuateua	Santa Isabel do Pará
14.	Bujaru	
15.	Castanhal	
16.	Inhangapi	
17.	Santa Isabel do Pará	
18.	Santo Antônio do Tauá	

A two-stage sampling approach first identified three survey districts, i.e. Castanhal, Igarapé-Açu, and Bragança, based on land use variables and under consideration of soil and rainfall distribution. Table 2.3 provides an indication on the captured diversity in farm-household characteristics measured in standard deviations of selected land use and production variables for the final selection of districts and two alternative approaches.

Table 2.3: Captured diversity of farm (< 100 ha) characteristics expressed in means and standard deviations over the selected districts

	Perennial share of total Cropland in (%)	Area under fallow per Farm in (ha)	Value of production In (1996 R$)
Final selection	52 (25.15)	5.2 (1.07)	4643 (11215)
Cluster analysis	33 (18.41)	4.9 (1.13)	3951 (9018)
Stratification	47 (7.82)	6 (2.25)	3172 (646)

The final selection differs from the result of the cluster analysis in that the district Castanhal has been substituted for the district Santa Isabel do Pará. In the latter, continuous horticulture and perennial systems have displaced the typical smallholder systems found in the rest of the study area. The district was therefore considered an exceptional case.

Secondly, 30% of all communities from each municipality were selected randomly. In the largest district Bragança, only communities of the *terra firme* areas were selected, because a substantial part of the district belongs to the costal mangrove ecosystem, which does not form part of the analysis. According to the IBGE demographic census

2000, the total rural population of the selected districts/areas differs only slightly, i.e. Castanhal (13449), Igarapé-Açu (12224), and Bragança (*terra firme*) (12417)[12].

Thirdly, farm-households were selected randomly and proportionally to the number of families per community (see figure 4.1 in section chapter 4). In total 271 households were interviewed in 22 communities. Given random sampling within the districts/areas the sampling error per district is 0.05, which corresponds to a confidence interval of 10.14% at the 95% confidence level (Poate et al. 1993).

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[12] This number was calculated based on data from FUNASA.

3.0 Methodology and Theoretical Background

3.1 Potential Methodological Approaches

Apart from general methodological considerations, the choice of methodology for this study has to be seen in the context of the SHIFT-project. An important research objective was to better understand the determinants of land use decisions and technology choice at the farm level in order to evaluate technological alternatives (especially mechanical mulching) and policy options for sustainable land use in tropical fallow systems. A suitable methodological approach must therefore accomplish three important tasks:

1. Integrating farm level bio-physical (e.g. soil degradation, nutrient- and fallow dynamics) with socio-economic information (e.g. farm-household characteristics, markets, technology access) from different sources and at different scales.
2. Account for the inter-temporal nature of decision-making with regard to the allocation of agricultural and renewable natural resources (e.g. labor, capital, land, fallow vegetation and soil quality).
3. Provide a predictive tool for the *ex-ante* evaluation of changes in technology access and policy mix.

Attempts to understand the behavior of complex systems have always involved the use of models that represent the interrelationship of system variables in a simplified manner based on theoretical underpinnings. In ‘A Skeptic’s Guide to Computer Models’ Sterman (1991) acknowledges the adaptive capacity and flexibility of *mental models* in taking into account both qualitative and quantitative information. Nevertheless, he points out that if decision-making is based purely on mental models, it is usually biased by other than system immanent factors. Hence, due to the difficulties in examining the underlying assumptions, contradictions and ambiguities often remain undetected.

Especially in developing countries, decision-making with regard to agricultural development and the environment is often built on poor quantitative and contradicting qualitative information. Policy instruments in these areas are typically limited to the provision of incentives in the form of taxes and subsidies or the imposition of standards (Pearce 1995). Yet for the most part, these instruments require knowledge about the type and degree of intervention necessary in order to change the behavior of economic and social agents in the desired way.

Using quantitative analytical tools in combination with theoretically justified assumptions to overcome data limitations, can therefore be an important step towards the evaluation of trade-offs between employing certain types of policy instruments at different degrees of intensity. Hence, Sterman concludes that, provided a clear purpose and a comprehensive and critical documentation of the model structure and underlying assumptions, decision-making is likely to benefit from using computer models for decision-support.

Since more than 30 years, computers have been used in economics and agricultural sciences to construct and solve essentially two different branches of models, namely econometric/simulation models, optimization models, or combinations of both (see Hazell and Norton 1986 for optimization models, Singh 1986 for econometric models, and Sadoulet and de Janvry 1995 for an overview of different models and related issues in quantitative policy analysis).

3.2 Model Types

Econometric models are used to statistically estimate system parameters from empirical observations based on theoretical assumptions about the system behavior (Berger 2000). An advantage of econometric models is that they represent the best possible guess of the true relationships between system variables. Moreover, numerous formal test procedures exist to validate estimation results. Kruseman (2000) presents an extended version of a bio-economic optimal control model developed by Bulte and Van Soest (1999) that accounts for the non-separability of household consumption and production decisions, changes in soil quality, imperfect markets, risk, and technology change. Theoretically this model overcomes many of the shortcomings of earlier econometric models that have been raised by Feder et al. (1985). However, Kruseman finally desists from a full econometric estimation of the proposed model for reasons similar to those that motivated Berger to search for new approaches to model technology diffusion processes in agriculture. Econometric models usually require the availability of large degrees of freedom both in terms of cross section and time series information. Besides, their ability to simulate changes that have no historical equivalent is rather limited (Brandes 1985). For example, changes in soil quality typically occur over a long period of time, especially in forest and fallow systems, and impacts on soil productivity are masked by management issues, weather conditions and random variation that are seldom measured altogether at the household level. As a consequence, many econometric and simulation applications adopt static approaches or higher units of analysis, such as the community or regional level (Saxena et. al. 1997, Lopez 1998, Kwansoo et al. 2001, Pascual 2003).

Optimization models allow to combine biophysical and socioeconomic data at different scales with expert information and stylized facts and are, hence, more adapted to the 'scientific reality' of farm-household research in developing countries. Even though, individual model components may still be estimated econometrically, these models are less consistent than econometric models, where all components are estimated simultaneously. Nevertheless, several recent applications of bio-economic farm-household optimization models exist that have enabled researchers to successfully address a broad range of development issues in both normative and positive forms of analysis (Shiferaw 1998, Barbier 1999, Berger 2000, Kruseman 2000, Vosti et al. 2002, Mudhara et al. 2004). Critical issues in bio-economic modeling are reviewed in the following sections along with deliberations on how they will be addressed in the context of this study.

3.3 Issues in Bio-economic Modeling

For Brown (2000), the term 'bio-economic model' has become a 'catch-all term' that describes all sorts of models that integrate bio-physical and socio-economic factors in one or the other way. Due to the sequential design of research in the SHIFT-project, few attempts have been made to align bio-physical and socioeconomic research in a way that allows for integrated model building. One of the challenges of this study is to incorporate the main agro-ecological findings of past research efforts into a modeling framework based on primarily socio-economic information from the farm-household survey of the last SHIFT-phase. A strong emphasis lies on the economic evaluation of technological alternatives at the farm level, which is why the approach chosen is closest to what Brown calls ‘economic optimization models with bio-physical features’.

3.3.1 Aggregation level

In a review of approaches, problems and experiences in mathematical programming, Hanf (1989) distinguishes two prototypes, namely representative independent farm or *farm sample models* and simultaneous multi-commodity equilibrium approaches or *simultaneous sector models*. Especially, in the presence of imperfect markets, behavioral deviations from pure profit maximization, and time dependent adjustment processes, i.e. conditions of technological change in developing country agriculture, farm sample models are judged advantageous. Both model types are subject to aggregation errors if they are used to simulate the agricultural sector as a whole; however, farm sample models allow to reducing the aggregation bias through the differentiation into various farm types, but do not account for interdependencies between them.

The main asset of the multiple-agent approach developed by Balmann (1995) and Berger (2000) is that it combines the features of simultaneous sector and farm sample models by allowing for interaction between farm types while maintaining a maximum degree of disaggregation. Yet, despite the enormous increase in computing capacity, model size continuous to be a limiting factor for this branch of multiple-agent models. The trade-offs between model size and complexity vs. regional disaggregation and household interactions have to be critically evaluated against the research objectives.

Although the this study was designed in a way to allow the construction of a multiple-agent model, it was found that explicitly modeling fallow dynamics and investment decisions in a disequilibrium unknown life approach[13] is more appropriate to analyze the inter-temporal nature of technology choice in the study area. A model is constructed for the dominant representative farm and the implications of changes of factors that distinguish between farm types are assessed via extensive sensitivity

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[13] McCarl and Spreen (1997) distiguish between equilibrium models that calculate the average optimal farm plan over time and disequilibrium models that explicitly represent each time period of a given planning horizon and are necessarily much larger. Known or unknown life refers to whether the life-span of production activities is exogenously determined or endogenous to the model.

analyses. In subsequent research efforts, specific issues of technology diffusion and household interdependencies can be addressed with the existing data base and modifications of the model developed below.

3.3.2 Farm-Household Classification

Classifying farm-households is crucial to reducing the aggregation bias of farm sample models and provides important clues about relevant factors that differ between farm types. A typical approach is the stratification of cross sectional farm-household data based on predetermined factors that are theoretically expected to make a difference, e.g. farm/family size, degree of intensification, or total value of production. One problem of stratification based on percentiles is that all groups have equal sizes, and hence, are not necessarily representative. Another problem is that a slight difference between two cases in only one of the factors may put them into separate groups although they might be similar in many other aspects. The *ad hoc* specification of group limits can solve the problem of representativeness, but has little effect on the grouping.

Multivariate methods, such as principal component (PCA) and cluster analysis (CA) are typically employed to overcome these limitations. To some extend these methods reduce the degree of subjectivity that is unavoidably involved in all classification exercises by ‘letting the data speak’ and providing several test procedures for the validation of results (Hair 1998, Backhaus 2000). A combination of PCA and CA, as proposed by Hair, was used to identify representative farm-households from the 2002/3 survey (figure 3.1).

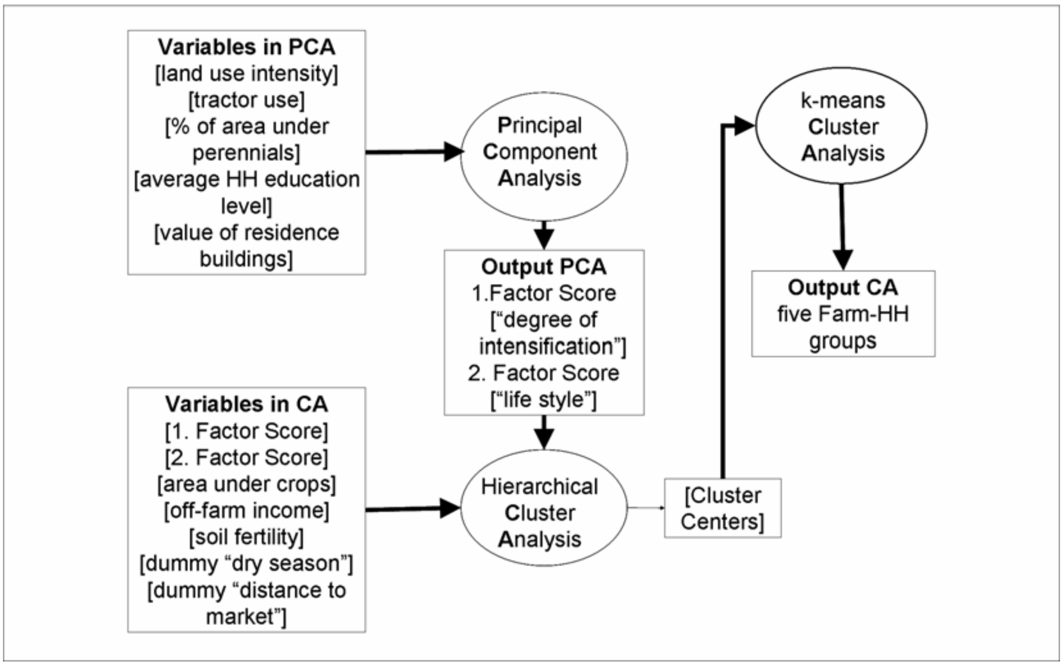

Figure 3.1: Combination of PCA and CA used to classify farm-households

What is the 'value added' of using PCA prior to CA? The identification of classification variables is an inherently subjective exercise even if it is guided by theoretical considerations. Often more than one variable are identified that describe the same or related properties of the object of classification, e.g. the degree of intensification. If these variables are correlated, which they typically are, the respective property will be overvalued in the clustering process. This can be illustrated by looking at the *heterogeneity measure* V_g employed by the hierarchical Ward-algorithm, which is frequently used to generate homogeneous groups of similar size (Backhaus 2000, Hair 1998):

$$V_g = \sum_{k=1}^{K_g} \sum_{j=1}^{J} (x_{kjg} - \bar{x}_{jg})^2 \qquad (1)$$

x_{kjg}: *value of variable j (j = 1,…,J) at case k (for all cases k = 1,…,*K_g *in group g)*
$\bar{x}_{jg}$ *: mean over all cases of variable j in group g*

The algorithm first treats all cases as separate clusters and then gradually joins clusters so as to minimize the increased V_g. This has three important implications: First, the more correlated variables the higher the influence of the related property in the clustering process (V_g increases less when cases with correlated variables are joined). And second, the more equal the values for observations of one variable, the higher the influence of the variable in the clustering process (V_g increases less if observations with the same value within one variable are joined). And third, even mild outliers produce large changes in V_g and therefore strongly influence the clustering of all other cases.

All but the third implication are not generally undesirable, for example, if an important distinguishing characteristic is equal for a subgroup of a sample, it can be included as long as it does not eliminate the influence of other variables. It was decided to employ PCA to reduce meaningfully correlated variables[14] into factor scores, because the influence of a set of correlated variables is more difficult to control than the impact of individual characteristics,. The factor scores then enter the CA as individual indicators for selected properties.

Several test procedures exist to evaluate the suitability of a data set for PCA. The Bartlett-Test is used to test for the null hypothesis that the variables are uncorrelated. If the significance level is lower than 0.05 the null hypothesis can be rejected with a 5% probability of error. A more common measure is the “measure of sampling adequacy” (MSA), which is calculated on the basis of an anti-image covariance matrix. The MAS ranges from 0.5 (unacceptable) to 0.9 (marvelous) describing the degree of interrelationship between the variables (Backhaus 2000).

Wiedenbeck and Züll (2001) show that the efficiency of CA can be improved by combining hierarchical and k-means methods. As opposed to hierarchical algorithms, the k-means approach can increase the homogeneity of clusters by moving cases between clusters so as to minimize the heterogeneity of the individual cluster. However, it requires that initial cluster centers, so called ‘seed points’, and the number of clusters be specified in advance. Following Wiedenbeck and Züll the initial cluster centers and the number of clusters were determined using the Ward algorithm and subsequently ‘optimized’ in a k-means CA. F and t statistics were calculated as follows to evaluate the solution:

$$F_g = \frac{V(j,g)}{V(j)} \text{ For the homogeneity of a group g.} \qquad (2)$$

V(j,g) = variance of variable j in group g
V(j) = variance of j in the sample

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[14] All variables were standardized such that $\mu = 0$ and $\sigma^2=1$, because differing scales tend to bias both PCA and CA.

$$F_v = \frac{MS(j,G)}{MS(j(g))} \text{ For the influence of a variable j in the clustering process.} \quad (3)$$

MS(j,G) = *mean square of variable j across groups g*
MS(j(g)) = *mean square of variable j in group g*

$$t = \frac{\overline{x}(j,g) - \overline{x}(j)}{S(j)} \text{ For the representation of a variable j within a cluster.} \quad (4)$$

$\overline{x}(j,g)$ = *mean of variable j in group g*
$\overline{x}(j)$ = *sample mean of j*
S(j) = *standard deviation of j in the sample*

Values for F_g should be smaller than 1 indicating that the intra-group variance is lower than the sample variance. High values for F_v indicate a high influence in the clustering process. t-values are used to characterize the cluster solution; negative t's indicate that the respective variable is underrepresented and positive t's *vice versa*.

The solution was further validated using independent-samples t-tests and by running the PCA and the CA for two sub-samples to see whether similar solutions emerged. Classification results are presented in section 5.1.1 and the correlation structure and validation results are presented in appendix 4. Three outliers were identified (using the single-linkage clustering algorithm as described in Backhaus et al.) and eliminated prior to the PCA.

3.3.3 Inter-temporal Decisions

This section discusses the typical approach to modeling renewable resource management and deduces a general model for the purpose of the study.

In the traditional slash & burn system under study, the farmer is facing essentially two types of inter-temporal decisions:

1. Fallow vegetation is a renewable natural resource. Cutting and burning fallow supplies the farm with nutrients and additional services[15]. Hence, the farmer has to evaluate the benefits of cutting fallow today against the benefits of cutting fallow in the future taking into account fallow re-growth and crop revenues.

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[15] See functions of fallow section 4.3.1.

2. Investments into perennial and semi-perennial crops or into pastures and livestock involve flows of costs and benefits over several years. Hence, the farmer has to evaluate the costs of investing today against the returns to the investment in the future.

Both problems can be expressed algebraically in a constrained optimal control model of renewable resource management in discrete time (modified from Conrad and Clark 1987 and Chavas et. al 1985):

$$\max_{u_t} \sum_{t=0}^{T} R(x_t, u_t, t) * \delta^t + F(x_T) * \delta^T, \qquad (5)$$

subject to the constraints:

$$x_{t+1} - x_t = f^i(x_t, u_t, t), \qquad \text{for all i} \qquad (6)$$

$$\sum_i g^i(x_t, u_t, t) \le c^i \qquad \text{for all i} \qquad (7)$$

$$x_0 = x(0), \qquad (8)$$

where $x_t = (x_{t1}, x_{t2}, \ldots)$ *is a vector of state variables (e.g, the stock of nutrients in fallow, perennial crops) in period t,* $u_t = (u_{1t}, u_{2t}, \ldots)$ *is a vector of control variables (i.e. the amount slashed and burned in t, other input quantities), R(●) is a concave utility function,* $\delta = 1/(1+r)$ *is the discount rate for interest rate r, and F(●) is the value of fallow and other production activities in the final period T. (6) are i equations of motion describing the rate of change of x, in the case of fallow this requires bio-physical information on the fallow re-growth capacity. (7) are i concave or linear constraints c (e.g. on family labor to convert nutrients into crops) that apply to the function g(●) and (8) is the initial condition for x.*

The optimal path of u can be determined analytically defining an extended current-value Lagrangian[16] (Chiang 1992):

$$\begin{aligned} L(x_t, u_t, \lambda_{t+1}, \alpha_{t+1}, t) = {} & R(x_t, u_t, t) + \delta\lambda_{t+1i} f^i(x_t, u_t, t) \\ & + \sum_i \delta\alpha_{t+1i}(c^i - g^i(x_t, u_t, t)) \end{aligned} \qquad (9)$$

with λ being the co-state variable or shadow price of the nutrient stock and α being the shadow value of the constraint c on g. The necessary conditions for an optimum of L are:

$$\frac{\partial L}{\partial u_t} = \frac{\partial R(\bullet)}{\partial u_t} - \sum_i \delta\alpha_{t+1i} \frac{\partial g^i(\bullet)}{\partial u_t} + \delta\lambda_{t+1i} \frac{\partial f(\bullet)}{\partial u_t} = 0, \qquad t = 0,1,\ldots,T\text{-}1; \qquad (10)$$

---

[16] Note that the Hamiltonian, which is used to set up unconstrained optimal control problems is used here as the objective function.

$$\delta\lambda_{t+1i} - \lambda_{ti} = -\frac{\partial L(\bullet)}{\partial x_t}, \qquad t = 1,\ldots,T\text{-}1; \tag{11}$$

$$x^i_{t+1} - x^i_t = -\frac{\partial L(\bullet)}{\partial \delta\lambda_{t+1i}}, \tag{12}$$

$$\frac{\partial L}{\partial \alpha_i} \geq 0, \text{ with } \alpha_i \geq 0 \text{ and } \alpha_i \frac{\partial L}{\partial \alpha_i} = 0 \quad \text{(complementary slackness)} \tag{13}$$

$$x^i_0 = x^i(0). \tag{14}$$

$$\lambda_T = F'(\bullet); \tag{15}$$

Equation 10 requires the sum of the marginal net benefit of cutting fallow (first two terms) and - due to the interdependence of u_t and x_t - the user costs, e.g. the impact of cutting fallow today on future utility from fallow (last term), to be equal to zero in each period. For the case of fallow, equation 11 states that the rate of change of the shadow value of fallow nutrients over time must equal the marginal value of fallow nutrients to the Lagrangian in each period. (12) re-states the equation of motion and (13) are the optimality conditions due to Kuhn-Tucker (Intrilligator 1971). (14) is the initial condition, i.e. fallow available in t = 0, and (15) is the value of x at time T, i.e. the transversality or terminal condition.

Similar models were successfully employed by Chavas et. al for the case of swine production and by Standiford and Howitt (1992) for optimal rangeland management. These models are typically solved on a computer by collapsing them into a non-linear mathematical programming format (Cacho 2000, Shone 2002). State and control variables are formulated as activities that are linked across time by the equation of motion and additional constraints. The resulting programming model can be solved by non-linear algorithms if the problem size is reasonable and the number of non-linear constraints is relatively low. In some cases the occurrence of non-linear relationships can be limited to the objective function, but, as noted by Cacho, this reduces the amount of dual information obtained in the optimization.

To accomplish the task of explicitly modeling several potential and existing technology options in a whole farm context that involves storage, processing and commercialization activities a linear dynamic optimization approach was chosen. Dean and Benedictis (1964) were among the first, who applied a multi-period linear programming model to simulate farm-household investment problems and optimal production paths over time. Kaiser and Boelhje (1980) developed a multi-period risk programming model to address inter-temporal decision-making under uncertainty.

Since then computing capacity has increased enormously, which allows for larger and more complex models to be solved on a personal computer.

The proposed model builds on the approach by Vosti, Carpentier, and Witcover (2002), which was developed to address agricultural intensification by smallholders in the western Brazilian Amazon. The underlying general model can be expressed as shown in McCarl and Spreen (1997):

$$\max \sum_t \sum_j \sum_e c_{je} y_{tje} \delta^t + \sum_{e \neq K} \sum_j F_{je} y_{Tje} \delta^T, \qquad (16)$$

subject to the constraints:

$$\sum_e \sum_j a_{ije} y_{tje} \leq b_{ti}, \qquad \text{for all i and t} \qquad (17)$$

$$y_{tje} \geq 0, \qquad \text{for all j, t, e} \qquad (18)$$

$$y_{0je} = \text{given} \qquad \text{for all j and e} < K \qquad (19)$$

$$F_{je} = \text{given} \qquad \text{for all j and e} < K \qquad (20)$$

$$-y_{t-1je-1} + y_{jte} \leq 0 \qquad \text{for all t, j and e} > 0 \qquad (21)$$

where y_{tje} is the level of the investment activity j at time t of elapsed age e; c is the per unit profit of variable j at age e and a are resource use coefficients. K is the maximum age of activity j. (17) are i constraints, for example on labor, land, and capital. (18) requires y to be non-negative and (19) and (20) define initial level and terminal or residual value of y respectively. Equation 21 links the activities over time.

Changes of state variables can be introduced by constraints of the form:

$$y_{t-1qe-1} d_{qe} - y_{t-1je-1} = y_{tqe}, \qquad \text{for all } t \neq 0, q, e \qquad (22)$$

$$F_{qe} = \text{given} \qquad \text{for all q and e} < K \qquad (23)$$

$$y_{0qe} = \text{given} \qquad \text{for all q and e} < K \qquad (24)$$

where y_q is a vector of state variables and d_{qe} respective growth coefficients; (23) and (24) are initial stock and final value of state variables.

One of the problems involved in dynamic optimization is that of specifying the terminal condition F_{je}. Depending on the number of periods, the "age" of production activities and the discount rate, the terminal condition may influence the optimal solution of earlier periods. Typically the planning horizon is chosen to be at least as long as the lifespan of the longest lasting production activity. The residual value for each y_{Tje} is than calculated as the discounted value of the remaining life of the respective production activity beyond the planning horizon. This may still involve a bias, because the constraints on the inputs of the production activity cannot be explicitly accounted for in the terminal condition. The approach chosen is therefore to divide the simulated period of 25 years into 5 recursive steps, such that for the first of the five model runs y_{0je} = initial conditions of the survey year; and for the remaining four model runs $y_{0je} = y_{t=5je}$ (of the previous model run). The number of periods for each individual simulation run can then be chosen so as to avoid a terminal condition bias in the solution of the first five periods. This approach also increases the amount of dual information obtained in the simulation, since shadow prices of initial conditions are calculated more than once.

3.3.4 Linearity and Production Functions

Algorithms for solving linear programming problems require all constraints and the objective function to be linear. Two of the basic assumptions of linear programming are therefore additivity and proportionality, i.e. no interaction effects between *model activities* are permitted and gross margins as well as resource requirements per unit of activity are constant. Consequently, if a *production activity* is represented by only one model activity and a respective constraint, the underlying technology is necessarily a Leontief production function (Hazell and Norton 1986).

However, non-linear input-output relationships and factor substitution can be modeled through linear approximation. Instead of expressing yields as a function of inputs and interaction effects between inputs, several model activities are defined, each with a different combination of yields and/or inputs. Depending on input costs and constraints, the model then chooses the optimal linear combination of model activities, which represents a piecewise approximation of the underlying production function[17].

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[17] Unfortunately this is only possible if the function is concave and output is to be maximized. For the linear approximation of convex relationships that are subject to maximization it is necessary to resort to mixed-integer linear programming algorithms (Hazel and Norton 1985). This study refrains from doing so, since integer programming does not allow the appropriate interpretation of shadow prices.

It remains the question how to determine the underlying production function. Table 3.1 summarizes possible approaches:

Table 3.1: Production function identification in bio-economic models

Approach	**Method**	**Advantages**	**Disadvantages**
Field trials	- yield experiments - estimation of yield response functions	- controlled conditions - empirical validation possible	- experiment station bias (yields higher than on-farm, inter-annual variation of exogenous production factors, e.g. rainfall) - expensive and time consuming, especially for perennial crops
Key informant interviews	- direct elicitation of technical coefficients in interviews with farmers and crop scientists	- includes unobservable factors - on-farm information on new technologies	- empirical validation difficult (low degrees of freedom) - interview bias
Empirical Estimation	- statistical/econometric estimation of production/profit functions based on-farm cross section or panel data	- empirical validation possible - on-farm information	- data demanding - survey year bias (cross section data)
Stochastic Simulations	- linear limited production function with random variations	- minimum data requirements - variance for each input level can be derived	- input combinations are difficult to consider

Source: own compilation

Most applications of farm level bio-economic models employ combinations of the first three approaches to generate technical coefficients for mathematical programming models. An example for a combined approach is the technical coefficient generator, i.e. a ‘set of rules’ that combines data, processes and relationships to calculate the required input-output coefficients of land use activities (Hengsdijk et al. 1996, Kruseman 2000). Shiferaw et al. (1998) combine empirically estimated yield impacts of soil erosion with technical coefficients from farm-household interviews; and Vosti et al. (2002) establish yield response functions based on interviews with crop scientists. Finally, Berg (1997) proposes to use stochastic simulation techniques, e.g. monte carlo analysis, to estimate yield and yield variance response to fertilizer use. This study draws on all four approaches:

1. Field trial data is used to model the impact nutrient deficiency on the yield of food crops (section 3.3.5.2).

2. Input requirements for the average yield of crop and livestock activities were derived from interviews with representative farmers from each farm-

household group and supplemented with expert knowledge and information from local literature (see results of investment analysis in section 5.2).

3. The value of fallow in annual crop production was determined by Mendoza (2005) in an econometric estimation and used to calibrate the impact of nutrient deficiency on farm income (explained below).

4. The yield and yield variance response to fertilizer use was estimated in a stochastic simulation approach and analyzed in an extended model version (see documentation below).

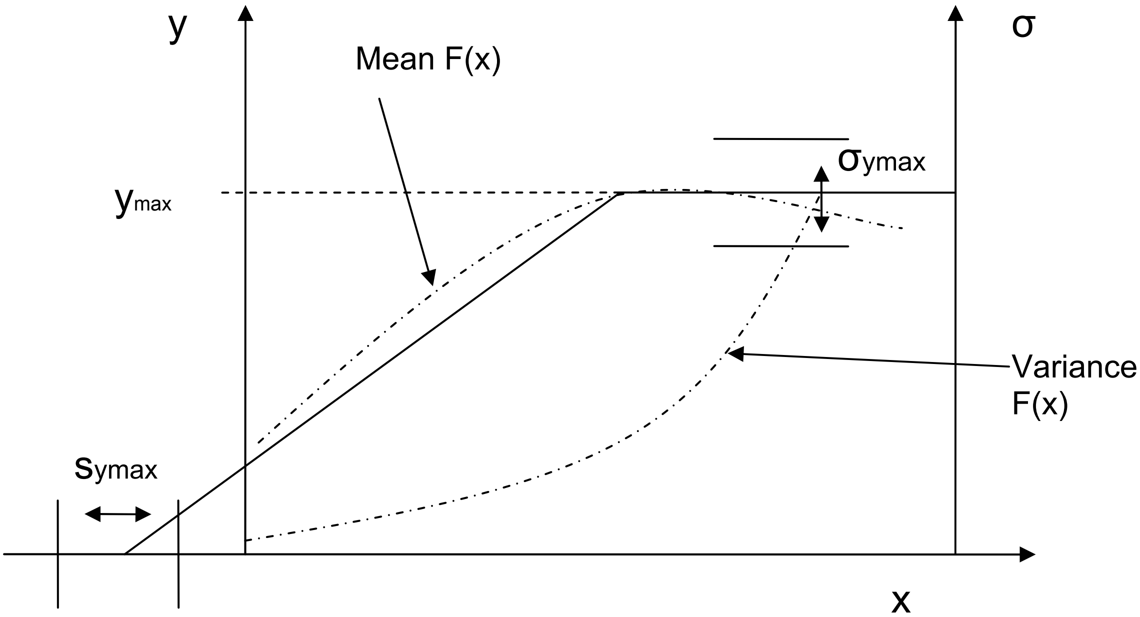
In the Bragantina it was found that, apart from fertilizer and labor, fallow length is the most important production factor affecting aggregate annual crop output annual crop production (Mendoza 2005). She found that fallowing contributes on average 22% to profits per ha of annual crops. The value of fallow in the model baseline should therefore correspond to the value found by Mendoza (see also section 3.3.5.2).

Following Berg (1998) the stochastic simulation approach is outlined below. According to Liebig's principle of the minimum factor, the maximum attainable output level is limited by the minimum input factor, e.g. phosphorus in the case of soils in the Bragantina (see Kato 1998 and the discussion in section 3.3.5.2). This allows representing the underlying technology as a linear limited production function of the form:

$$y = a^{-1}(x+s) \text{ for } y \leq y_{max} \text{ and } y = y_{max} \text{ otherwise} \qquad (25)$$

with $y_{max} = N\{\bar{y}_{max}, \sigma_{ymax}\}$ and $s = \{\bar{s}, \sigma_s\}$

where y is the yield, x is the level of input and a represents the quantity of x necessary per unit of y. y_{max} *(maximum yield) and s (plant available phosphorus in the soil) are assumed to be uncorrelated random variables and the sources of uncertainty for the decision-maker.*



Source: Modified from Berg (1998)

Figure 3.2: Linear limited production functions and Monte Carlo simulations

Depending on the distribution function of y_{max} and s, a Monte Carlo simulation generates a sample of potential progressions of the linear limited function in figure 3.2, which allows estimating a production function with decreasing marginal productivity (see Mean f(x) in figure 3.2). An additional useful output is the variance function (Variance F(x) in figure 3.2) that describes the variance of yield depending on x. Note that depending on σ_{ymax}/σ_s the variance function can be increasing (large σ_{ymax} small σ_s) or decreasing (large σ_s small σ_{ymax}) with increasing x. This has important implications when comparing tropical soils with generally low nutrient reserves (i.e. low potential variability) and soils in temperate zones with generally higher nutrient reserves (high potential variability). Hence, in temperate zones, applying fertilizer can be interpreted as a means to reducing yield variance, whereas the opposite can be the case on nutrient poor tropical soils. This issue will be further investigated using an extended version of the bio-economic model.

3.3.5 Bio-physical Processes

Several ways exist to incorporate bio-physical processes into bio-economic models ranging from complex biological process models to the mere accounting of sustainability indicators, e.g. soil loss or carbon sequestration, parallel to the process of economic optimization (Brown 2000). The evolution of such indicators over time depends on land use and technology choice and represents valuable information for policy makers. Treating dynamics explicitly in a multi-period model allows tracking changes of sustainability indicators within the planning horizon.

3.3.5.1 Climate and Soils

As a result of the farm-household classification, climate can be considered homogeneous within farm-household groups, but not between them (see section 5.1). In the latter case, the heterogeneity is captured by the differences in yield levels and technical coefficients between farm-household groups. This cannot necessarily be expected to hold for soil types as well. A Bragantina soil map prepared by Vieira et al. (1967), however, shows that roughly 80% of soils in the region are oxisols and ultisols with small patches of sandy entisols. Da Silva (1986) later confirms the relative homogeneity of soils, albeit on a larger scale. It is, therefore, not unrealistic to assume that differences in soil quality depend largely on the land use history. Also yield differences appear to be much more related to the heterogeneity of climate and management factors (e.g. weeding, fertilizer use, and fallow length) than to soil quality, which can be shown by simply comparing the average level of these factors for the three districts (table 4.5 in section 4.7). Consequently, the model specification considers soil types and quality as exogenous factors, whereas more emphasis is placed on endogenizing management decisions. This involves decisions on the optimal allocation of labor and fertilizer, as described in the previous sections, as well as decisions about the optimal fallow length. The latter requires information about the relationship between fallow length and the yields of the crops in the slash-and-burn system.

3.3.5.2 The Fallow/YieldRelationship

When talking about a yield/fallow relationship, it is important to differentiate between the immediate effect of a given fallow period on the productivity of the subsequent crop and the long-term negative productivity effect of shortening fallow periods. While the latter seems to be a logical consequence of Ruthenbergs model of declining soil productivity[18] in shifting cultivation systems, few empirical evidence exists to support the hypothesis. As will be shown in section 4.7., long term productivity

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[18] Ruthenberg (1980)

effects are often masked by technological change and other factors, while historical data on slash-and-burn systems are fragmentary.

Even with regard to the immediate productivity effect of fallow length, Merz (2002) points out that the empirical basis is weaker than the widespread postulation of the relationship might suggest. In fact, 7 out of the 12 studies presented by Merz, obtained none or inconclusive evidence on the matter. Nonetheless, both studies from the eastern Amazon confirm a positive fallow/yield relationship at least for some annual staple crops. A main limitation of most studies is the low sample size and the omission of management factors from the analysis.

The plot level data collected in the course of the field work for this study exceeds the scope of all studies reviewed by Merz both in terms of the sample size and the collected amount of socioeconomic, agronomic, and biophysical information. Mendoza (2005) combines this information in an econometric estimation of input demand and output supply functions that shows a clear positive relationship between fallow length and profit/ha from annual consumption and cash crops. Mendozas estimation provides an indication of the aggregate value of fallow in annual crop production. Yet, the optimal fallow length is likely to differ for agricultural crops depending on factors such as the nutrient requirement, optimal ph, etc. The individual yield response of crops in the slash-and-burn system can be represented by nutrient deficit response or damage functions. Theoretically, such a damage function is expected to be S-shaped as shown in figure 3.3.

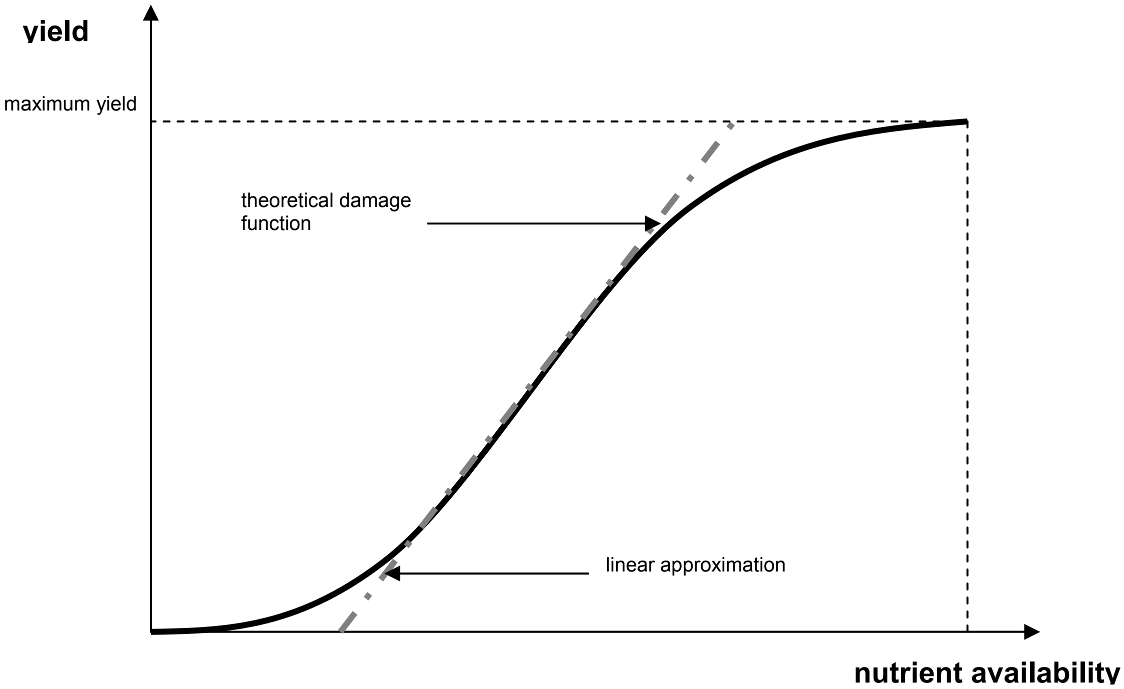

Figure 3.3: Theoretical damage function

Modeling each crop in the slash & burn system with an individual damage function allows for the model to determine the optimal fallow length per production activity endogenously.

Due to the problems involved in representing the convex segment of the yield damage function in a maximizing linear programming framework it was decided to use a linear damage function (figure 3.3). To specify such a function it is necessary to know the nutrient requirement per unit of yield for each crop (usually found in the literature) and an indication on the expected yield drop off due to nutrient shortages. The link to fallow length is then established by estimating the nutrient input of burned fallow at different ages. Fertilizer experiments with limiting nutrients and yield drop off measurements in continuous cropping periods after slash-and-burn have shown that assuming a linear damage function is not too problematic after all (de Souza Cruz et al. 1982, Jordan 1989, de Oliveira et al. 1986).

Kato (1998) conducted a controlled field experiment comparing yields of the main staple crops in two consecutive cropping cycles with and without fertilization in the district Igarapé-Açu (Table 3.2).

Table 3.2: Yields in two cropping cycles with and without fertilization

	First croping cycle yields in kg/ha		Second cropping cycle yields in kg/ha	
	Fertilizer	No fertilizer	Fertilizer	No fertilizer
Cassava	30100	15900	26800	10750
Beans	1550	300	1800	300
Rice	2850	1850	3300	1400

Source: Kato (1998) mean values from two sites

The yield decrease between the first and the second cropping cycle without fertilization can be interpreted as the linear yield response to nutrient deficiency and other factors influenced by the fallow period. A comparison with second cycle yields on fertilized plots shows lower or no yield reduction, which suggests that the negative yield response without fertilization is almost entirely due to nutrient deficiencies.

In a slash-and-burn system without fertilization on soils with relatively poor chemical properties, the ashes from burning fallow vegetation are the main source of nutrients for agricultural crops. This and other field experiments in and close to the study area have shown that phosphorous (P) is the main productivity enhancing nutrient on the dominant soil types with regard to annual staple crops, such as rice, beans, corn, and cassava (de Souza Cruz et al. 1982, Bünemann 1998, SEPEF I without date). The empirical basis with regard to the yield effects of other soil characteristics, such as ph and soil organic matter is not as univocal as in the case of P and does not allow for the construction of a consistent crop model. Thus, it was decided to use P as the accounting nutrient for the damage function.

Hölscher (1997), Kato (1998), and Sommer (2000) measured the P content in fallow vegetation of different ages up to ten years and Viera et. al (2002) estimated biomass accumulation in fallows up to 70 years. A stylized biomass and P[19] accumulation curve for fallow of an age up to 20 years was estimated with the data from these studies using the specification below:

$$P/ha = 2.413 * \ln(t) + \varepsilon \qquad (R^2adj = 0.88, n = 5) \qquad (26)$$

$$biomass/ha = 4.519 * t\ \ 0.038 * t^2 + \varepsilon \qquad (R^2adj = 0.93, n = 22) \qquad (27)$$

Despite the small sample size, the estimated accumulation curves represent a realistic average scenario for the study region. In the model a constant was added to (26) in

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[19] P stock measured in the ashes after the burn.

order to represent soil nutrient reserves. Changes in this constant can be used to simulate long term sustainability impacts of shortening fallow periods.

Nonetheless, fallow re-growth capacity does not depend exclusively on time. Honderman (1995), Baar (1997), and Wiesenmüller (1999) show that fallow re-growth after mechanization and intensive cash crop cultivation is reduced due to the removal of roots and stumps for vegetative reproduction. In the model this was implemented by requiring four years of rehabilitation after allowing for a given area to accumulate biomass and nutrients again (see model documentation in appendix 13, equations 7c and 7d).

In the model calibration process, the system of damage functions was multiplied with a weight factor to adjust the shadow price of fallow to the aggregate value obtained in Mendozas econometric estimation. This assures an adequate representation of yield response to fallow length at the regional level.

3.3.6 Socio-economic Processes

3.3.6.1 Markets

The representation of input/output, labor, land, and credit markets is one of the limitations of farm-household linear programming (LP) models. Only if interaction between farms is an option, e.g. in agricultural sector or multiple-agent settings, these markets can be modeled explicitly. However, input supply curves and effects of changes in market factors can be simulated by changing right-hand-side (RHS) values, i.e. constraints in the LP matrix, or via changes in factor prices. This is illustrated in table 3.3 for the case of local labor supply.

Table 3.3: Stepwise labor supply

	q1	q2	q3	q4	RHS
Objective function (R$/day)	-7	-9	-11	-13	
Labor q1 (man-days/month)	1				≤ 2
Labor q2 (man-days/month)		1			≤ 6
Labor q3 (man-days/month)			1		≤ 9
Labor q4 (man-days/month)				1	≤ 11

The LP formulation in the table approximates the labor supply curve faced by an individual farm. The increases in wage (q1 to q2 ..) and respective labor supply for the bio-economic model, were determined based on the average community size and composition[20]. Hiring workers in other communities or in the urban center involves additional transaction costs in the form of transportation, alimentation and time. Hence, depending on the location and size of the community, wage or RHS-values can be altered to represent the conditions of individual farm-households. The same approach was used to represent labor selling options for the farm-household.

Land markets do not seem to play an important role in the smallholder economy of the Bragantina, which is why land buying, selling and renting options are not included in the model. Credit is not an option in the baseline model, but is introduced at a fixed interest rate in some scenarios.

Access to inputs, such as fertilizer and agrochemicals is assumed to be unconstrained at a fixed price. Yet, due to the presence of asymmetric information and traditions they are considered as technologies that are not available for some production activities.

Although individual farms are considered price takers, the model farm-household has to be understood as a representative of a large group of smallholders in the study area. Thus, product prices cannot realistically be assumed to stay constant as supply increases, e.g. as a consequence of agricultural policies or technological change. Ignoring this might lead to an overestimation of the impact of technological change on land use as illustrated in figure 3.4.

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[20] Not all communities are pure farmer communities. Especially in Castanhal a considerable share of the rural population consists of permanently or temporarily employed rural workers.

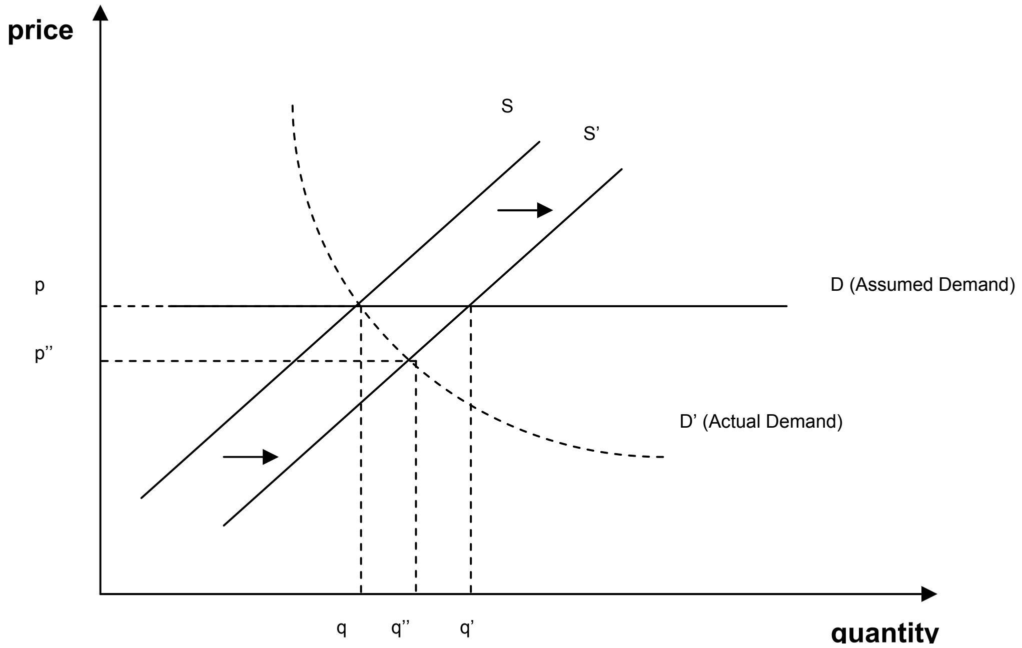

Figure 3.4: Supply response to technological change

Technological change shifts the supply function S to S'and if prices are fixed (perfectly elastic demand curve D) output would increase from q to q'. However, if the actual demand was rather inelastic (D') price would drop from p to p'' and the corresponding equilibrium quantity would be only q'' instead of q'.

Especially in the case of staple crops prices are likely to reduce as supply increases at least in the short run. In the absence of adequate data to estimate regional demand elasticities it was decided to explore the supply response to product price changes through sensitivity analyses. Whenever large supply changes occur relative to the baseline, the effects of price changes will be explored in more detail.

3.3.6.2 Consumption and Production Decisions

An important issue in modeling farm-household behavior is the fact that households are producers and consumers at the same time (Ellis 1988). In the presence of perfect markets, theory suggests that, just like in the case of a private firm, farm-households value all production factors and consumption goods at their respective market prices. This allows solving the producer problem (profit maximization) prior to the consumer problem (utility maximization), because household utility depends solely on market prices and income (indirect utility function) (Bardhan and Udry 1999).

In many developing country settings, however, markets exhibit imperfections, such as high gaps between buying and selling prices (.i.e. price bands) for consumption crops or between the wage rates for sold off and hired labor. In these cases, the opportunity costs of goods and family labor are no longer their market values, but endogenous shadow prices that depend on the width of the price band and the household's production factor endowment and consumption requirements.

For example, if land is fixed, the family labor constraint is binding, and the market for hired labor fails, farm-households cannot respond to product price according to the optimality condition:

$$MVP_L = dF_j/dL * p_j \qquad (28)$$

MVP = *marginal value product of labor to produce good j*
F_j = *production function of good j*
L = *labor*
dF_j/dL = *marginal product of labor*
p_j = *price of good j.*

Instead

$$MVP_L = (df_j/dL * p_{j)} + \lambda_{lc} \qquad (29)$$

λ_{lc} = *shadow price of the hired labor constraint*

This implies that the farm-household would allocate more labor to produce good j, if it had access to more hired labor. Since λ_{lc} depends on the size of the household, the latter becomes a decision variable in the production problem, i.e. MVP will be higher for small farm-households than for larger ones instead of being equal among all households[21]. Consequently, de Janvry et al. (1991) find African farm-households to be less responsive in production quantity to increases in cash crop prices if the labor market fails.

Furthermore, comparing the first order conditions of a farm-household model with price bands for production/consumption crops shows that the marginal product of a production factor is valued against purchase prices in the case of utility maximization, whereas it is valued against market prices in the case of profit maximization (Kruseman 2000). Thus, the production problem is no longer independent from the consumption problem or production decisions are *non-separable* from consumption

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[21] Or as Benjamin (1992, p. 288) puts it, "with separation, the number of workers in Baron Rothschild's vineyards should not depend on the number of daughters he has."

decisions. A formal test for non-separability has first been proposed by Lopez (1984) although the notion of the problem dates back to Chayanov (1923). Chayanov's model, however, assumes the non-existence of a labor market, which is rather unrealistic especially in the case of farm-households in the Bragantina.

A typical way to deal with non-separability in bio-economic mathematical programming models is the maximization of household income (as a proxy for utility) subject to constraints on the production of certain food crops or food crop combinations and a reservation wage rate (Kutcher 1981, Barbier and Bergeron 2001). In the presence of market failures for food crops, this assures that the farm-household's minimum consumption requirement is met through production. If labor is subject to a market failure, the reservation wage represents the value of leisure to the farm-household. This is especially useful if the opportunity costs of farm work are low or zero in the absence of off-farm employment opportunities or if home time, e.g. reproductive activities, are not explicitly represented in the model. Since off-farm employment is quite common in the study area, a reservation wage rate was not *a priori* specified.

Shiferaw et al. (1998) and Kruseman (2000) employ direct utility functions to account for the notion that household preferences might change as income changes. For example, the consumption of leisure tends to increase as income increases (superior goods), whereas the consumption of certain staple crops goes down (inferior goods). Direct utility functions express utility directly as a function of consumption of income, leisure, and goods and can easily be derived from budget data. Here again pure linear programming is limited as only non-linear convex consumption functions can be represented through linear approximation (Hazell and Norton 1986). Since theory suggests a declining marginal propensity to consume, consumption functions should be concave. However, if the range of income changes is rather small, it can reasonably be assumed that consumption functions are linear.

The 2001/2 baseline survey did not explicitly include the allocation of family labor to farm work and home time. Yet, technical coefficient interviews with households from the highest income group have shown that family members other than the household head are not directly involved in farm work. In households from the lowest income group, on the contrary, the whole family participates in many farming activities, such as planting, weeding, harvesting, and cassava processing. This allows specifying a stylized linear Engel curve for family labor excluding the household head:

$$q_l = a + bY \qquad (30)$$

such that

$$b = \frac{n\sum q_{li}Y_i - \sum q_{li}\sum Y_i}{n\sum {q_{li}}^2 - (\sum q_{li})^2} \text{ and } a = \overline{Y} - b\overline{q_l} \text{ and } \eta = \frac{q_l - a}{q_l}$$

where

q_l = family labor units available for farm work (excluding household head), a = available family labor units at income Y = 0, n = i = 2 (upper and lower income group), Y_i = mean of income in group i, and η = the income elasticity.

In the model this has the effect that family members are less involved in farm work as the income level rises, which is plausible in the context of the Bragantina.

For the consumption of food and other essential goods (e.g. education fees, medical costs, clothing etc.) a set of linear Engel equations for staples and other goods has been estimated from deflated household budget data[22] as proposed in Sadoulet and de Janvry (1995). Since the budget data includes the urban center Belém it was compared to 1977 consumption data for rural households (Fundação IBGE 1977) as shown in table 3.4.

Table 3.4: Consumption of staples in rural and urban areas

Staples/Categories	1996 Urban in kg/cap	1977 Rural in kg/cap	difference in %
Rice	1.60	3.95	147
Beans	0.81	1.32	63
Cassava flour	2.82	3.09	9
Sugar	1.50	1.67	11
Fruits	2.62	2.69	3
Legumes	1.84	1.25	-32
Meat	3.56	2.50	-30

Sources: IBGE (1995/6), Fundação IBGE (1977)

Especially for rice and beans per capita consumption seems to be a lot higher in rural households, while more legumes and meat are consumed in urban households. Hence, the minimum consumption requirement for these staples was adjusted to rural consumption patterns. The resulting set of Engel curves appears to be a reasonable representation of rural consumption requirements, and the value of non-farm products

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[22] Pesquisa de Orçamentos Familiares IBGE (1996).

that have to be bought in corresponds to the estimate of total monthly household expenditure that farmers reported in technical coefficient interviews. The coefficients and regression statistics are presented in appendix 5.

3.3.6.3 Risk

Many bio-economic models employ measures of risk to account for the uncertainty involved in agricultural production. In fact, risk is also one of the factors tying together farm-household consumption and production decisions as it contributes to open up price bands between purchase and sale prices (Sadoulet and de Janvry 1995). Table 3.5 summarizes the most widely employed techniques to integrate the notion of risk in mathematical programming models based on Hardaker (1997a) and McCarl et al. (1998):

Table 3.5: Risk in mathematical programming models

Method	**Technical Issues**	**Comments**
Objective Function Coefficient Risk		
Expected Value - Varianze Analysis (E-V-Analysis)	- non-linear (quadratic) objective (utility) function - risk aversion parameter	- assumes that total net revenues (expected utility) are normally distributed
Minimization of Total Absolute Deviations (MOTAD), Target MOTAD	- linear objective function - risk aversion parameter	- approximation to E-V efficient frontier - Target MOTAD combines MOTAD and safety first
Safety First	- linear objective function	- imposes a minimum constraint on total farm income
Direct Expected Utility Maximizing Non-linear Programming (DEMP)	- non-linear (utility of wealth) objective function	- minimum (initial) wealth constraint - no assumptions regarding expected utility
Right-Hand-Side Risk		
Chance Constrained Programming	- linear objective function	- stochastic constraints (right-hand-side 'RHS') - minimum data requirements
Quadratic Programming	- non-linear objective function - two risk aversion parameters (variance of income, variance of RHS)	- combines E-V and chance constraint programming - accounts interdependence of constraints - theoretical flaws: as RHS risk aversion increases expected income increases too
Technical Coefficient Risk		
Merrill's Approach	- non-linear constraints - computational difficulties	- stochastic input requirements - only effective if constraints are binding
Wicks and Guise Approach	- linearized constraints	- MOTAD version of Merrill's approach

Method	Technical Issues	Comments
Multiple Sources of Risk		
Stochastic Programming with recourse	- linear or non-linear objective function and constraints	- decisions are divided into stages, with risky events embedded between stages

Source: Hardaker (1997a) and McCarl (1998)

The development of most of these techniques started in the 1950ies with the E-V model being one of the first mathematical programming approach to simulate portfolio diversification based on the subjective expected utility (SEU) model (see v. Neumann and Morgenstern (1947) on SEU and Markowitz (1959) on E-V). Despite advances in utility and investment theory since then, the E-V model continues to be the most widely applied approximation to the SEU model (Robison and Hanson 1997). Also the linearized E-V model, Minimization of Total Absolute Means (MOTAD), continues to be used due to its ease of application (Maleka 1993, Vieth 1996, Hardaker et al. 1997b, Carvalho et al. 1997).

As will be further explored in chapter 4, the main sources of risk in the study area are price and production risk, i.e. objective function coefficient risks. MOTAD and E-V analysis are employed here, not only because these are the most widely applied techniques for these types of risk, but also for technical reasons regarding the model size. First, the MOTAD approach will be used to assess farmers' behavior with regard to production activity diversification in response to price variability; and second, the E-V technique serves to explore the question of input use intensity in a separate model. The specification of the objective function and related issues for both approaches are discussed below:

MOTAD

$$\max \sum_t \sum_j \sum_e \overline{c_{je}} y_{tje} \delta^t + TC - \psi \sum_t \sum_k (d^+_{tk} + d^-_{tk}) \delta^t \qquad (31)$$

subject to:

$$\sum_j (c_{kje} - \overline{c_{je}}) y_{tje} - d^+_{tk} + d^-_{tk} = 0 \qquad \text{for all k} \qquad (32)$$

and the usual constraints for a linear programming problem (section 3.3.3).

Following the notation used above, c are the gross margins for activities j at elapsed age e; y is the activity level at time t; $\bar{c}$ *is the expected value of c;* d^+ *and* d^- *are positive variables denoting positive and negative total gross margin deviations at each state of nature k (time series of activity gross margins) and t;* ψ *is the risk aversion parameter (RAP); and TC is the terminal condition.*

In the baseline model the k states of nature are derived from a deflated time series of product prices between 1995 and 2002 (IBGE PAM 1995 – 2002). The price variation for cassava roots was used here as a proxy for the price variation of cassava flour.

E-V Analysis

The link between E-V Analysis and expected utility is the certainty equivalent CE, i.e. the sure sum of money that a decision-maker would rate equivalent to a risky prospect (Haradker et al. 1997a). The CE is defined as the expected return of the risky prospect less a risk premium π, which Pratt (1964) has shown to be approximated by:

$$\pi = -\frac{[U''(y)/U'(y)]\sigma^2}{2} \qquad (33)$$

where U'(y) and U''(y) are the first and second derivative of the underlying utility function of income y; and σ^2 *the variance.*

The term in the brackets is called the Arrow-Pratt Measure of Absolute Risk Aversion (ARA) and can be constant (CARA), increasing or decreasing (DARA) in y. Hardaker (2000) states that decision-makers can usually be expected to be decreasingly averse to risk if income rises. However, as he notes in Hardaker et al. (1997a), the convenience of the functional form of CARA has prompted its extensive use in decision analysis since it allows expressing the measure of ARA as a constant such that (Robison and Barry 1987, Berg 2003):

$$CE = E(y) - \frac{\lambda}{2} V(y) \qquad (34)$$

where E(y) is expected return, V(y) the variance and λ the risk aversion parameter (RAP). In this specification, as in the case of the MOTAD approach, decreasing risk aversion at higher income levels can only be introduced by parameterization of λ (or ψ).

Many studies have also tried to directly elicit utility functions from farmers and derive the RAP from the estimated utility functions. However, measuring risk attitudes is as old as it is controversial (Dillon and Scandizzo 1978, Hardaker et al. 1997b). The discussion centers around the elicitation of utility functions via either lottery games with real pay-offs or a questionnaire based approach confronting the farmer with a number of risky prospects. The latter was attempted in the context of this study, but in line with Hardaker et al. (1997b) the obtained utility functions were not consistent. Instead it was decided to derive the RAP through parameterization of the model to observed behavior and explore the implications of changing risk aversion through sensitivity analysis.

Following Berg (2003) the objective function of a stochastic programming model with price and production risk, deterministic costs and excluding the covariance of prices and yields can be set up maximizing (34), where

$$E(y)=\sum_{i=1}^{n}(E(p_i)E\left[f_i(x_i)\right]-c_{0i}-c_{1i}x_i)v_i-FC \tag{35}$$

and

$$\begin{aligned}V(y)=&\sum_{i=1}^{n}(E(p_i)^2V[f_i(x_i)]+V(p_i)E\left[f_i(x_i)\right]^2)v_i^2\\&+2\sum_{i=1}^{n}\sum_{j=i+1}^{n}v_iv_j\operatorname{cov}(GM_i,GM_j)\end{aligned} \tag{36}$$

p are prices for activities i, f(x) is the production function of activity i depending on input level x (here chemical fertilizer), v is the activity level, c_0 and c_1 are fixed and variable costs of i, FC are fixed farm costs and GM are the activity gross margins.

Omitting v and the covariance terms for simplification the first order condition for the optimal x of an individual activity becomes:

$$\begin{aligned}&E(p)\frac{d}{dx}E[f(x)]-c_1\\&-\frac{\lambda}{2}\left\{E(p)^2\frac{d}{dx}V[f(x)]+2V(p)E[f(x)]\frac{d}{dx}E[f(x)]\right\}=0\end{aligned} \tag{38}$$

Solving for the marginal expected yield results in:

$$\frac{d}{dx}E[f(x)]=\frac{c_1}{E(p)-\lambda V(p)E[f(x)]}+\frac{\frac{\lambda}{2}E(p)^2\frac{d}{dx}V[f(x)]}{E(p)-\lambda V(p)E[f(x)]} \tag{39}$$

Examining (39) provides some insight as to how the optimal input level x depends on the variance of yields and prices. For example, evidence from the Bragantina suggests increasing yield variance in response to fertilizer use. Hence, the derivative of V[f(x)] is positive until its maximum, which *ceteris paribus* leads to an increase of the second term on the right hand side of equation 39. The result is a higher marginal expected yield, i.e. a lower optimal input level. The same effect has an increase in price variability as it would reduce the denominators of both terms on the right hand side. As Berg (2003) shows, the impact of an increase in price variability may be neutralized if yield variability decreases in response to fertilizer use, which can be the case in temperate zones.

3.3.6.4 Inter-year income variation aversion

So far, only the risk induced variation of household income has been considered by maximizing the certainty equivalent of annual non-essential consumption. Yet, some authors argue that aversion to inter-year variation of income might also influence farmer's decision making (Gilboa 1989, Kennedy 1997). In the present case, the inter-year income variation is not necessarily a consequence of production or market risks. Intensive cash crops, for example, require high investments in the first year and start yielding returns only after two or more years, which can be reflected in deterministic income variations. Hence, it appears worth to test whether the aversion to inter-year income variation has an impact on land use and technology choice.

Building on Gilboa, Kennedy derives the following multi-period utility function:

$$U(E[u(y_t)],\ldots,E[u(y_T)]) = \sum_{t=1}^{T}[\rho_t E[u(y_t)] + \varsigma_t(\left|E[u(y_t)] - E[u(y_{t-1})]\right|)] \qquad (40)$$

$$\rho_t \geq |\varsigma_t| + |\varsigma_{t-1}| \text{ for } t < T \qquad (41)$$

$$\rho_T \geq |\varsigma_T|,\ \varsigma_1 = 0 \qquad (42)$$

for variation aversion

$$\rho_t > 0 \text{ for all } t,\ \ \varsigma_t < 0 \text{ for all } t \geq 2 \qquad (43)$$

E[u(y$_t$)] is the expected utility of farm income y at time t and ρ and ς are weights for current year expected utility and inter-year expected utility variation respectively.

In his example, Kennedy uses a dynamic programming framework, which becomes rather large as the model size increases. However, it is possible to modify the objective function of the MOTAD model (equations 31 and 32) to account for inter-year variation:

$$\max\ \rho\left(\sum_t\sum_j\sum_e \overline{c_{je}}\, y_{tje}\delta^t + TC - \psi\sum_t\sum_k(d_{tk}^+ + d_{tk}^-)\delta^t\right) - \varsigma\sum_t(v_t^+ + v_t^-)\delta^t \qquad (44)$$

subject to:

$$\sum_j\sum_e \overline{c_{je}}\, y_{tje} - \sum_j\sum_e \overline{c_{je}}\, y_{t-1je} = v_t^+ - v_t^- \ \text{ for } t > 1 \qquad (45)$$

as well as the known linear programming constraints.

In addition to the known elements, v_t^+ and v_t^- are introduced to measure the absolute change in income between two consecutive years. The weights are considered equal for all years. Inter-year income variation aversion is not *a priori* assumed in the scenario analyses using the bio-economic model. However, tentative interviews to elicit variation aversion have shown that some farmers prefer low inter-year variation to high inter-year variation even if the average income is lower. Consequently, the sensitivity of scenario results to varying ς's will be evaluated for some cases.

3.3.7 Sustainability and Bio-economic Modeling

It is not attempted here to establish a new definition of sustainability for the context of this study[23]. However, for its objectives it appears useful to examine how bio-economic modeling can contribute to answer questions regarding the sustainability of agricultural practices, land use and technology change. An important branch of the sustainability debate has focused on the concepts of weak and strong sustainability (Turner 1992, Gowdy et al. 1997, Ekins et al. 2003). The discussion centers on the degree of substitutability of natural and physical capital, i.e. weak sustainability implies almost perfect substitutability and strong sustainability implies rather perfect complementarity. Both extremes are based on the notion that the total economic value of all types of capital should at least not decrease over time, such that today's consumption does not compromise future consumption. Yet, policy action can be quite different depending on which of the two concepts has served as the basis of decision making. For example, environmental conservation policies, such as bans, are often formulated in the face of irreversibility, the latter being a powerful argument of strong sustainability advocates.

One of the strengths of bio-economic household models that has particularly been exploited by Vosti et al. (2002) is the simultaneous treatment of all cornerstones of the 'critical triangle' of development goals (Vosti and Reardon 1997). The development of environmental indicators, such as carbon stocks and biodiversity, welfare indicators, such as household income and resource endowments, and indicators of economic growth, such as hired labor and input purchases, can be evaluated over time (and/or space) and in terms of their relative importance for farm decisions, e.g. by comparing shadow values. This can help to identifying tradeoffs and synergies between policy and technology options and allows setting up policy scenarios that explicitly address farm level constraints.

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[23] See Ruttan in Vosti and Reardon (1997) for a critical review of sustainability concepts regarding agricultural development.

It is, however, seldom mentioned that the majority of these models, including the one presented here, is based on strong assumptions regarding the substitutability of natural and physical capital. As mentioned by Ruben et al. (2001), the production module of farm-household bio-economic models is typically set up by the discrete definition of technical production coefficients. Especially if technological innovations are included, these coefficients are, often necessarily, justified based on expert knowledge rather than on empirical grounds.

The author has imposingly experienced the implications of this in numerous discussions with local experts on the vulnerability of soil productivity to substituting traditional fallow based technologies by continuous production based on external inputs. The convictions of renowned scientists covered the whole range of substitution possibilities, which is certainly not surprising given the sparse empirical evidence on the matter. Nonetheless, it shows that caution is required in deriving sustainability judgments from simulation results. For the current context this means that, whenever strong assumptions on substitution possibilities have been made, the effect of relaxing the assumptions needs to be investigated. One of the candidates for further investigation is, for example, the effect of improved access to conventional mechanization technologies as will be seen further down.

3.4 Summary

The introductory discussion to the chapter stresses the advantages of quantitative modeling approaches in assessing policy instruments with regard to their impact on land use, technological change, and the environment. It distinguishes between essentially two types of bio-economic models, namely econometric and optimization models, and provides a justification for the use of an optimization model to address the study's research questions.

Subsequently, the theoretical underpinnings of the bio-economic model and its components are described formally together with a critical evaluation of typical approaches found in the literature. To reduce the aggregation error inherently present in modeling farm-household behavior, a combination of cluster and principal component analysis is proposed.

The inter-temporal nature of land use decisions and technology choice in the study area can be illustrated by the optimal control model of renewable resource management and it is shown how linear programming can be used in a similar way to address the issue. Modeling the fallow system in the Bragantina requires a quantification of the fallow/yield relationship, which is introduced via the concept of nutrient deficit functions. Furthermore, it is necessary to account for the farm/household inter-relationship in smallholder agriculture, i.e. non-separability of production and consumption decisions, aversion to risk and income variation. A final discussion centers on the usefulness of bio-economic optimization models in addressing sustainability issues and points to the need of a critical evaluation of model results with regard to the underlying assumptions of the substitution potential between natural and physical capital.

Part II Descriptive Analysis and Model Inputs

Part II starts off with a descriptive analysis of smallholder agriculture in the Bragantina (chapter 4). Subsequently, the results of pre-modeling analytical steps are presented in chapter 5.

4 Smallholder Agriculture in the Bragantina: Ecological Constraints and Economic Change

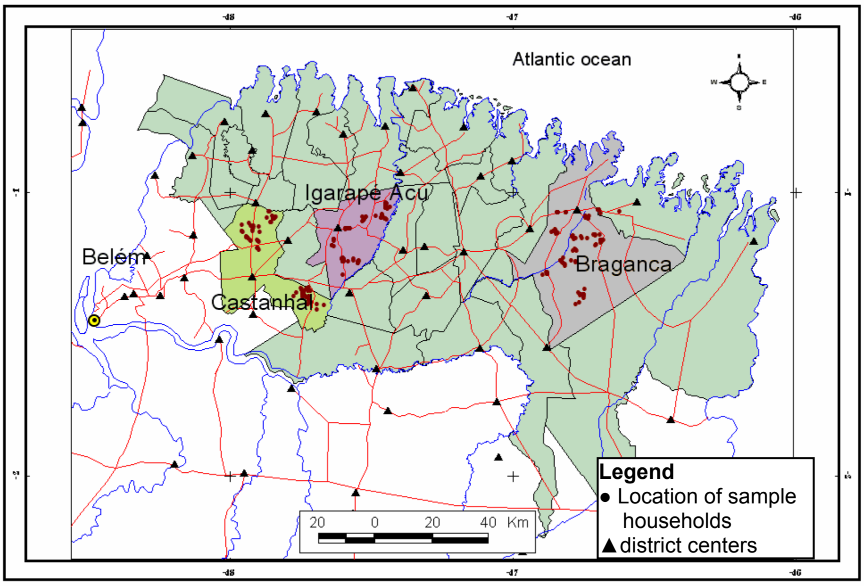
This chapter summarizes background information on ecological, socio-economic, and institutional key characteristics of the study area. It centers on the question how agriculture has evolved beyond the removal of primary forest cover and tries to identify potential limitations of sustainable development in the future based on the descriptive analysis of cross section primary data and the actual state of research. It further provides the background necessary to define policy and technology scenarios and interpret model outcomes. After a brief geographical characterization of the Braganina region, section 4.2 describes the emergence of smallholder agriculture in the area. Section 4.3 reviews general and specific findings of natural and social scientists and centers around the introductory research question 2. Sections 4.4 through 4.10 present a descriptive analysis of the farm-household and regional level data collected during the fieldwork. Whenever possible, links are established to earlier research results to set the findings into a broader context. Finally, section 4.11 reviews the development of land use in response to major policy changes and section 4.12 summarizes the findings.

4.1 Geography

Location and Population

The Zona Bragantina is located east of the state capital Belém and extends almost until the neighboring state Maranhão (figure 4.1). In 2000 the Micro-regions Bragantina and Castanhal (here Zona Bragantina), as defined by the *Instituto Brasileiro de Geografia e Estatística* (IBGE), included 18 municipalities with 555 thousand inhabitants on 12410 km^2 (or 44.7 inh/km^2, IBGE 2000). Roughly 36% of the population lives in rural areas and has grown at an average annual rate of 1.4% (as compared to 2.4% including urban centers) between 1996 and 2000. With 44.7

inhabitants per square kilometer the regions population density lies far above the Brazilian average (19.9 inh/km^2) and the state of Pará (4.9 inh/km^2) (IBGE 2000).



Source: EMBRAPA CPATU and SHIFT/NAEA field survey

Figure 4.1: Study area and household sample distribution

Climate

The Zona Bragantina has a tropical moist forest climate, with a short dry season between September and November. Following the classification by Köppen (1936), the western part of the Zona Bragantina is influenced by the climatic type “Afi”, whereas the eastern part exhibits a more “Ami” type of climate. This is most obviously reflected in the rainfall distribution (Figure 4.2) that reveals a relatively intensive dry season at an increasing distance to Belém. According to local agronomists[24], this imposes constraints on the cultivation of intensive cash-crops, such as black pepper and passion fruit, and on some annual crop rotations. Mean annual temperature lies at about 25°C and seldom falls below 22°C. The average annual precipitation amounts to 2400-2700 mm and the annual sunshine duration lies between 2200-2400 hours (Denich 1989).

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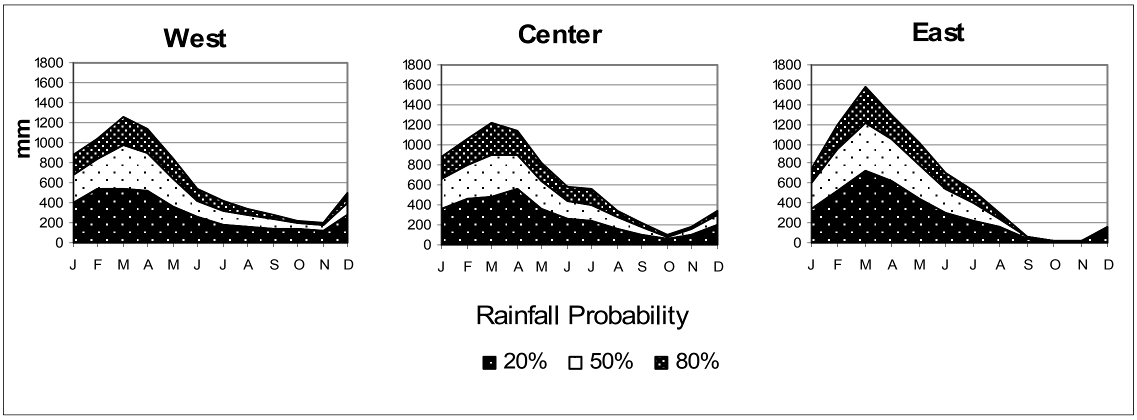
[24] Personal communication (2003): EMBRAPA, EMATER Bragança.



Source: Embrapa CPATU

Figure 4.2: Monthly rainfall probability and distribution

Soils

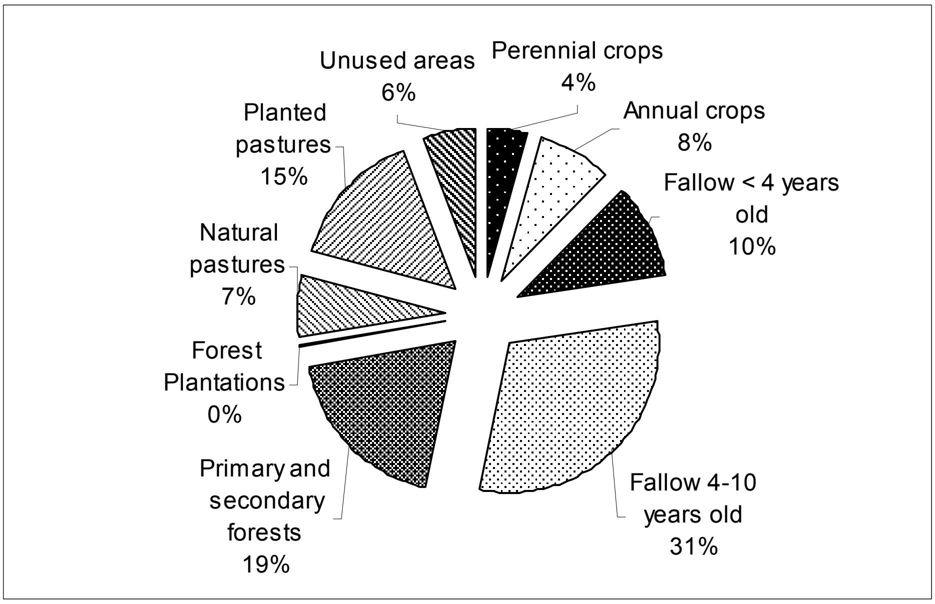
One third of the Zona Bragantina is covered by highly weathered marine limestone-sand-clay sediments with patches of very high limestone content east of Igarapé-Açu (Sioli 1968, Denich 1989). Most soils can be classified as Oxisols and Ultisols with a low nutrient content, a cation exchange capacity below 16 mval/100g, a rather low ph and high aluminum concentration. At the plot level, spots of rather unproductive sands exist, but in general soils can be classified homogenous and with good physical properties (Vieira et al. 1967, and Embrapa personal communication 2004). Local differences in soil productivity are, therefore, a result of the land use history rather than a function of the soil type.

For the most part, the region is relatively flat, which makes water erosion a problem of secondary importance. Conditions for agriculture change radically in the region's few flood plains (*varzeas*), which is why this study concentrates on the *terra firme*, i.e. areas with a lower ground water table that are not flooded during the rainy season.

Land Cover, Land Use and Agricultural Production

Land cover and vegetation is treated here together with land use and agricultural production, because the regions natural vegetation, an evergreen to semi-deciduous tropical rainforest, has practically been replaced by forest like secondary vegetation, and agricultural crops (figure 4.3). Primary forests are typically limited to riparian areas, which are protected by law. Nevertheless, about 60% of the land cover is made up by secondary vegetation of different ages, showing that it is part of the fallow based agricultural production system.

In 1996/7, 75% of planted pastures were found on farms larger than 100 ha, whereas 76% of annual and perennial crops grew on smallholdings (IBGE 1998). Typical annual crops that serve for both home consumption and commercialization are cassava and beans. Corn is a common intercrop and mainly used for home consumption and as animal feed. Passion fruit, black pepper, coco nut, and oranges are widespread perennial cash crops on smallholder farms.



Source: IBGE Agricultural Census 1995/6

Figure 4.3: Land cover and land use in the Zona Bragantina in 1995/6

According to the agricultural census 1995/6, the value of agricultural production in the Zona Bragantina amounts up to 12.8% of the total agricultural value produced in the state of Pará. The two micro-regions Castanhal and Bragantina, however, differed considerably in terms of the average value of production per establishment. While farms in the micro-region Castanhal had an average annual output of R$/farm 14042 ranking third among Pará's 22 micro-regions, farms in the neighboring Bragantina micro-region ranked at place 15 with on average R$/farm 4539.

4.2 Historical Background

Most authors agree that the colonization of the Bragantina region was driven by the huge increase in demand for labor during the rubber boom towards the second half of the 19th century (Egler 1961, Penteado 1967, Santos 1980, de Oliveira 1983). Yet, it was not so much the search for rubber itself, but the need to supply the urban center with food and firewood, that led to the official promotion of settlements around 1875 (Santos 1980). Most settlers came from the drought plagued north-east, although considerable efforts were made to attract European immigrants, such that about 17% of roughly 10000 settlers in 1902 were foreigners (Penteado 1967).

The first colonization effort in the Bragatina, however, was unanimously judged a failure, for many colonists had abandoned the settlements by the beginning of the 20th century leaving to Belém, back to the northeast or into other areas of the Amazon. The economic downturn following the rubber boom and the poor infrastructure in the Bragantina region had made many agricultural activities unprofitable. However, the completion of the railroad connecting Belém to the easternmost district Bragança in 1908, slowly heralded another phase of economic development in the region (Cruz 1953).

According to Sawyer (1979) and Costa (1989) the increasing demand from the urban center in combination with the free distribution of land to settlers, led to a 4% average annual increase in population between 1916 and 1940. By 1940 one third of agricultural establishments in the state Pará, were located in the Bragantina region and the neighboring costal zone Salgado. Apart from cotton, grains, and pulses, cassava presented the most important production activities with 72% marketable surplus. Yet, Sawyer (1979) mentions the rapid decrease in the production of nutrient demanding crops, such as beans, rice, and corn, which he attributes to a loss of soil fertility as a result of the dominant slash-and-burn practice. Apart from agricultural products, fire wood and charcoal continued to be an important commercial commodity and contributed to continuous deforestation. Already in 1950, only 13% of the area on agricultural establishments was covered by primary forests, which have continued to disappear until today.

Hurtienne (1988) concludes that it was the gradual switch from purely annual to more intensive mixed cropping systems including perennial cash crops, e.g. black pepper that allowed balancing ecological degradation against the increasing population density.

4.3 Agriculture beyond Deforestation

In the 1960ies, alerted by the almost complete removal of primary forest cover, some authors predicted an ecological collapse as a necessary consequence of the massive human intervention in the natural ecosystem of the Bragantina (Egler 1961, Penteado

1967, Sioli 1973)[25]. But, as mentioned before, agriculture continues sustaining smallholder livelihoods until today. A brief excursion to the development of research in tropical ecology can help to explain this apparent contradiction.

The classical literature of tropical ecology stressed the high stability, albeit low resilience of tropical moist forest ecosystems (Weischet 1980, Sioli 1984, Reichholf 1990, Odum 1991). It was argued that the combination of high temperature, year-round high rainfall, and solar radiation with poor chemical soil properties and a flat root system restricts nutrient recycling to the vegetation and the topsoil layer. Thus, the large scale substitution of forest covers with agricultural crops or pastures was expected to lead to a break down of water and nutrient cycles in a relatively short period of time (Jordan 1985, Odum 1991). Ecological, and more specifically soil degradation, was therefore considered the main obstacle to agricultural activities in most areas of the Amazon.

Yet, soil degradation in tropical ecosystems is a multifaceted process that involves a complex interplay of physical and chemical soil characteristics with soil organic matter, vegetation cover and land preparation. As Jordan shows in 1989, the immediate productivity decline in the second and third cropping cycle after forest clearing is mainly due to decreased phosphorous availability in combination with increasing soil acidity. As ashes from burning biomass increase the soil ph, long fallows and short cropping periods represent a means to stabilizing yield levels even without external inputs. Long-term trials with continuous cropping and fertilization in the Peruvian Amazon have shown that soil compactation, pest attacks, and micronutrient availability put limits on continuous agriculture without fallow periods Jordan (1985). More recent experiences at the Trans-Amazon highway, however, indicate that the careful combination of organic fertilization, green manuring, and weed control can stabilize and even increase corn yields in continuous cropping systems with mechanical soil preparation (Schmitz 2002).

At a first glance, the problems of large agricultural settlement projects, such as at the Transamazônica and in Rondônia seemed to confirm the classical hypothesis of low

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[25] The discussion in this and the following section draws heavily on an unpublished analytical review by Hurtienne (1998).

ecosystem resilience; as yields rapidly declined, large and degraded areas were abandoned a few years after colonization. But, as Smith (1982) and Moran (1981) note, poor planning, lacking output markets, failing input and credit markets, and weak extension programs were important contributing factors, apart from ecological limitations at least during the initial phase of settlement. While yields declined, the lack of markets, infrastructure, and knowledge has contributed to the low returns to soil conservation and high input agriculture.

The experiences in old colonization regions and the increasing recognition of other than purely ecological criteria spurred research efforts that led to a change of paradigms in the tropical ecology literature. Climatic zones in the Amazon differ considerably in terms of rainfall distribution, vegetation and soil types. Nepstad et al. (1994) were among the first who analyzed the important role of deep-rooting tree-species on abandoned pastures in the eastern Brazilian Amazon. This type of vegetation recycles nutrients and water from depths of more than 8 m and was found to be especially common in areas that are exposed to dry seasons, such as the northeast of Pará. Based on satellite images these areas were estimated to cover roughly 36% of the Amazon region. During the 1990, the SHIFT-project could then confirm that the secondary vegetation in the Bragantina, although degraded through continuous agricultural use, fulfills several important ecological and agronomic functions (Denich 1989, Hölscher 1994, Vieira 1996, Baar 1997, Wiesemüller 1999, Sommer et al. 2000):

- Nutrient and water recycling from deep soil layers
- Water nutrient and soil organic matter pool
- Erosion control
- Above and below ground carbon sequestration
- Suppression of weeds and diseases
- Biodiversity conservation

For the rural population it also represents the only source of firewood for cassava flour processing, charcoal, and other extraction products, and thus, contributes to household income (Hedden-Dunkorst et. al 2003).

The experience of the Bragantina shows that forms of agricultural use exist that can, under certain socio-economic and ecological circumstances, maintain soil fertility and rural welfare over several decades. Nonetheless, the SHIFT project's investigations have also shown that both modern and traditional agricultural technologies can contribute to the degradation of secondary vegetation and soils in the Bragantina (Baar 1997, Wiesemüller 1999, Sommer 2000). For example, shortening fallow periods in the slash-and-burn system reduces fallow re-growth capacity and tree species diversity. This has given rise to concerns regarding the long-term sustainability of the traditional slash-and-burn system that is practiced by smallholders in the area (Denich 1996, Vielhauer et al. 1998). These concerns were basically driven by two assumptions: first, ecological degradation increases over time, and second, farmers' land use decisions and technology choices do not fully account for its future costs.

Based on the cross-section data of the household survey, the average fallow period on smallholdings in the Zona Bragantina appears to be longer than previously assumed[26] (table 4.1) and differences between farmers from different income groups are not statistically significant.

Table 4.1: Average fallow period of different cropping activities

Crop type	Area (ha)		Average fallow age before planting (years)		N
Beans	1.1	(1.1)	6.5	(5.5)	33
Beans + cassava	1.3	(2.2)	8.9	(7.8)	32
Cassava	2.0	(3.3)	8.9	(5.7)	177
Cassava + other annuals	1.2	(1.2)	9.7	(7.3)	124
Intensive perennials	1.0	(1.2)	8.3	(5.7)	93
Extensive perennials	1.0	(2.4)	8.3	(7.1)	66

Figures in parentheses are standard deviations
Source: SHIFT/NAEA field survey 2002/3

Little empirical evidence exists with regard to the temporal dimension and the economic costs of ecological degradation on smallholdings in the Bragantina. Data from three agricultural censuses for the districts of the sampling frame shows that the average share of fallow per farm has reduced from 70% to 58% between 1980 and 1995. However, the reduction from 1980 to 1985 was faster than from 1985 to 1995 and especially in the western part of the Bragantina it was accompanied by an increase in old secondary vegetation since 1985 (figure 4.4). Quite likely the latter can be attributed to agricultural intensification in the form of continuous annual crop and increased labor intensive perennial crop production that reduced the need to repeated conversion of fallow vegetation.

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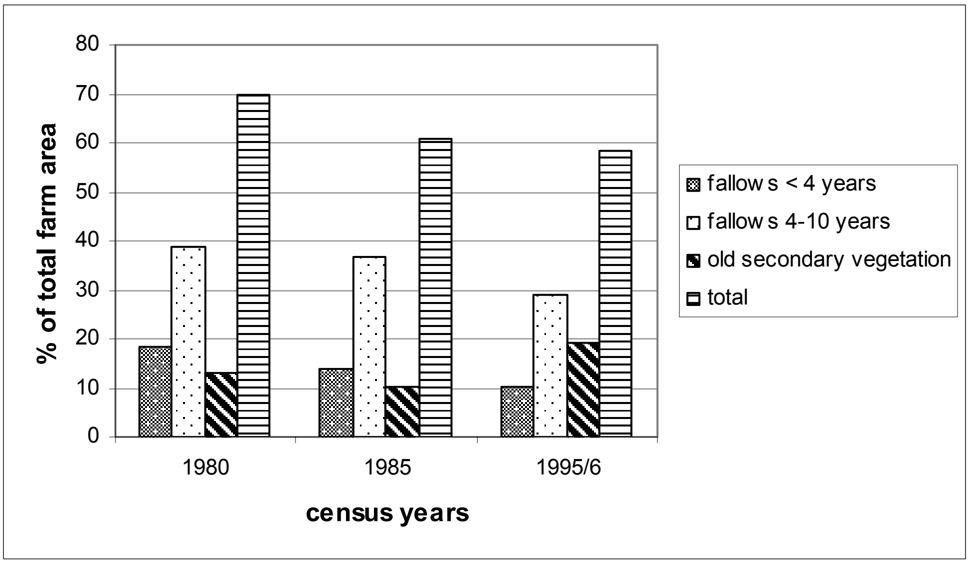
[26] Denich et al. (2004): 3-7 years.



Source: IBGE agricultural census (1980, 1985, 1995/6)

Figure 4.4: Share of secondary vegetation on farmed land in the study area (1980-1995/6)

Also recall interviews with 25 representative farmers from the three survey districts confirmed a reduction of the average age of fallow per farm between 1997 and 2003. Whether this is an involuntary consequence of economic hardship or a rational response to a changing economic environment remains to be answered. Meanwhile, even rational economic decisions involve unknown consequences especially in the presence of technological change. Fallow re-growth, for example, depends primarily on the vegetative reproduction of roots from woody tree species, which are practically removed through mechanical land preparation and intensive perennial production. Consequently, switching from slash-and-burn with fallows to conventional mechanization is an irreversible decision at least in the medium term. Experiences in Castanhal have shown that weeding demand in mechanized systems more than doubles apart from the additional costs of fertilizers and agrochemicals[27]. Hence, eliminating the fallow system involves important trade-offs at the farm level that will be further investigated using the bio-economic model.

4.4 Farm-Household Characteristics

Despite the cultural homogeneity of the study region, farm-households differ considerably in terms of wealth and resource endowment. Local experts suggested that many of these differences follow a gradient from west to east, such that

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[27] EMATER Castanhal personal communication, farmer interviews in Castanhal and Igarapé-Açu.

households in the easternmost survey district have lower incomes and employ more traditional production technologies and land use strategies.

Table 4.2 confirms this hypothesis by presenting farm-household characteristics on the basis of household per capita income quintiles. Low income households are concentrated in Bragança (east) and high income households in Castanhal (west). The wealth index[28] follows this distributional pattern suggesting that income, as measured in the survey year, correctly reflects the distribution of physical and financial resource wealth in the study region. The index was estimated for household and agricultural assets and provides some insight on the types of technologies employed by farmers in different income quintiles. Low income households in the eastern Bragantina are less endowed with capital intensive agricultural equipment, such as chain saws, motorized processing plants, pulverizers for pesticide application, planting devices, agricultural buildings or even tractors.

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[28] Standardized index based on household durables. See Appendix 1 for calculation and interpretation.

Table 4.2: Farm-household characteristics

	1. Quartile	2. Quartile	3. Quartile	4. Quartile	Means	Census	Gini
Total per capita income	***285***	***792***	***1651***	***7599***	***2585***		*0.66*
Agricultural per capita income							
Crop production (R$/year)	158	500	1083	4844	1649		
Livestock production (R$/year)	11	-8	24	1944	495		
Total agricultural production (R$/year)	169	493	1107	6788	2143	863	
Share of commercialized production value (%)	46	60	63	73	60		
Off-farm per capita income (R$/year)							
Non agricultural off-farm employment	49	103	166	342	165		
Remittances	4	6	9	8	7		
School grants	10	8	7	5	7		
Old age grants	33	173	334	427	241		
Agricultural off-farm employment	21	10	28	29	22		
Physical endowment							
Total farm land (ha)	17.4	19.6	15.8	31.9	21.2	15.0	0.53
Old fallows in % of farm land (average age)	13.6 (12)	14.4 (13)	14.2 (15)	19.6 (19)	15.4 (17)		
Young fallows in % of farm land (average age)	46.1 (5)	41.8 (5)	32.2 (5)	36.8 (6)	39.3 (6)		
Cropland (ha)	2.4	3.1	3.4	6.7	3.9	3.5	
Soil quality	2.24	2.05	2.13	2.09	2.29		
Wealth index (agricultural assets)	-0.91	-0.42	0.06	1.28	0.00		
Wealth index (household assets)	-1.43	-0.04	0.15	1.33	0.00		
Labor use							
Familiy labor (adult equivalent)	3.4	3.0	2.9	2.7	3.0	3.5	
Hired labor (man days year^{-1})	29	40	47	115	63		
Social and political capital							
Members in farmers' organizations (%)	38	56	66	81	60		
Household composition							
Familiy size	7.5	6.3	6.2	4.6	6.2	4.7	
Number of childern (< 16 years)	3.9	2.3	2.1	1.4	2.4		
Education of the head of the household (years)	2.5	2.9	2.3	4.0	2.9		
Location							
HHs Castanhal (west)	11	19	24	36	90		
HHs Igarapé-Açu (center)	18	25	25	22	90		
HHs Bragança (east)	39	24	18	10	91		
Total N	68	68	67	68	271		

Source: SHIFT/NAEA survey 2002/3, IBGE agricultural census 1995/6

Agriculture is the most important income source in all quartiles; however, old age grants and off-farm employment contribute on average 20% to household per capita income. Although the largest farms are found in the highest per capita income quartile, farm size is not necessarily coupled to household wealth. Especially in the eastern part of the Zona Bragantina, low income households can be comparatively well endowed with land, but poor in terms of household durables, such as electronic devices, furniture, and sanitary infrastructure.

Family size and education on the other hand, are not clearly related to household wealth, although the highest income group stands out in terms of a small family and a relatively high degree of education.

Wealthier farmers in the western part of the study area, hire a considerable share of labor, whereas in the eastern part farming is primarily done by the family. The degree of organization among farmers also falls with the per capita income level. Although most of the farmer associations were formed with the single objective to apply for rural credits, this shows that wealthier farmers in the western Bragantina have been more successful in organizing themselves. On average farmers in all income groups, except for the lowest, commercialize more than half of their total value of production. Hence, on average smallholder agriculture is rather commercially than subsistence oriented.

Based on the available environmental indicators, i.e. soil quality and fallow vegetation per farm, poorer farmers do not seem to be exploiting their natural resources more than wealthier ones. Comparison of mean tests did not show significant differences of soil quality between per capita income quartiles, and only a slight difference in the relative endowment with fallow vegetation (table 1 in appendix 2). Wealthier farmers seem to conserve old secondary vegetation more than farmers in low income groups.

4.5 Local Governments and Organizations

The organizational landscape in the Bragantina is very diverse and its examination helps to explain part of the diversity found in agriculture. The state of Pará is divided into 143 administrational units or municipalities. The approval of the federal constitution in 1988 initiated an ample and ongoing process of decentralization that has enabled the districts to raise certain types of taxes and execute budgetary autonomy in many areas, such as education and health, public transport, urban planning, and agriculture.

This has important implications for rural development in terms of the ability of the local government to invest into rural infrastructure and extension. For example, the urbanized district Castanhal has higher tax incomes than Igarapé-Açu, which has only a small urban center. Hence it is not surprising that the Agricultural Secretariat (SAGRIm)[29] of Castanhal offers professional extension and machine services to local farmers' organizations, while the SAGRIm in Igarapé-Açu can hardly afford transport

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[29] The SAGRI exists independently at the state-level (SAGRI) and at the municipality level (SAGRIm).

for the secretary.[30] It is easy to see the link here to a finding of Toni and Kaimowitz (2003), who found densely populated and urbanized Amazonian municipalities more successful in establishing an institutional infrastructure for environmental management. In line with their findings, Castanhal, at its short distance to the state capital Belém, is a more attractive location for agro-industry, extension head-quarters, NGO's, and commercial enterprises than the less urbanized municipalities farther east.

Equally important for the agricultural sector, but certainly related to the issue above, is the competence and orientation of the local government. This includes the qualification of administrative staff as well as the willingness to cooperate with local and regional trade unions and cooperatives, extension offices, and other government institutions. For example: Since 1996, the nationwide local infrastructure program Pronaf Infraestrutura requires municipalities to establish a Municipal Council for Sustainable Rural Development (CMDRS), involving government and non-government organizations, and elaborate a rural development plan (PMDRS) as a minimum requirement to obtain funds for rural infrastructure projects. Until 2002, this had effectively been accomplished by only one of the survey districts.

Apart from the weak performance of some municipal governments, peculation and corruption is a rather widespread phenomenon. In April 2003, the newspaper *O Liberal* reported that only in the cases brought to court during the first four month of the year a total of R$12.5 million was found to be peculated by municipal governments[31]. Three of the accused districts were part of the study region.

As a consequence, farmers' opinions of government services are quite mixed. A survey evaluating the social capital at the community and municipality level in Igarapé-Açu found government organizations among the least trusted[32].

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[30] Personal communication of the respective Agricultural Secretaries.

[31] O Liberal 01.06.2003 p.8: 'Prefeitos enriquecem. Municípios ficam pobres.'

[32] Kahwage, C. : Instituições e Organismos locais e suas influências na configuração do Capital Social Local. Presentation at the Final Project Seminar: SIMPÓSIO INOVAÇÃO E DIFUSÃO TECNOLÓGICA PARA AGRICULTURA FAMILIAR SUSTENTÁVEL. Experiências com Agricultura Sem Queima. Resultados e Implicações do Projeto SHIFT sócio - economia. 28/29 de Julho - Belém/Pará.

Table 4.3 gives an overview of agriculture related organizations and their degree of activity in the three survey districts. The Pará wide rural extension service EMATER has local offices in almost all municipalities. However, due to severe budget constraints in 2001/2 the activities in most districts, again with the exception of Castanhal, were limited to those farmers who applied for credit in the FNO[33] regime.

Table 4.3: Agriculture related organizations and their activity in the survey districts

Organization	Castanhal	Igarapé-Açu	Bragança
EMATER	+++	+	+/-
Local SAGRI (machine service, extension)	+++	+/-	+
State SAGRI (extension, research)	+	n.a.	n.a.
Cooperatives (production + commercialization)	++	+	n.a.
Farmers' Associations (credit + lobby)	++	+	+
STR (insurance + lobby)	+/-	+	++
Agroindustry	+++	+	n.a.
University / agricultural school	++	++	+
International projects	+	+	+
EMBRAPA	+	+	+

Source: SHIFT /NAEA field survey 2003

Farmers' trade unions (STRs) are organized at the district, regional and national level and, apart from being involved in the rural pension and health security system, accomplish an influential lobby function. Many internationally financed programs, such as PPG-7[34] and PRORENDA RURAL[35], put the local trade unions in charge of groundwork and local project administration.

Farmer's cooperatives are mostly related to specific production activities, such as passion fruit in the case of Igarapé-Açu or honey production in Ourém.

By the middle of the 90ies many farmers started to organize in community associations, which was a precondition for eligibility in the smallholder credit system of the FNO (see also next section).

4.6 Infrastructure and Markets

The **transportation** infrastructure in the Bragantina is relatively advanced if compared to agricultural frontier areas. Most communities are attended around the year by private bus lines at least twice a week up to several times per day. Travel time by bus to an urban center, with product and input markets as well as health centers,

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[33] Constitutional Fund for Financing the Northern Region.

[34] Pilot Program for the Protection of the Brazilian Rainforest (PPG7).

[35] Program for the economic support of low-income groups in rural areas.

range from four hours to 10 minutes and a one way ticket costs between 10% and 30% of the daily wage per person or per 60 kg bag of produce. However, remote communities may be cut off from the transport system during several months after the breakdown of bridges, which happened in two of the 22 survey communities between January and April 2003. Traveling from the easternmost district Bragança to the capital Belém takes between three and four hours and costs roughly 120% of the daily wage.

Commercialization systems differ remarkably between the three survey districts as shown in table 4.4.

Table 4.4: Percentage of commercialized production value by type of marketing channel

	Castanhal	Igarapé-Açu	Bragança	Total
Local traders	8.1	7.3	12.1	8.3
Wholesalers	14.8	12.5	21.1	14.8
Sold at public market	15.5	10.4	25	15.1
Mobile traders	59.6	68.9	35.9	59.8
Others	2	0.9	5.9	2
N	90	90	91	271

Source: SHIFT/NAEA field survey 2002/3

Depending on product type and location farmers sell their produce to mobile traders, local and regional wholesalers, or directly to the consumer at public market places. The latter is more common in Castanhal and Bragança, where urban demand is higher than in Igarapé-Açu. A farmers' market place run by a smallholder association exists only in Castanhal. Higher prices on this market have spurred engagement in horticulture and on-farm processing activities that are rather uncommon among smallholders in the other two districts. Farm-gate commercialization to mobile traders is more common in Castanhal and Igarapé-Açu, where traders are also involved in covering up-front investments for short-cycle perennials, such as passion fruit. Mobile traders may be independent or contracted by wholesalers and depending on product and season, the marketing margins lie between 5 and 30% (Santana and Amin 2002, Wander 1998, Guimarães 2000).

Agro-industry, e.g. cassava flour, juice and fruit concentrate, and palm oil production is more common in the western part of the study areas and farmers eventually sell standing crops depending on the relative price of raw and processed products (see also section 4.11).

Consequently, **off-farm labor opportunities** are rather scarce in the east of the Bragantina. In the majority of the communities in Bragança, and Igarapé-Açu each household owns a plot or works on his own account on somebody else's land. The less diverse the production systems within a community the more difficult is hiring labor during peak seasons or selling off labor when it is idle. Small and traditional communities, therefore, employ labor exchange systems that allow for seasonal agricultural activities to be accomplished in a shorter period of time. In Castanhal, on the contrary, many communities have developed into small agro-villages. Only 20% of roughly 200 households in Bacabal, for instance, are actual farm-households, whereas the remaining 80% are permanent or temporary rural workers[36].

Rural credit started to be a real option for smallholders with the introduction of the FNO in 1990. In section 4.11 more will be said about the impact of the FNO and related problems. On average 18% of the surveyed farmers obtained a commercial credit between 2000 and 2002. The great majority of the credits were FNO smallholder credits with very low interest rates between 4 and 5 percent. Micro-credits are rather uncommon, but can be obtained from the *Banco do Povo* in some districts.

4.7 Technological Change, Productivity and Agricultural Intensification

Since the early colonization of the Bragantina, the dominant production technology among smallholders was slash-and-burn. Technological change took place in the form of gradually switching between crop types of more or less commercial character depending on a combination of factors, such as relative prices, the productivity impact of pests and diseases, and soil degradation (Penteado 1967). During the 1940ies and 1950ies, mallow and tobacco were among the more important cash crops especially in the eastern part of the study area, not at least due to the more adapted ecological conditions for tobacco in the *varzea* areas. Chemical fertilizers were hardly used until the introduction of black pepper in the western part of the Bragantina by 1950. Cotton experienced a moderate boom starting in the early 1970ties, but almost disappeared in the 1990ies. This and similar experiences (see also figure 4.6 in section 4.11) show

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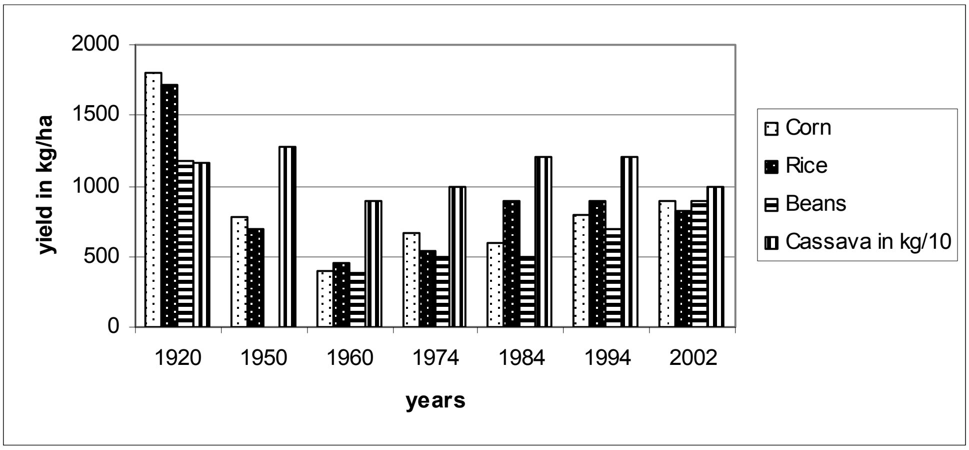
[36] Funasa and SHIFT/NAEA field data.

that farmers react quite flexible with regard to new income opportunities in the form of cash crops.

Figure 4.5 shows the development of yields of annual cash and consumption crops as reported in various data sources for the municipality Igarapé-Açu. It shows that yields dropped off sharply with the elimination of primary forest and the population increase during the second colonization phase. However, yields of the more nutrient demanding crops, e.g. rice, beans, and corn gradually increased from 1960 until 2002, most probably with the introduction of chemical fertilizers and agrochemicals and, to some extend, mechanical land preparation.



Source: Denich (1996) and IBGE PAM 1974-2002

Figure 4.5: Average yield levels in Igarapé-Açu (1920-2002)

As such, the data base does not generally support the assumption of continuously decreasing yields due to soil degradation that has been put forward by several early and recent observers (Egler 1961, Penteado 1967, Sá et al. 1998). The census suggests that yields for crops, such as cassava and pepper are higher on average sized smallholdings than on larger farms, whereas yields on very small farms are considerably lower than the average. The SHIFT/NAEA survey data partly confirms this at least at the lower end (figure 1 in appendix 2). In addition it shows that soil quality increases with farm size, which suggests that lower yields on small farms are rather due to soil degradation as a consequence of shortened fallow periods and low input use, whereas decreasing returns to scale eventually let yields drop off as farm and plot size increase beyond the average of the study area.

However, the average regional yield level of the most common annual crop cassava (figure 4.5), lies between 50% and 70% lower than the yields obtained on-farm with moderate fertilizer application in Castanhal (table 4.5) and on experiment stations[37]. This brings up the question why the majority of smallholders does not use fertilizers to increase output per hectare of cassava. This question deserves more attention, since fertilizer is an essential ingredient of most fire-free alternative land preparation technologies (e.g. conventional mechanization, mechanical mulching, direct planting, and even some sorts of agro-forestry systems).

4.7.1 The Use of Fertilizers

Economists usually expect fertilizer use to be determined by factors, such as relative prices, relative scarcity of production factors, and risk preferences. Relative prices are quite obviously in favor of using fertilizer for almost all common crops in the region (table 5.5 section 5.1.2 initial conditions) and due to the permanent nature of cassava flower production, temporary liquidity constraints are at least not as binding as in the case of more seasonal agricultural activities in other parts of the Amazon. Labor is relatively abundant, hence pointing to a preference for labor intensive rather than cash intensive technologies. Land can be a limiting factor depending on the degree of dependence on slash-and-burn and in areas close to urban centers. Production and market risk can, in fact, be an important determinant of fertilizer use, which will be explored further using the bio-economic model. Nevertheless, factors, such as asymmetric information and traditions, also play an important role in determining technology use at the farm level.

A Probit regression model was specified to assess how farm level factors and regional fixed effects affect the probability of fertilizer use (see results in appendix 3). While table 4.5 below reveals that cassava yields go hand in hand with income gradients, the Probit estimates suggest that net per capita income and other farm-household characteristics are rather unimportant when it comes to fertilizer use. Instead, fertilizer use seems to depend on the type of crop that is to be planted.

Planting watermelons, cucumbers, or beans increases the probability of using fertilizer by 40 - 77%. Apart from perennial cash crops, that are also fertilized, these crops are among the most nutrient demanding annual cash and consumption crops and would

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[37] In most fertilizer experiments, moderate fertilizer applications resulted in cassava root yields around 30 t/ha (de Souza Cruz 1982, de Oliveira et al. 1986, Kato 1998, SEPEF without date)

practically not produce without fertilizers (Kato 1998, SEPEF without date, Kato et al. 1999). Cassava and corn on the other hand produce low but sufficient yields without external nutrient supply, and hence, represent a minimum risk alternative to activities that require up-front cash outlays. In addition, modern methods used in cassava production are not equally well know in all municipalities, as they require a more sophisticated management or even mechanical land preparation. The Probit estimates partly confirm this by showing that the probability of fertilizer use drops off in the districts east of Castanhal although beans are frequently fertilized even in Bragança.

Both technological change and agricultural intensification, however, are obvious trends at least in the western part of the Bragantina (table 4.5), where EMBRAPA, EMATER, and the local governments are actively promoting conventional mechanization and intensive perennials through research and extension programs and machine services. Moreover, the proximity of two large urban centers and the presence of agro-industry provide the essential economic environment for farmers to engage in such activities.

Table 4.5: Determinants of agricultural productivity by district

	Castanhal	Igarapé-Açu	Bragança	Mean
Net per capita income (R$/year)	4874	1890	1009	2585
Average yield cassava roots (t/ha)	21.7 (12.7)	17.9 (5.1)	10.4 (6)	16.2 (11.7)
Fertilizer use (% of farmers)	90	86	43	73
Tractor use (% of farmers)	76	49	18	47
Extension contact (% of farmers)	44	17	11	24
Tractors per agricultural establishment*	0.26	0.09	0.01	0.05
Ploughs per agricultural establishment*	0.15	0.03	0.01	0.03
Soil quality indicator	2.27	2.01	2.57	2.29

Figures in parentheses are standard deviations

** IBGE agricultural census 1995/6*

Source: SHIFT/NAEA field survey 2002/3, IBGE

No empirical evidence exists as to how shifting from fallow based to continuous agriculture will impact on long term soil productivity and production costs, and hence, environmental and economic sustainability. Preliminary experiences have shown that soil conservation measures, such as organic fertilization to maintain soil organic matter and no-tillage techniques are necessary in regular intervals to maintain soil fertility and avoid subsoil compactation (EMATER 2003 personal communication). Since animal husbandry is rather uncommon in the area, access to large quantities of organic fertilizers is likely to represent a limiting factor.

4.8 Local and Regional Externalities

Most agricultural activities come with costs and benefits that are external to the individual farmer. In many, not only developing, countries this has increasingly been used as an argument for government intervention. Environmental taxes or subsidies are the most prominent examples of policy instruments that can be used to internalize external costs and benefits (Pearce 1995).

In the case of slash-and-burn agriculture in the Amazon it was made clear that the use of fire for land preparation produces exclusively negative externalities, such as health costs due to smoke and accidents, material damage caused by accidental fires, greenhouse gas emissions, and smoke related interruptions of air traffic (Nepstad et al. 1999). These externalities, however, were observed primarily at agricultural frontiers and do not necessarily apply to an old colonization region, such as the Bragantina, where the average amount of burned biomass per ha is much lower than at the primary forest margins. In addition to interviews with local health centers and government institutions, the SHIFT-socioeconomia 2001/2 survey covered the household level health and other costs related to the use of fire for land preparation (table 4.6). Health centers and government institutions in the survey districts do not keep record of fire related health or material damages and respondents unanimously rated them of minor importance.

Table 4.6: Average annual costs related to the use of fire for land preparation by per capita income quartiles

	1. Quartile	2. Quartile	3. Quartile	4. Quartile	Mean
Average annual costs of accidental fires from land preparation (R$/farm)	17 (56)	21 (101)	93 (395)	70 (392)	50 (284)
Annual smoke related health costs (R$/HH)					0.76 (6.6)

Figures in parentheses are standard deviations
Source: SHIFT/NAEA field survey 2002/3

The table confirms that smoke related health problems are rather negligible. Material damages caused by accidental fires, on the other hand, are considerable even if compared to estimates from agricultural frontiers – R$200 per year for smallholders, R$500 year for medium size farms (IBAMA 2004[38]). A possible explanation for the variation between income groups is that the average value of standing crops is higher in upper income groups - due to capital intensive perennial plantations -, and such is

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[38] http://www2.ibama.gov.br/proarco/apresentacao.htm

the potential damage caused by accidental fires. Most of these damages occur in perennial plantations and fallow vegetation and the claimants are rarely compensated.

That damages on public property can be quite significant as well shows an investment by the Northern Electricity Company in 1999. The company invested R$700,000 to clear the surroundings of power lines on the main roads that connect the states Maranhão and Pará in order to prevent damages from accidental fires[39].

4.9 Global Concerns: Biodiversity and Carbon

Two concerns that are frequently brought up with respect to agriculture in the tropics are its negative impact on biodiversity and carbon sequestration. No attempts have been made to systematically measure the social value of biodiversity in the Bragantina, but it can be expected to be very low if compared to areas of virgin forest that attract national and international tourism and private companies.

As with the degradation of soils and secondary vegetation, the costs related to reduced on-farm biodiversity are borne by the farmer, and hence, of a private nature. Examples of such costs would be a reduced benefit from extracting medicinal plants, honey, and construction materials among others. Theoretically, one could expect negative externalities of a biodiversity loss at a regional scale. Several studies have shown that pressure from insects and pests increase as a consequence of biodiversity losses in agricultural landscapes (Altieri 1999). Experts attribute the severe pest problems in pepper and passion fruit plantations in the 80ies and 90ies respectively, to the expansion of plantations using the same crop varieties[40].

A comparison of biodiversity indices from data collected by Baar (1997) shows that it is rather not species diversity that suffers from repeated conversion of fallow to agricultural land, but the quality of species composition. After repeated cultivation and mechanized land preparation, Baar found significantly less woody species than in less disturbed areas, which reduces the economic value of conserving these areas for future extraction activities. Nevertheless, some younger development projects have shown that the private value of the species diversity in old stands of secondary

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[39] http://www.nuca.ie.ufrj.br

[40] Personal Communication (Embrapa 2003)

vegetation can be increased substantially, by introducing fallow management and on-farm processing activities[41]. In the district Ourém southeast of the survey district Igarapé-Açu, honey production in old fallows has become an important income generating activity[42]. Markets for such products are likely to develop together with urban centers, which makes an increasing value of high quality and species rich fallow stands a likely future scenario.

Currently carbon has virtually no opportunity cost in the study area. As with biodiversity, shortening fallow periods, intensive perennials, and continuous agriculture lead to considerable losses of both above and below ground carbon. Sommer et al. (2000) found that living roots under annual crops and fallows contain between 5 and 16 t/ha of carbon. Under intensive perennials this was reduced to 1 – 2 t/ha. Moreover, the roots of 40 year old secondary vegetation can accumulate up to 37.5% more carbon than the roots of primary forests in the same region. Above ground carbon ranges between 1.6 t/ha in pure annual stands, 37.5 t/ha in 10-year old fallows, and up to 160 t/ha in primary forests (Denich et al. 2000). The dominant type of technological change, i.e. intensive perennials and conventional mechanization, will therefore likely contribute to further depletion of both below and above carbon stocks in the study area. Even in the absence of a functioning carbon market this is one of the most powerful arguments of promoters of 'carbon friendly' technologies, such as mechanical mulching and agro-forestry systems. While only the latter has chances to become be eligible under the clean development mechanism, both are currently being tested in the nationwide Program Proambiente, an upcoming credit program to compensate farmers for environmental services.

4.10 Risk and Uncertainty in the Bragantina

In line with Hardaker et al. (1997a) risk is defined here as uncertain consequence, while *uncertainty* is understood as imperfect knowledge. The sources of risk in agriculture are manifold, e.g.:

1. Production risk (e.g. weather, pests)
2. Price/market risk (e.g. fluctuations)
3. Institutional risk (e.g. government action or non-action)

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[41] Personal communication project 'Manejo de Capoeira' Cifor/Embrapa

[42] Personal communication Honey Producer Association Ourém.

4. Human/personal risk (e.g. accidents, diseases)

While risk is certainly prevalent in all economies, rural and poor societies in tropical countries are affected most by risk from the sources mentioned above (Binswanger and McIntire 1987). Depending on local environmental and institutional conditions, farmers have therefore developed a variety of risk coping strategies that are summarized in table 4.7 based on Fafchamps (2003).

Table 4.7: Risk coping strategies

Strategy	Forms of the Strategy
Reducing exposure to shocks	1. Selecting and modifying environments 2. Specialization 3. Diversification 4. Self-sufficiency 5. Flexibility
Saving and liquidating assets	1. Seeking wage income 2. Liquidating productive assets 3. Reducing consumption to keep productive assets 4. Labor bonding and debt peonage 5. Precautionary saving 6. Borrowing
Risk sharing	1. Households, groups, associations 2. Gifts, transfers (e.g. Remittances) 3. Insurance 4. Interlinking and patronage 5. Contracts (e.g. With merchants)

Source: Fafchamps (2003)

That some of these strategies appear contradicting owes to the diversity of ecological, institutional and socio-economic conditions in which farm-households operate. Drought-plagued west-African farmers might rather specialize in drought resistant millet production, while farmers in the Bragantina prefer to diversify production to buffer against market price fluctuation or unexpected inundations after heavy rainfalls.

25 representative farmers from five groups (see classification section 5.1) have been interviewed with respect to the main sources of risk in agriculture and results are summarized in table 4.8.

Table 4.8: Sources of risk for farmers in the Bragantina

	Respondents	Share of sample in (%)*	Loss in % of total value of damaged asset	Frequency of occurrence in 10 years
Pests (crops)	19	70	25 - 100	2 - 10
Excess rain	10	37	10 - 100	1 - 5
Drought (dry season)	7	26	5 - 100	1 - 3
Disease (human)	3	11	10 - 100	1 - 3
Underestimated input prices	2	7	30 - 100	2 - 5
Overestimated output prices	21	78	5 - 75	1 - 10
Transport problems	4	15	10 - 30	1
Labor shortage	3	11	50 - 100	1 - 2
Accidental fire	4	15	30 - 100	1 - 10

	Respondents	Share of sample in (%)*	Loss in % of total value of damaged asset	Frequency of occurrence in 10 years
Property right issues	0	0	0	0
Theft	9	33	3 - 100	1 - 10
N	27			

*several sources of risk could be named by one respondent

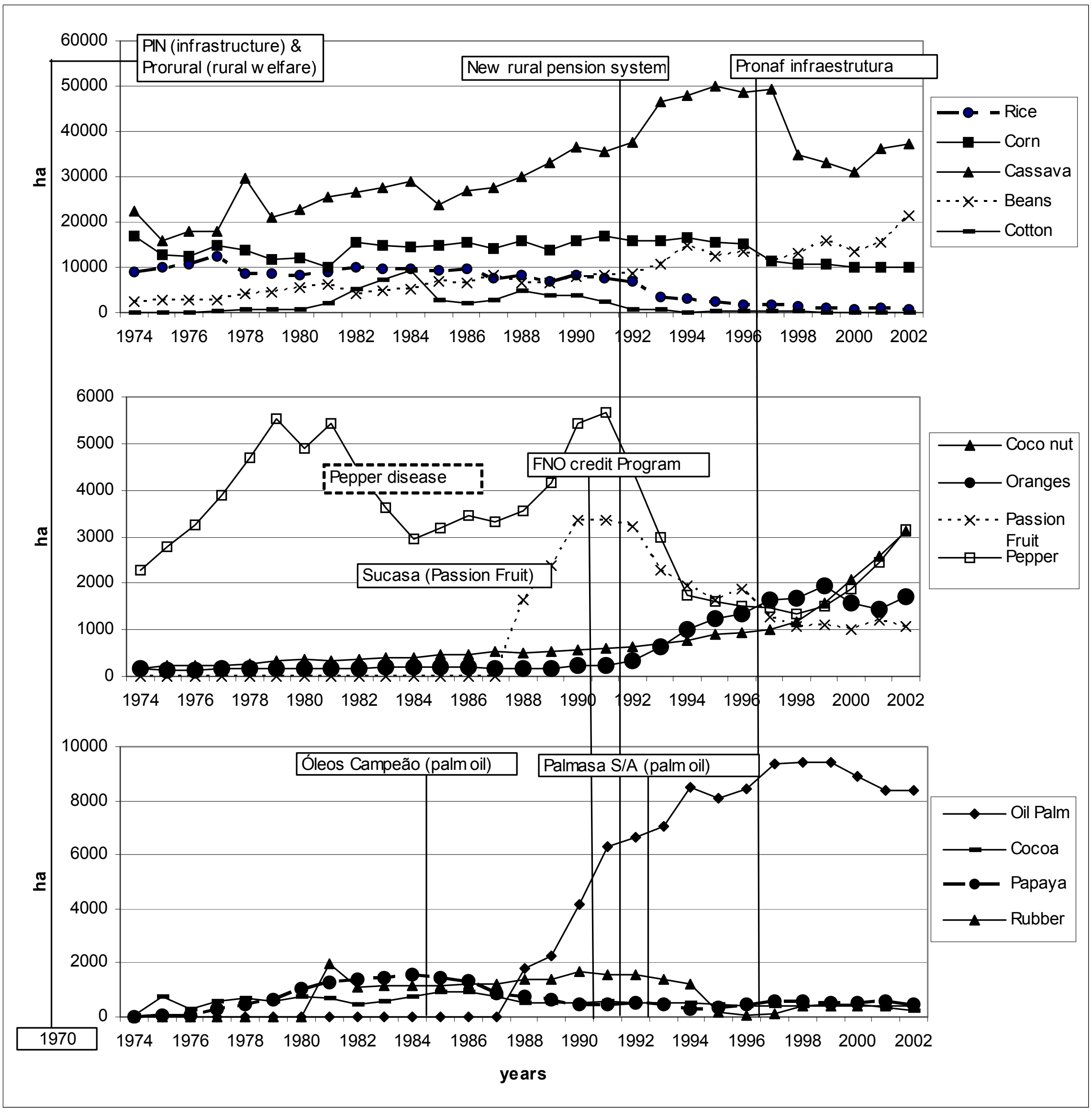
Source: SHIFT/NAEA field survey 2003

The table shows that market and production risks due to pests, heavy rainfalls, and unexpected droughts are by far the most important risk sources named by representative farmers. In the case of production risk, total losses are not uncommon. Especially, producers of pepper and water melons reported theft as a significant unpredictable annual loss, while predominantly farmers from remote communities mentioned losses due to transport problems. More recently in the western part of the Bragantina, labor shortages seem to be a problem for bean producers who cannot offer wage rates as high as commercial pepper plantations. For many other traditional activities labor may become even scarcer, albeit not as unexpected as in this case.

Risk coping strategies from all three categories (table 4.7) can be observed in the Bragantina. Farmers reported to abandon land that is prone to inundations after heavy rainfall, early harvest and the application of agro-chemicals is another strategy to avoid pest induced losses. However, no effective treatment exists for the widespread cassava root diseases *(Phytophtora spp., Pythium scleroteichum).* To reduce market risks some farmers sell standing crops in the form of pre-harvest contracts, i.e. hedging. Siegmund-Schulze (2002) finds that cattle holders use the liquidation of livestock in times of economic hardship, for investments, and to cover medical treatments. In many communities quite strong family bands exist that may serve as a safety net and off-farm employment is an important strategy to stabilize family income. Probably as a consequence of extremely high inflation rates during the nineties, precautionary saving is rather uncommon.

4.11 Agricultural and Environmental Policies: A Timeline

The idea of this section is to assess, to what extent policies at the national, and regional level had an impact on smallholder agriculture in the study area. Land use is used here to characterize the impact, partly for being one of the few indicators for which reliable longitudinal data exists, but mainly because it reflects farmers' decisions with regard to production and technology choice. Not all types of policy instruments show a direct impact on land use patterns, but they are considered here to give an overview of government action with respect to the smallholder environment.



Source: IBGE PAM 1974 - 2002

Figure 4.6: Development of the acreage under typical crops in response to direct and indirect policy action

4.11.1 Credit and the Environment

Figure 4.6 shows that governmental initiatives to encourage plantations of mainly perennial cash-crops, e.g. cacao, rubber, and to some extent papaya, had their repercussions in the Bragantina during the 70ies and 80ies. Yet, the introduction of the FNO in 1990 was the first government program that had an obvious impact on smallholder production patterns by providing low interest loans to smallholders. In practice, albeit not officially, credits were linked to specific production activities that differed between municipalities depending on the interests of local governments and the orientation of EMATER. Oranges, coco-nuts, passion fruit, beans, and also pepper were the main cultures, for which projects were approved especially during the early phase of the FNO. Unfortunately, due to the poor adaptation of the standard project design to the conditions of smallholders, many projects failed and in 1998, 25% of 32% of the credit holders that were declared incapable of debt service were smallholders. Continuous adaptations of the FNO led to a gradual improvement of the system (Tura and Costa 2000).

The impact of the environmental policies of the 80ies and 90ies on land use in the Bragantina is ambiguous. The law 7.754 was passed in 1989 and protects riparian vegetation of small and large river streams. In the survey, farmers seemed to be quite aware of the regulation and satellite images confirm that it is widely applied (Wickel 2004, Puig 2005). The “legal reserve”, on the other hand, was changed several times since 1965 and today requires 50% of the forest cover per agricultural establishment to be preserved. As Michelotti (2004) notes, the re-definition of the legal reserve in 2001 remains unclear about the status of different stages of secondary vegetation within the regulation. Even though farmers in the Bragantina are generally unaware of the legal reserve, the current situation rather encourages the regular conversion of secondary vegetation in order to reduce the probability of it being declared as legal reserve.

A more recent and ambitious credit program is Proambiente, which goes back to an initiative of social movements and proposes a credit system that compensates farmers for environmental services, such as carbon sequestration, biodiversity conservation, river stream protection etc. The program is currently being tested in 12 pioneer areas in the Amazon region. The program is innovative in pursuing both environmental and socio-economic objectives and collaborates with governmental and non-governmental organizations to offer better quality technical assistance.

4.11.2 Agro-industry and Market Integration

Unlike the moderate impact of price policies and environmental standards, world market developments (black pepper, passion fruit), regional integration (passion fruit), and local agro-industry projects (palm oil, passion fruit and other fruits) seemed to have had considerable impact on land use in the Bragantina. According to Wander

(1998), the subsidy-induced foundation of two important local juice production units[43] in the middle of the 80ies in combination with high product prices, initiated the 'passion fruit boom' in the beginning of the 90ies. However, due to the incidence of severe pests and price fluctuations, just as in the case of pepper during the 80ies, the area under passion fruit reduced by 68% between 1990 and 2002 (figure 4.6) (Santana and Amin 2002, Duarte et al. 2003). Commercial palm oil production started in 1984 with the foundation of *Óleos Campeão*, in Santa Izabel do Pará close to Belém and was expanded when the *Agroindustrial Palmasa S/A* was founded 1992 in Igarapé-Açu (Homma without date). As shown in figure 4.6, oil palm production increased from almost zero to more than 9000 ha in 10 years, mainly due to the formation of commercial plantations. However, about 30% of the total area under oil palms in 1996/7 was planted on farms smaller than 100 ha (IBGE 1995/6).

Relatively little larger-scale agro-industry exists for the production of annual crop derivates. The main factories for cassava flour processing are located in and close to Castanhal. As a result, farmers in Bragança depend on small labor intensive individual and community processing plants with a very low degree of mechanization. The gradual decrease of the area under rice is often attributed to soil degradation, but might just as well be the consequence of an increased inter-regional competition and a more commercial orientation of smallholders in the area.[44]

4.11.3 Welfare Policies

The milestones of policy action to counteract rural poverty were the Program of Assistance to the Rural Worker (PRORURAL) in 1972 and promulgation of the *New Constitution* in 1988. PRORURAL introduced a monthly old age payment for registered rural workers of 50% of the legal minimum salary, which was augmented to 100% in 1991. In an analysis of the impact of the pension system after 1991 in the district Igarapé-Açu, Schwartzer (2000) found that the rural pension system contributed to improve the position of the district in a ranking of the human development index. Table 4.2 in section 4.4 also confirms that rural pensions represent an important income source.

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[43] Sucasa and Amafrutas both in relative proximity to Belém.

[44] According to farmer interviews, especially upland rice was primarily used for home consumption. Also corn is seldom sold, but used to feed poultry for home consumption.

An additional result of the New Constitution was an improvement of the health system at the district level (Toni and Kaimowitz 2003 and interviews with local government officials). The impact of welfare policies on land use change is difficult to separate from other effects. It might, however, have contributed to alleviating seasonal liquidity constraints for short term investments and to the reduced cultivation of annual subsistence crops, e.g. rice.

In addition to active policies to combat poverty, a series of tax exclusion exists in favor of smallholder agriculture. The land tax, for example, does not apply to landholdings smaller than 100 ha in the western Amazon and smaller than 50 ha in the eastern Amazon[45]. Moreover, special regulations and exclusions are in place regarding the payment of income and value added tax for low income groups and small businesses.

4.11.4 Infrastructure

During the 1970ies, policy action of the military regime practically neglected the old Amazonian colonization areas and focused on promoting development of agriculture and extractivism the western Amazon and the south of Pará through fiscal incentives and infrastructure programs, for example, through the Program of National Integration (PIN) in 1970. However, the Bragantina benefited in the form of an improved road network that connected Belém to the neighbor state Maranhão and the south of Pará and may have greatly influenced regional trade patterns (Homma 2003).

The National Program for the Strengthening of Smallholder Agriculture (PRONAF) has been invoked in the end of the 90ies as a counterbalancing measure in the process of decentralization. It provides funds and credit for local infrastructure, small agro-industry, and technical assistance projects. Access to the program is restricted to municipalities that establish a minimum institutional infrastructure that guaranties farmer participation in the elaboration of project proposals etc.

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[45] Ministério da Fazenda: http://www.fazenda.gov.br/

4.11.5 Price Policies and Risk Reduction

Since poverty makes farm-households more vulnerable to risks, policy action that targets poverty alleviation can be expected to reduce vulnerability and risk averse behavior. Nevertheless, policy instruments exist to target risk and uncertainty more explicitly, for example, insurances and minimum prices. Schlieper (1997) provides an international review of crop insurance schemes that have been used mainly to protect against hazards in crop production. The *Programa de Garantia da Atividade Agropecuária* (PROAGRO) in 1973, was the first crop insurance for Brazilian farmers. However, it is rather unknown among Amazonian smallholders since it applies only to investments that have been financed through agricultural credits. Nonetheless, in 2003, 295000 Brazilian farmers contracted PROAGRO and the introduction of harvest monitoring and agricultural zoning systems in 1996 has contributed to lifting it out of deficit[46].

The agricultural ministry defines minimum prices for the main staple crops on an annual basis, but they usually lie far below market prices (e.g. 26% of the market price for cassava flour and 46% of the market price for beans in 2002), which makes them rather ineffective as an uncertainty reducing policy instrument at least in the northeast of Pará.

4.11.6 International Community

Finally, many internationally financed development projects with socio-economic and ecological objectives are carried out in the Brazilian Amazon. Prominent examples are the demonstration projects (PDA) under the patronage of the Pilot Program for Protection of the Brazilian Rainforest (PPG7). Since 1995, 194 PDAs have been approved corresponding to a total investment of U$ 33.6 million[47].

4.12 Summary and Preliminary Conclusions

Despite the peculiarities in the colonization history of the Bragantina, some parallels can be drawn to what has been called the "frontier cycle" in attempts to characterize development at the recent agricultural frontiers of the Amazon: A high, often policy

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[46] www.agricultura.com.br/proagro

[47] www.mma.gov.br

induced, migration inflow is followed by substantial land abandonment a few years after settlement. Reasons for abandonment are manifold, e.g. soil fertility decline, poor infrastructure and property rights as well as agricultural expertise, lacking markets, economic hardship, and increasing opportunity costs as land prices rise or new frontiers open up, etc. Consequently, many colonists move on to new agricultural frontiers, to urban centers and sometimes back to their origin. But with the general economic and institutional development also agriculture develops albeit often at a slower pace.

A peculiarity of the Bragantina case is that large-scale commercial agriculture in the Amazon was not as economically attractive during the first half of the 20th century as in the second half due to a variety of reasons. Large infrastructure projects and subsidized credit schemes after 1970 made it easier for investors to engage in commercial agriculture or cattle production and to encroach on smallholder land. By that time, the Bragantina had already developed a smallholder sector with relatively strong social structures and economic ties to the urban center Belém. This has certainly contributed to the persistence of smallholder agriculture in the study area. Of course, not all of today's agricultural frontiers in the Amazon are likely to embark on a similar development pathways. If large-scale commercial agriculture and cattle-holdings continue to benefit from positive economic incentives, high rates of land turn over on agricultural frontiers will make the development of stable smallholder communities more difficult. Nevertheless, urban centers in the western Amazon and at the *Transamazônica* will increasingly provide markets for the range of products produced on smallholder farms.

Apart from socio-economic determinants, findings in tropical ecology have shown that conditions for agriculture are quite heterogeneous in the Amazon. The deep root system of the semi-deciduous vegetation in the north-east of Pará and the absence of steep slopes make soils in the Bragantina less prone to nutrient leaching, run-off, and water erosion than in many other parts of the Amazon. This and the dominance of diverse small-scale production systems with relatively long fallow periods and a considerable share of labor intensive perennial cash crops have helped to maintain agricultural productivity at reasonable levels even in the absence of primary forest resources.

Apart from providing a background for the quantitative analysis below, this chapter contains information that fills the general conceptual framework (section 1.3) with specific content. We have seen that *asset components of poverty* are quite unevenly distributed in the Bragantina. Nevertheless, the distribution follows a certain pattern that shows parallels to the theory of transport cost and development put forward by von Thünen. Farm-households in the western Bragantina and close to the state capital are generally better endowed with human resources, except for family labor. Also on and off-farm resources, community owned resources and political capital seem to be more abundant in some communities in Castanhal and Igarapé-Açu than in Bragança. Abundance of land and secondary vegetation is not necessarily coupled to wealth nor do richer farmers cultivate a greater proportion of their land than low income households. Instead, wealthier households seem to employ more intensive production technologies, such as mechanical land preparation, chemical fertilizer and agrochemicals, which leads to a higher agricultural income per ha of cultivated land. That the average soil quality appeared slightly better on less intensively cultivated soils in the eastern Bragantina supports the findings of natural scientists with regard to the degradation of soils in the study area (see also table 5.4 in section 5.1.1). Since this degradation is primarily driven by technological change, choosing appropriate technologies and strategies for their dissemination represents a key policy issue for the quantitative analysis below.

Communities in Castanhal are comparatively large and many dwellers are rural workers, not land owners. Hence, the labor market in Castanhal can react more flexible to seasonal peaks apart from facing a more diverse set of agricultural activities with comparatively diverse off-farm labor opportunities. This and many other *conditioning factors* of poverty and environment links, e.g. village and district level infrastructure and technology access, are doubtless more in favor of agricultural growth than in the eastern part of the Bragantina. This applies also for investments that contribute to the conservation of soils and/or secondary vegetation, such as chemical and organic fertilizers, agroforestry, and no-tillage continuous agriculture. Most farmers in the eastern Bragantina do not have access to the knowledge and technology required for these investments and may, in addition, face more serious seasonal labor and liquidity constraints. Hence, conservation investment poverty is a problem that cannot exclusively be tackled by general policies to alleviate cash constraints, such as credit schemes, pensions, and school grants. Production and market risk play an important role in that regard as they have shown to introduce a great deal of uncertainty into production planning. Model simulations should therefore explore the implications of risk averse behavior for land use decisions and technology choice in the face of regional differences in market and technology access.

Finally, land use change in the Bragantina has shown to be more influenced by regional economic integration, infrastructure improvements, and agro-industry development, than through direct agricultural policies, such as minimum prices. Agro-industry development was often policy induced and increased the demand for labor intensive perennials, such as passion fruit.

The FNO credit scheme induced many smallholders to engage in perennial crop operations, but due to a lack of experience in the early stage, many projects failed leaving farmers unworthy of future credits. The example of Castanhal, although a special case due to its high degree of urbanization, indicates that district level efforts to induce technological change, e.g. tractor service provision, can be quite promising if accompanied by professional agricultural extension.

5. Model Inputs

This chapter presents the results of the preparatory analytical steps involved in setting up the bio-economic model. Section 5.1 summarizes the farm-household classification result and how it was used to specify the initial conditions of the baseline model. Section 5.2 describes the most important production activities and the underlying technologies. Lastly, section 5.3 provides an overview of risk parameters included in the model.

5.1 Farm Types

5.1.1 Principal Component (PCA) and Cluster Analysis (CA): Results

Ten variables were selected for the farm-household classification and are briefly summarized in table 5.1. The variables were chosen in order to capture the heterogeneity of farm-households in terms of agricultural intensification, i.e. land and technology use (1.-4.), soil degradation/quality (5.), 'exogenous' factors[48] (6.,7.), and household wealth (8.-10.).

Table 5.1: Farm-household classification variables

	Variables & abbreviations	Mean	sd	Description
1.	Land use intensity (RT)	30.2	17.5	Ruthenberg factor (% of time a piece of land is under cultivation in one fallow cycle); indicator of intensification of land use
2.	% of area under perennials (PERM)	19.9	28.3	Indicator of capital intensive investment and diversification
3.	Tractor use (TRAC)	0.7	1.1	Frequency of tractor use between 1997 and 2002; indicator of intensification
4.	Area under crops (CROPLAND)	3.7	3.6	Operational scale (ha)
5.	Average soil fertility (AVBIOMAS)	2.3	0.7	Average biomass (g) of rice seedlings from bio-assay; soil fertility indicator
6.	Distance to urban center (DIST)	42.2	25.1	Duration of one way trip (min) indicator of transport/transaction costs
7.	Dry season intensity (PRECIP)	54.2	31.4	Average monthly precipitation (mm) during the four driest months; indicator ecological heterogeneity
8.	Value of residence buildings (VALRES)	4002.7	5496.6	Estimated value of household residence building (R$); indicator of wealth
9.	Off-farm income (OFFINC)	2368.4	2589.8	Total non-farm income (R$); indicator of dependence on farming
10	Average household education level (EDUMEAN)	4.7	2.1	Average years of school attendance of household members (years); indicator of wealth and education

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[48] In this context exogenous refers to factors that are exogenous to the farmer's decisions in the short run. In the long run it can be expected that some of these factors become endogenous, e.g. through intra-regional migration.

Highly correlated variables for the PCA were identified from the correlation matrix in appendix 1. The test scores for the standardized (Zscore) selected variables are presented in table 5.2:

Table 5.2: PCA test scores

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.719
Bartlett's Test of Sphericity	Approx. Chi-Square	176.522
	df	10
	Sig.	0.000

The Bartlett's Test is highly significant and the KMO measure indicates a "middling" sampling adequacy, i.e. the sample is suited for PCA. The rotated component matrix is the main outcome of the PCA showing the factor loadings of the classification variables (table 5.3).

Table 5.3: PCA output

Rotated Component Matrix

	Component	
	1	2
Zscore: SMEAN(RT)	.842	-4.00E-02
Zscore: SMEAN(PERM)	.607	.286
Zscore: SMEAN(TRAC)	.641	.263
Zscore: SMEAN(VALRES)	.355	.728
Zscore: SMEAN(EDUMEAN)	3.642E-02	.881

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

The table reveals that the factor loadings, i.e. correlations of components and variables, are high for the first three variables and component 1 and for the last two variables and component 2. The two components can therefore be interpreted as "degree of intensification" (component 1) and "life style" (component 2). The PCA was validated by running the full analysis for two equally large sub-samples, which shows that the solution is robust and the interpretation valid (appendix 4).

The factor scores entered the CA together with the remaining five variables. The combination of hierarchical and k-means CA resulted in five representative household groups that are characterized in table 5.4. Again, the validation of the CA was done by running the analysis for two sub-samples and is presented together with a comparison of means test in appendix 4.

Table 5.4: Group means and test scores for farm-household classification variables*

	N	Land use intensity	% of area under perennials	Tractor use	Value of residence bulidings	Average HH education level	Off-farm income	Area under crops	Soil fertility	Distance to market	Dry season intensity
Mean Group 1	*32*	42	38.0	1.4	10284	7.2	4437	3.7	2.1	37	70
Mean Group 2	*139*	33	25.5	0.9	3366	4.3	569	3.1	2.1	37	74
Mean Group 3	*11*	32	32.3	1.8	9936	6.3	869	16.5	2.5	39	77
Mean Group 4	*59*	23	1.2	0.2	2045	4.6	822	2.9	2.3	31	12
Mean Group 5	*27*	19	6.0	0.1	1696	3.1	656	3.4	3.3	104	14
					Cluster Analysis Test Scores F-Value Group (Fg) and F-Value Variables (Fv)						
F-Value Group 1		*0.8*	*1.4*	*1.0*	*3.1*	*1.4*	*2.6*	*0.4*	*0.2*	*0.3*	*0.6*
F-Value Group 2		*1.1*	*1.1*	*1.0*	*0.4*	*0.5*	*0.2*	*0.4*	*0.6*	*0.3*	*0.1*
F-Value Group 3		*1.7*	*1.3*	*2.3*	*1.3*	*0.3*	*0.9*	*1.8*	*0.8*	*0.1*	*0.5*
F-Value Group 4		*0.5*	*0.1*	*0.4*	*0.3*	*1.0*	*0.4*	*0.4*	*1.3*	*0.3*	*0.0*
F-Value Group 5		*0.2*	*0.2*	*0.1*	*0.5*	*0.5*	*0.6*	*0.4*	*0.7*	*0.5*	*0.1*
F-Value Variables		*[*	*1. Component: 20.7*	*]*	*[2. Component: 27.5]*		*48.3*	*84.0*	*22.5*	*144.7*	*332.0*
					Cluster Characterization t-Values						
t-Value Group 1		*0.7*	*0.6*	*0.6*	*1.1*	*1.2*	*1.4*	*0.0*	*-0.2*	*-0.2*	*0.5*
t-Value Group 2		*0.2*	*0.2*	*0.1*	*-0.1*	*-0.2*	*-0.2*	*-0.2*	*-0.3*	*-0.2*	*0.6*
t-Value Group 3		*0.1*	*0.4*	*1.0*	*1.1*	*0.8*	*-0.2*	*3.6*	*0.2*	*-0.1*	*0.7*
t-Value Group 4		*-0.4*	*-0.7*	*-0.5*	*-0.4*	*-0.1*	*-0.1*	*-0.2*	*0.0*	*-0.5*	*-1.3*
t-Value Group 5		*-0.6*	*-0.5*	*-0.6*	*-0.4*	*-0.7*	*-0.2*	*-0.1*	*1.4*	*2.5*	*-1.3*

*See standard deviations and mean difference test results at the end of appendix 4

The table shows that five groups have been identified that differ most in wealth, intensification related variables, dry season intensity, and distance to markets. Groups 4 and 5 exclusively comprise farm-households from the biggest and easternmost municipality of the study area. This district has been colonized several decades earlier than the rest of the Zona Bragantina and production systems are still rather traditional. Moreover, precipitation during the dry season drops to almost zero, thus representing unfavorable conditions for some cash crops and water demanding traditional crop rotations. Apart from the lack of appropriate extension service, credit opportunities, and technology access, this is one of the reasons for the low share of perennial cash crops cultivated on farms in group 4 and 5. Most indicators show group 5 to be the least wealthy and intensified out of the five farm types.

Group 3, although too small to be called “representative”, comprises a group of technologically advanced farmers from the westernmost part of the study area. These farms are considerably larger than the average small-scale farm resulting in an operational scale five times higher than on average. Most of the farmers in this group are entrepreneurs and contributed valuable information for the simulation of technological change.

Group 2 represents the typical small-scale farm in the middle and western part of the study area, which, in many aspects, compares to the picture provided by the 1995/6 Agricultural Census for farms between 10 and 50 ha.

Group 1 stands out in terms of off-farm income and wealth as well as capital intensive and/or labor saving intensification strategies. Many of these households have one or two family members receiving pensions or working outside agriculture. They are often located close to urban centers and have access to technology and credits.

The Groups 1,2,4, and 5 can be called representative farm types and capture the main aspects of the heterogeneity in the study region that are considered relevant in the context of the research objectives.

5.1.2 Initial Conditions

Initial conditions are the starting values of the model in year zero, i.e. the survey year 2002/3. Not all values can be directly derived from the farm-household survey, which is why additional group interviews have been conducted to specify, for example, upper limits to hired and sold labor (table 5.5). Some prices differ between farm-household groups due to quality differences or market related factors, for instance, cassava flour processing is traditionally different in Bragança than in most other districts. Apart from being slightly more time consuming, the traditional process results in higher quality flour.

Family labor units available to farming were determined according to the following scale based on labor-type/activity data and interviews with trade union leaders:

adult male = 1, adult female = 0.5 (to account for reproductive activities, such as cooking, child care, etc.), boy/girl in school age = 0.4 (to account for school/study and respective commuting time).

Table 5.5: Initial conditions for four representative farm-households

Characteristics	Group I	Group II	Group IV	Group V
Farm-household level				
Farmsize	23.5	15.30	14.9	35.1
Initial Cash in R$**	1500	650	400	300
Storage Capacity for Grains and Pulses in kg*	3000	2000	2000	2000
Adult Male Family Workers	1	1	1	1
Other Family Workers (adult male equivalents)*	1	1.35	1.5	1.5
Old secondary vegetation in ha	4.0	2.8	1.6	7.5
Young secondary vegetation in ha	8.1	6.9	6.4	15.6
Initial Perenials in ha	1.4	0.8	~0	0.2
Initial annuals in ha	2.3	2.3	2.9	3.2
Maximum Hired Labor (man-days per month)*	40	35	25	15
Maximum Sold Family Labor (man-days per month)*	25	15	10	5
Transportation Costs per 100 kg of Produce in R$	3.5	3.5	3	4.5
Transportation Time per Round Trip in man-days*	0.5	0.6	0.4	1
Monthly Minimum Expenses in R$*	380	380	160	230
Input Prices per kg in R$				
Average Wage Rate per Day in R$	8.5	8.5	8.5	8.5
Fertilizer Price per kg in R$	1.1	1.1	1.1.	1.1
Product Prices per kg in R$				
Cassava flour	0.7	0.7	0.9	0.9
Beans	1	1	1.2	1.2
Corn	0.26	0.26	0.2	0.2
Passion Fruit	3	3		
Black Pepper	4.2	4.2	3.6	3.6
Agroforestry (Murici)	0.4	0.4	0.4	0.4
Charcoal	0.15	0.15	0.15	0.15
Sample share in %	12	51	22	10

* These values are assumptions based on information from individual farmers and group interviews.

**The model starts the agricultural year in October shortly after harvest of most perennial cash crops is cashed in.

Source: ZEF/NAEA/EMBRAPA field data, IBGE 2002

5.2 Production Activities and Technologies

Defining production activities for linear programming models always involves tradeoffs between the model size and the representation of reality. This is especially the case in multi-period models, as the number of single year activities is multiplied by the number of years. As a consequence, only the most frequently found activities are represented in the model. Moreover, not all technology levels are made available in the baseline, since access to machinery is restricted in many parts of the study area. Table 5.6 summarizes the available production activities and technology levels; “b” indicates the availability of the technology in the baseline run and “x” that it is optional. Including commercialization and additional model activities the model has 24045 variables and 10128 equations.

Table 5.6: Production activities in the bio-economic model

		Technology level				
Production activity	**Intensity levels per technology type**	**Slash & burn**	**Mechanical mulching**	**Conventional mech-anization**	**Traditional processing**	**Mechanized processing**
Cassava	2	b	x	x		
Cassava/beans	2	b	x	x		
Cassava/corn	2	b	x	x		
Beans	2	b		x		
Black pepper	1	b		x		
Passion fruit	2	b				
Extensive perennials	2	b				
Charcoal	1	b			b	
Livestock	2	b				
Cassava flour	1				b	x

Most emphasis was put on technological and agronomic alternatives of annual cropping activities, because the mulching technology developed by the SHIFT project has primarily been tested and proposed for annual crop production.

For the main activities and technologies investment analysis has been conducted prior to modeling (based on Gittinger 1985). The key parameters of the main production activities are presented in table 5.7.

Table 5.7: Production activity/technology investment analysis

	Production activities and technologies	**Average carbon: above-ground (t/ha)**	**Returns to land (private prices) (R$/ha)**	**Returns to labor (private prices) (R$/man-days)**	**Average labor requirements (man-days/ha/year)**
1.	Traditional annual/fallow	9.04	459 - 627	10.7 -11.1	30-36
2.	Mechanized Annuals	4.2	2982 - 3999	12.7 - 13.3	97.4 - 112
3.	Mulching Annual/fallow	10.6	(-708) - 124	7.6 - 9.2	53 - 60
4.	Secondary forest (20 y)	60.8	73	14.6	1.6
5.	Extensive perennials	20	307	9.6	58
6.	Black pepper/fallow	7.2	13627	17	148
7.	Passion fruit/fallow	10.5	11356	27	57
8.	Traditional Pasture/livestock	7.9	(-1825)	2.2	24

Source: SHIFT/NAEA field data 2002/3

All values in table 5.7 are based on an 18 year horizon including fallow periods (if indicated). Returns to land are activity net present values (NPV) using a 10% discount rate, while all labor is valued at the average wage rate. Returns to labor represent the wage rate necessary to setting the net present value to zero. All annual cropping activities include labor, equipment costs for cassava processing and all activities include marketing costs. Financial returns to annual cropping activities can differ considerably for all technologies depending on the crop mix and the application of fertilizer. The ranges shown for annual cropping activities refer to cassava mono-cropped (lower value) and cassava and beans intercropped (upper value). Cassava and corn intercropped lies within this range. Intercropping of corn and cassava is very common in the whole study area, while intercropping of beans and cassava is less common in the eastern part due to the intensive dry season. For the same reason, probably in combination with market factors, passion fruit and black pepper are hardly found in the eastern Bragantina.

Livestock turns out to be the least attractive production activity. Livestock and alternative pasture systems have been intensively studied by Siegmund-Schulze (2002), Hohnwald (2002), and Bornemann (2002). Especially Siegmund-Schulze finds that cattle-keeping is of a rather discontinuous nature mainly driven by liquidity reasons. In addition, returns to the scale of cattle keeping are certainly increasing as the average size of farms surveyed by Sigmund-Schulze is two to three times larger than the typical group II type of farm.

Extensive perennials can be individual plantations or combinations of tree crops. The system shown in table 5.7 is based on the returns to Murici[49] plantations that are often found in Igarapé-Açu, but the gross margin compares to plantations of Coco nuts or Oranges (IBGE (1995/6). Cost calculations for experimental agro-forestry systems (AFS) have been presented by (Prorenda 2002), however, the returns are unrealistically high as they are not based on observed sales but on assumed annual yields. In addition, the presented gross margins depend heavily on black pepper as a component in the AFS, which is assumed to produce without application of fertilizers.

5.2.1 Annuals

Comparing financial returns to alternative annual cropping technologies and perennial crops shows huge differences. The slash-and-burn technique and the two alternatives considered in the model, i.e. conventional mechanization (No. 2 in table 5.7) and mechanical mulching (No. 3 in table 5.7) will be characterized below.

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[49] Local berry type of tree fruit.

5.2.1.1 Slash & Burn

Slashing is done towards the dry season and is one of the most labor intensive activities for smallholders. On average 14 man-days are needed to slash one hectare of fallow vegetation of an average age of 11.7 years[50]. No significant correlation exists between age of fallow and slashing time. Roughly three to four additional days are necessary to burn, clean, and prepare the field for planting. Chemical fertilizers are only used if beans a part of the rotation. For the E-V model described in section 3.3.6.3, the result of the Monte Carlo simulations will be presented here as well.

5.2.1.2 Conventional Mechanization (Plowing)

Conventional mechanization involves the complete manual or mechanical removal of trees, tree stumps, and roots prior to land preparation. Most commonly the land is prepared using tractor pulled plows or harrows. Soil ph correction is necessary in regular intervals and included here through the application of lime. The system underlying the cost calculation in table 5.7 is more common in the western part of the Bragantina[51]. To reduce soil compactation and organic matter loss direct planting in combination with herbicides and organic fertilizer substitutes for mechanical land preparation in every second cropping cycle. The price of machine service (R$/ha 180), as charged by private contractors, is assumed here, although some districts offer subsidized machine service at 50% of this rate. Due to the exhaustion of soils in such a system it is assumed that 50% of the area under mechanical plowing has to be abandoned every year for rehabilitation.

Conventional mechanization appears to be most profitable at the first glance. However, these figures do not show the risk involved in engaging in continuous cropping. First, for most farmers it is not guarantied that tractor services are available when needed. Missing the optimal planting date can have negative yield impacts and once an area is mechanized it cannot easily be put back into the slash-and-burn cycle. Moreover, as mentioned before, it is not clear how continuous cropping will affect soil fertility in the long run. Assuming a 5 or 10% annual yield loss due to soil degradation, for instance, reduces the net present value of mechanized annuals from

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[50] Average of 355 surveyed fields weighted by field size.

[51] 2002/3 SHIFT/NAEA/EMBRAPA survey and EMATER personal communication.

R$3999 to R$1953 or R$260 respectively. This and the relatively high up front investments in the form of chemical fertilizer, lime, and machinery services put a limit to the adoption among smallholders. Since conventional mechanization is not readily available for all farmers, it is not an option in the model baseline.

5.2.1.3 Mechanical Mulching

Mechanical mulching is done using a tractor-driven bush chopper that converts fallows of up to 12 years (i.e. 20 – 150 t of fresh biomass, Denich et al. 2004) into a mulch layer. Other techniques were tested to convert fallow vegetation into mulch, but have turned out to be extremely labor intensive. Mulching has shown to improve various soil productivity characteristics, such as moisture, organic matter, weed pressure, but due to the high biological activity in tropical climates, most of the effects are limited to one or two cropping seasons (Thurston 1997, Sommer 2000). In addition, mulching, as an alternative to burning, avoids the immediate volatization of 96% of nitrogen, 47% of phosphorus, 76% of sulfur, and 35% of calcium apart from other nutrients (Hölscher 1994). Mulch has the effect of a plant nutrient reservoir that gradually releases nutrient instead of making them available at once as in the case of burning. This allows sustaining annual crop yields over two instead of one cropping seasons (Kato 1998). The decomposition of mulch is known to immobilize plant nutrients, but the process is complex and not fully understood. As a result, the yields of crops planted shortly after mulching are lower than after slash-and-burn, which is why mulching is recommended in combination with chemical fertilizers (Kato 1998, Bühnemann 1998).

The estimated on-farm profitability of mechanical mulching depends heavily on the underlying assumptions regarding the machine service costs, management, yield level, crop mix, and opportunity costs of capital, land, and labor. To date the empirical evidence is limited to experiences of individual farmers under experimental conditions.

Regarding the machine service costs, estimates by Michelotti (2002), Block (2004) and Bevilaqua (2004) range between R$/ha 490 (lowest value in Michelotti) and R$/ha 1178 (highest value in Bevilaqua) and Michelotti reports an observed range of R$/ha 266 to R$/ha 1071 depending on the amount of biomass per ha among other factors. Appendix 6 presents a calculation using the data from both studies that results in an average cost of R$/ha 936 and a range of R$/ha 807 to R$/h 984 depending on the amount of biomass. As in the case of conventional mechanization, mechanical mulching is not included in the baseline scenario.

5.2.2 Perennials

Perennial crop plantations can be established manually or with the help of a rented tractor for land preparation and stake setting, e.g. in the case of pepper and passion fruit. Mechanized perennials produce higher yields but require more fertilizers, pesticides and labor inputs than manually established plantations.

5.2.3 Pastures and Livestock Technologies

Two pasture and livestock activities have been specified based on farm-household data collected by Siegmund-Schulze (2002) in the study area. The two pasture management systems differ in maximum stocking rates, pasture life span, labor requirements for pasture management, and animal growth rates.

5.2.4 Monte Carlo Simulations: Expected Value and Variance Functions

Linear limited production functions were specified to further analyzing the determinants of fertilizer use intensity in an Expected Value – Variance (E-V) framework as described in section 3.3.6. The respective input parameters are shown in table 5.8.

Table 5.8: Input parameters for Monte Carlo simulations

	$\bar{y}$ max (kg/ha)	$\sigma\ y_{max}$ kg/ha	P uptake (a) kg/kg	N uptake (a) kg/kg
Cassava S&B + mulching	26604	6591	0.001[1]	
Cassava mechanized	32185	8574	0.001[1]	
Beans S&B	1256	275	0.026[2]	
Beans mechanized	1499	832	0.026[2]	
Black pepper traditional (y2 - y6)[5]	1513 - 3094	453 - 928		0.03[3]
Black pepper intensive (y2 - y6)[5]	1747 – 5826[4]	854 -1747		0.025[3]
Mobilized P (kg/hha) from soil beans (s) =	3.3	sd s = 0.99		
Mobilized P (kg/hha) from soil s&b (s) =	12.6	sd s = 4		
Mobilized P (kg/ha) from soil mechanized (s) =	6.69	sd s = 6.1		
Mobilized N (kg/ha) from soil (pepper) (s) =	20[3]	sd s = 3[3]		

[1] Rehm and Espig (1991)
[2] Kato (1998)
[3] parameterized based on Freire et al. (2002 and 1998)
[4] Freire et al. (1998)
[5] Yield increases with age as shown in Freire et al. (1998)
Primary sources: SHIFT/NAEA Baseline survey, plot survey and soil analysis

In the case of cassava and beans, maximum yields and standard deviations correspond to the average yield of the 4th quartile of yields observed for slash-and-burn and mechanization in the 2001/2 cropping season. For traditional pepper, the maximum yield and standard deviation correspond to the 4th quartile of maximum yield expectations formulated by farmers in the baseline survey. For intensive pepper the maximum yield was obtained from Freire et al. (1998), who studied commercial pepper plantations in the study region. The standard deviation was assumed to be 30% of the yield at each age. Freire et al. (1998 and 2002) have shown that the yield of pepper is primarily limited by the application of nitrogen. However, pepper as well as passion fruit production is far more complex than the production of annual staple crops. The combination and application timing of several types of organic and chemical fertilizers has a considerable impact on yields as well as on nitrogen use efficiency (a). For example, a plant nutritionist at Embrapa has analyzed the average fertilizer mix of smallholder pepper plantations as observed in the baseline survey (here ‘black pepper traditional’). It was found that the corresponding yields should be much higher as the observed ones if the fertilizer application timing and other management aspects would have been optimal. Hence, the difference between the ‘traditional’ and the ‘intensive’ pepper production activities lies mainly in the optimal application rates and timing, which also results in an improved nitrogen use efficiency a (see table 5.8). Unfortunately, no such empirical information exists with regard to passion fruit production and extensive perennials, which is why these production activities were implemented without fertilizer response functions.

A monte carlo simulation was performed using 1000 iterations and expected value and variance functions were estimated from the results (appendix 7). Several functional forms were tested and the best fit was obtained using the following:

$$E(Y) = a + bx + cx^2 + dx^3 \tag{46}$$

where

E(Y) is the expected yield, x is the amount of P_2O_5 *applied, a is a constant, and b,c, and d are linear quadratic and cubic coefficients respectively.*

$$V(Y) = \frac{a}{(1 + b\exp^{-cx})} + d \tag{47}$$

where

V(Y) is the yield variance, a/(1+b)+d = minimum variance at x=0, a+d = maximum variance.

In the E-V model E(Y) and V(Y) were linearized for each production activity using four model activities as described in section 3.3.4.

5.2.5 Cassava Processing

Two technologies for cassava processing are considered in the model, traditional and mechanized. Only the traditional option is available in the baseline. The two options differ in investment cost and labor requirements per kg of cassava flour that were derived from technical coefficient interviews (table 5.9).

Table 5.9: Cassava processing options

	Traditional	Mechanized
Man-days/100kg (male)	1.7	2
Man-days/100kg (female)	1.1	1.1
Investment cost R$/unit	500	15000

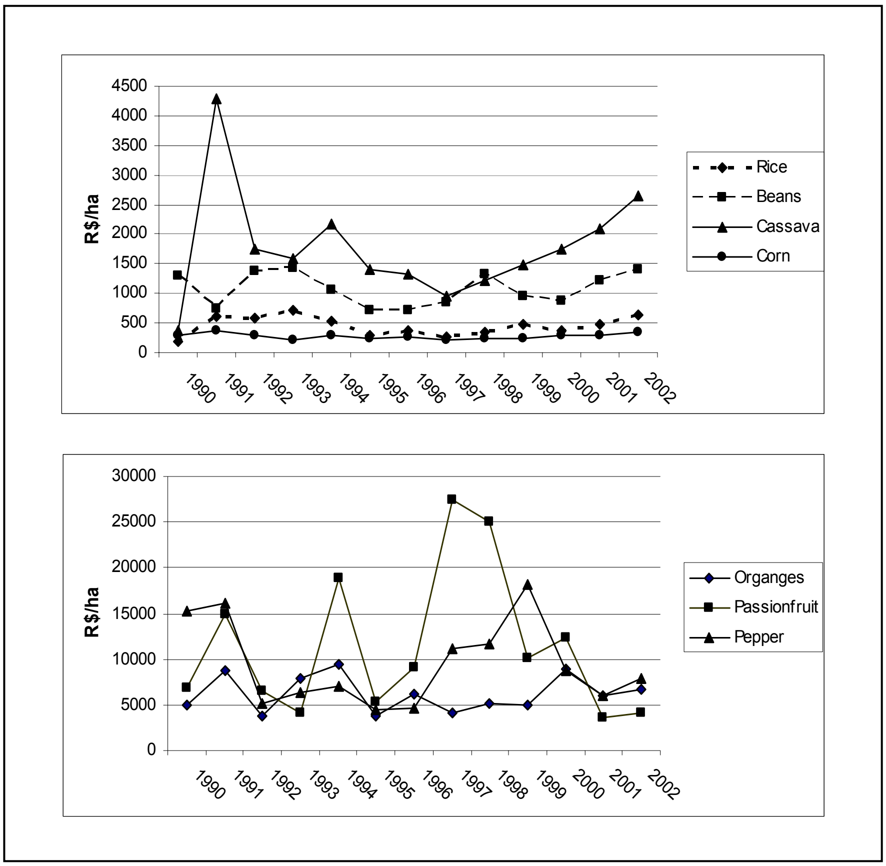
Source: SHIFT/NAEA field survey 2003

Cassava processing can be done throughout the year, because the mature roots can remain in the fields for several months.

5.3 Production and Market Risk

Looking at the revenues of typical agricultural production activities gives an idea of the degree of uncertainty involved in agricultural activities in the Bragantina (Figure

5.1). Apart from cassava roots the fluctuations of revenues of annual staple crops are by far lower than for perennial cash crops. Although this is primarily due to the high variation of prices, pests and diseases are important co-factors at least in the case of perennials. Only the price variations are taken into account in the baseline model. As shown in section 3.3.6.3, the use of the E-V model requires the specification of co-variances (correlations) between activity gross margins under the assumptions that costs are deterministic (table 5.10). Only the correlations between the gross margins of cassava and corn and between rice and cassava seem to make sense as these crops are all staple crops that are typically intercropped. However, rice is not an available cropping activity in the model, because only very few farmers of the sample actually cultivated rice in 2001/2 and previous years. The high correlation between cassava and corn is, hence, the only one that is accounted for in the model.



Source: based on IBGE PAM (1990-2002). De-trended and deflated time series.

Figure 5.1: Annual fluctuation of activity revenues 1990 - 2002

Table 5.10: Correlations of activity gross margins (R$/ha) at the regional level

	Oranges	Passion Fruit	Pepper	Rice	Beans	Cassava	Corn
Oranges	1						
Passion Fruit		1					
Pepper			1				
Rice				1			
Beans					1		
Cassava	0.57*			0.68*		1	
Corn	0.49					0.78*	1

* = significant at the 5% level, 10% level otherwise

Source: based on IBGE PAM (1990 – 2002)

5.4. Concluding Remarks

This chapter has described the basic ingredients of the bio-economic model and its modifications used for the simulations in the following chapters. The model consists of three parts; the farm-household initial conditions, a production side, and a consumption side (see section 3.3.6.2). Both initial conditions and the technical coefficients of production side were specified on the basis of the farm-household classification that helped to identify four representative types of smallholder families. The technical coefficients differ mainly between technology levels, but also between farm-household groups, as in the case of cassava flour processing.

The variation of activity gross margins in the study area is quite high, especially in the case of perennial cash crops. It therefore makes sense to consider both production and price risks and their impact on land use and technology choice in the modeling exercise. Since the use of chemical fertilizers plays a key role in technology based agricultural intensification, special attention needs to be paid to risk aversion as a determinant of fertilizer use intensity.

Part III Results and Conclusions

6.0 The Baseline

The baseline is understood here as a 'business as usual' type of scenario that should give an idea on the development of a typical smallholder unit over the 25 year simulation horizon assuming that all conditioning factors remain constant. Hence, technology access is limited to those technologies that can typically be accessed by the four types of farms identified in chapter 5.

The baseline solution of mathematical programming models can be evaluated in two ways. First, through an examination of the primary solution that should represent the observed behavior, i.e. land use, value of production, and factor demand in the survey year. And second, by looking at the dual solution that should attribute meaningful shadow values to production factors, such as fallow vegetation, land, and family labor that do not usually have a known price.

The following sections document the process of model calibration and validation and provide an analysis and interpretation of the baseline model that will be used for the simulations in sections 7. and 8.

6.1 Calibration

Calibration is the process of comparing a models output with reality and may involve the estimation of some model parameters under the assumption that the model is correct, as a middle step in the study of other parameters. Moreover, results and parameters from similar models can be used to test and verify the calibration outcome.

The first procedure is employed here with regard to the risk aversion parameters (ψ and λ as described in section 3.3.6.3). The results from Mendoza's (2005) econometric estimation of a profit function for annual crop production in the Bragantina serve as a reference point for the second approach. She found that the marginal value of fallowing is R\$/ha 385 at the average fallow length. Comparing this value to the shadow price of fallow in the baseline model can serve as a benchmark to weight the slope parameters of the damage functions derived from Kato (1998) as mentioned in section 3.3.5.2. However, it is expected that the shadow price in the baseline will be slightly lower than the value obtained in the econometric estimation, because:

1. Other than Mendoza's profit function, the model includes perennial cash crops, for which the nutrients from fallow have practically no value, i.e. yield is zero without the application of chemical fertilizers. For these activities only the costs of cutting fallow are taken into account, which has a negative effect on the shadow price.

2. For the programming model, stylized annual crop activities were defined based on the most dominant crop combinations found in the survey year. The econometric estimation, on the other hand, accounts for all annual crop activities found on the farms in the study area.

Table 6.1 shows the result of running the baseline model with ψ (MOTAD risk aversion) = 0, damage function weight $\alpha = 1$, and the initial conditions of the dominant farm type II (see section 5.1.2) and compares the solution to the empirical evidence.

Table 6.1: Initial model runs and empirical evidence

	Empirical (statistical) evidence	**Model result 1st year** *α = 1*	**Model result 25 year average** *α = 1*	**Model result 1st year** *α = 0*	**Model result 25 year average** *α = 0*
Non- essential consumption (R$)	~4900	0	7152	0	7323
Shadow price of fallow (R$)	(385)	41	43	6	74
Land use in % of farm size					
Annuals	15.0	14.6	0.7	18.8	1.3
Perennials	5.2	5.4	19.6	6.2	20.3
Fallow	63.4	61.0	22.2	56.0	28.1
Pasture	5.9	5.2	2.9	5.1	2.9
Unused	10.5	13.1	38.3	13.2	39.0

The table shows that first year land use and income differ dramatically from the average land use and income pattern over 25 years. In fact, annual crops, such as cassava and beans, virtually disappear in favor of perennial cash crops, mainly passion fruit, shortly after the first year. Consumption of non-essential goods in year 1 is 0 as surplus income is invested into cash crop operations, while the shadow price of fallow is extremely low. The model result does not seem to be sensible to changes in the damage function weight factor as the solutions for $\alpha = 1$ and $\alpha = 0$ are rather similar.

Up to this point, however, the model does not account for risk in the form of price variation. Since prices of perennial cash crops are known to fluctuate more than prices of beans and cassava flour it can be expected that introducing aversion to price risk will change the solution in favor of annual crops.

Figure 6.1 shows how the shadow price of fallow and the perennials' share in total cropland evolve, based on equidistant changes of α holding $\psi = 1$. The value of fallowing seems to be reasonably high for $0.1 < \alpha > 0.3$, which is also the range in which the share of perennials in the first year correspond to the situation observed on group II type of farms in the survey year. For $\alpha = 0.22$ the share of perennials is 25.9% as compared to 25.8 on group II farms in 2002/3.

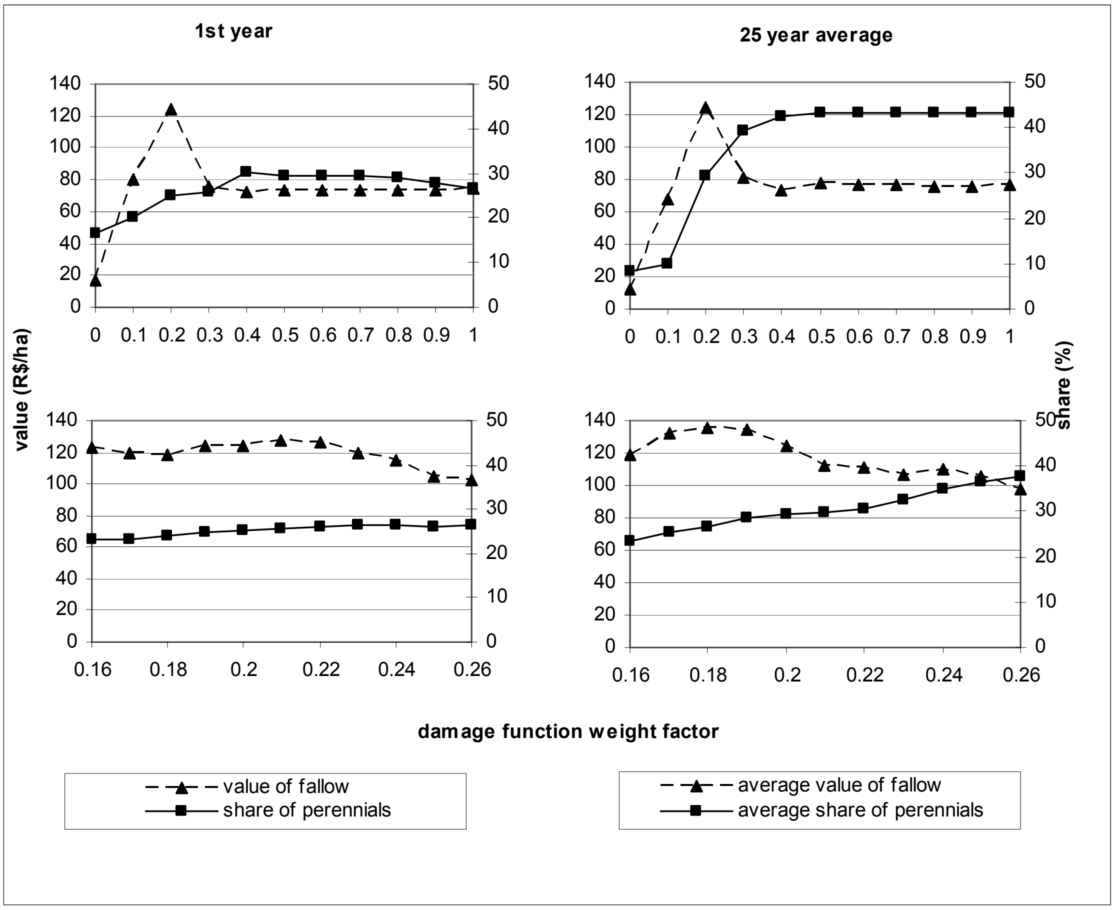


Figure 6.1: Development of indicator variables given equidistant changes (0-1 upper part and 0.16 -0.26 lower part) in α

The model output can be further fine tuned using the risk aversion coefficient ψ as shown in Figure 6.2. Higher ψ's further increase the value of fallow and at $\psi = 1.2$ the perennials' share in total cropland is equal to observed behavior. Since such a solution cannot be achieved with a different combination of α and ψ, the final parameter choice is considered unique.

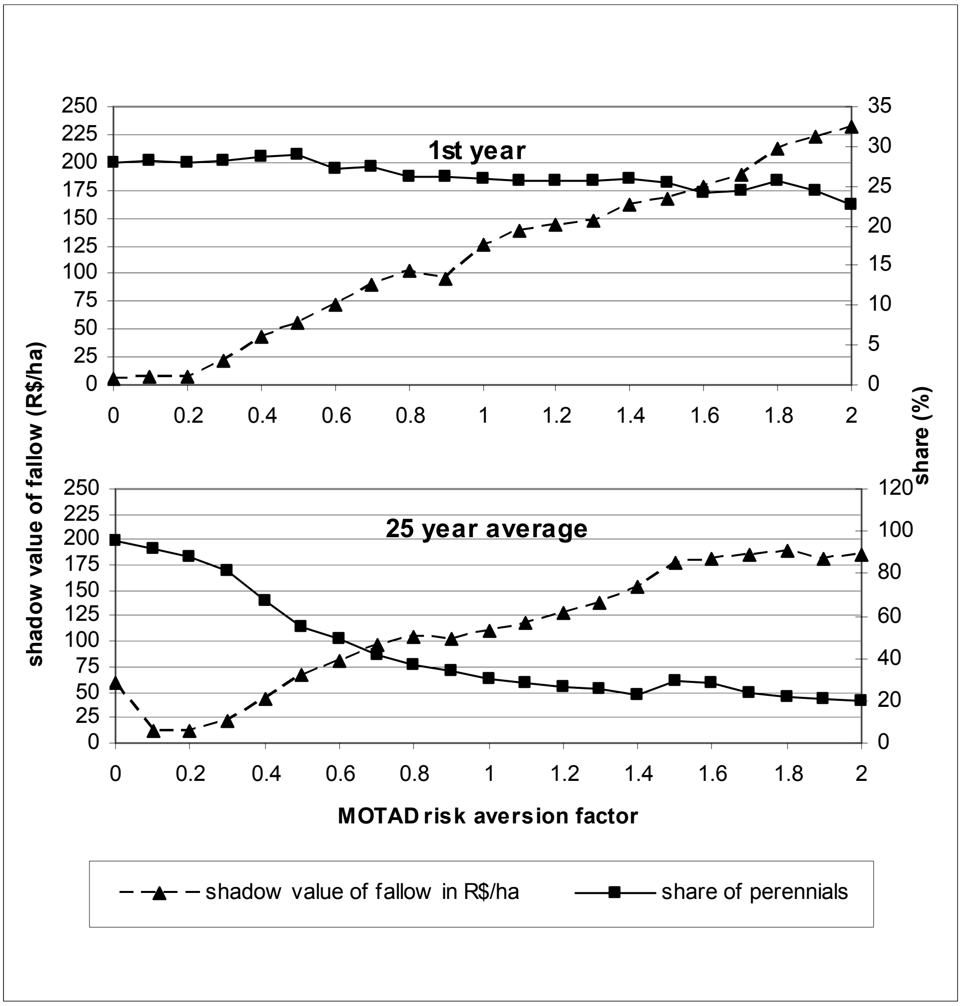


Figure 6.2: Development of indicator variables given equidistant changes in ψ

This section documents how the model reacts to changes in the damage function weight factor and the risk aversion coefficient. Since these parameters have shown a considerable effect on the model solution, it is necessary to characterize their impact on a more comprehensive set of indicator variables and to evaluate the final choice based on the available validation criteria.

6.2 Validation

In order to quantitatively assess the degree to which the model is sensitive to the calibration parameters, the parameters (x) were regressed on a set of indicator variables υ_i (equation 48), which allows the calculation of quasi-elasticities[52] (θ) (equation 49) (Krusemann 2000):

$$\nu_i = \alpha + \beta x + \varepsilon \tag{48}$$

$$\theta = \beta \frac{x_0}{\nu_{i0}} \tag{49}$$

where
ν_{i0} = indicator variable value in the baseline
x_0 = parameter value in the baseline

Appendix 8 shows the results of the regression analysis and the sensitivity of the model to changes in calibration parameters. A low R^2 indicates that the parameter has no clear unidirectional impact on the indicator variable. If R^2 and θ are high the parameter has a strong influence on the indicator variable. It appears that almost all indicator variables are correlated with the calibration parameters. The quasi-elasticities for changes in the risk aversion provide interesting insights with regard to the potential impact of alternative risk attitudes on policy variables, such as household income, the area under productive as well as degraded fallow, and carbon sequestration. This issue will be taken up again in sections 6.3.1 and 6.4.

To validate a multi-year programming model, both short and long run validation criteria are necessary. Due to a lack of consistent time series data to estimate long term land use trends, 25 representative farmers were asked about land use change on their farms during the five years prior to the survey. The information is of a rather qualitative nature, but it is still useful to evaluating the baseline solution.

To assess the short-run robustness of the model, the first year baseline solutions for the four representative farm groups can be tested using the survey data. Kleijnen (1998) proposes the following statistical test for cases, in which empirical evidence is available:

$$(\chi^m - \chi^e) = \alpha + \beta(\chi^m + \chi^e) + \varepsilon \tag{50}$$

where
χ^m = empirical evidence

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[52] The quasi-elasticity represents the percentage impact on the indicator variable given a unitary change in the parameter.

χ^e = model result

and α and β are parameters expected to be zero if the model is robust.

The null hypotheses that α = 0 and β = 0 can be tested with the standard F-test. Four models were set up, based on the initial conditions of the representative farm groups I, II, IV, and V presented in section 5.1.2. The models for the groups I, IV, and V were calibrated using incremental changes in the risk aversion coefficient, holding the damage function weight factor constant at α = 0.22 (see previous section). Table 6.2 shows input data and test results for testing the short-run robustness of land use variables across the four representative households. The F-test shows that the null hypothesis cannot be rejected even at the 90% confidence level; hence the model is robust in the short-run.

Table 6.2: Results for testing the short-run robustness of the model with respect to land use

		Empirical evidence (% of total farm size)	**Model result (% of total farm size)**	
Group I	Annuals	9.8	9.8	
	Perennials	6.0	7.3	
	Fallow	51.5	47.1	
	Pasture	11.5	9.2	
	Unused	21.3	25.3	
Group II	Annuals	15.0	16.6	
	Perennials	5.2	5.8	
	Fallow	63.4	58.7	
	Pasture	5.9	5.9	
	Unused	10.5	12.4	
Group IV	Annuals	19.5	18.2	
	Perennials	0.0	0.3	
	Fallow	53.7	56.7	
	Pasture	4.7	4.8	
	Unused	22.1	20.1	
Group V	Annuals	9.1	8.9	
	Perennials	0.6	0.6	
	Fallow	65.8	69.2	
	Pasture	2.0	3.9	
	Unused	22.5	15.4	
Test results		*alpha*	*beta*	*F-statistic*
	Value	0.0393	-0.0059	0.1413
	t Stat	0.0438	-0.3759	

The first criterion used for evaluating the long-run robustness of the baseline model for group II is the shadow price of fallow, since it represents the value of fallowing over the models planning horizon. To better compare the model specification with Mendoza's econometric estimation, the model was run without the option of perennial cropping and livestock activities. The resulting shadow value of fallow was R$/ha 307, which is quite close to the R$/ha 385 estimated by Mendoza.

The qualitative information on land use trends on the survey farms corresponds to the model results for all farm groups, which can be illustrated by the following two examples:

1. Farmers of all groups observed that they disposed of older fallows five years ago than today, although the area under fallow has remained constant. This implies that the average age of fallows has been reducing over time.

2. The majority of these farmers did not report major changes in the operational scale during the five years prior to 2002/3, which implies that farms are in a type of steady state situation with regard to the division of the farm in cropland and fallow.

To compare this information with the model results, trends have been estimated for the first 10 years of the baseline model results of the four farm groups (table 6.3).

Table 6.3: Estimated trends in land use indicators from the baseline model

Groups	I		II		IV		V	
	beta	*R2*	*beta*	*R2*	*beta*	*R2*	*beta*	*R2*
Fallow age (years)	-0.2234742 *	0.61	-0.3097323 *	0.96	-0.2777717 *	0.86	-0.1981448 *	0.95
Fallow area (ha)	0.0865406	0.36	-0.0831477 *	0.65	-0.1221945 *	0.53	0.0111987	0.01
cropland (ha)	-0.0233755	0.36	0.0691131 *	0.60	0.0933564 *	0.52	0.0380097	0.18

* = significant at the 95% confidence level

Although the annual growth for fallow area and cropland is significant for farm group II and IV, it is relatively small and in the case of group II due to an extension of perennial crops, which is in line with the trends in aggregate time series data for the study region. For the groups IV and V, however, very high risk aversion coefficients have to be assumed for the result to be in line with the farmers' observations on land use trends (see also section 6.3.1). At lower risk aversion, the operational scale on group IV and V model farms increases shortly after the first year to a level that is much higher than observed in the field.

After testing different assumptions with regard to the flexibility of farm-household labor demand and supply two different interpretations are possible. First, the specification of production activities in the model might fall short of costs (in the form of labor or cash) that accrue on group IV and V farms, but not on group I and II farms. Or second, the specification of the model's objective function (i.e. maximization of non-essential consumption and minimization of risk) does not properly account for the actual utility function of group IV and V farmers. In line with

Chayanov (1923) and Costa (2000) it could be argued that farmers[53] tend to minimize the amount of family labor applied to the farm subject to consumption constraints. Promising results have been generated by implementing such a notion using multiple-objective programming techniques. However, strict assumptions with regard to formal and informal labor markets are necessary for using this approach without explicitly modeling interaction between farms at the community level. Consequently, and because it does not directly contribute to answering the research questions, the approach is not further pursued below.

In the following, the model for farm group II is used for the analysis of technology and policy change. Whenever necessary, a reference is made as to how results and interpretation may differ for other farm types.

6.3 Sensitivity Analysis

Sensitivity analysis is a useful tool not only to evaluate model solutions; it also provides policy relevant insights with regard to the response of the model to changes in input and output prices. Such changes can have a considerable impact on land use decisions and technology choice, which is why sensitivity analysis is used to assess not only the baseline, but also some technology and policy simulations. This section is concerned with the sensitivity of the model baseline to changes in prices and discount factor. Since these parameters are known constants for the whole simulation horizon, the 25-year average of the indicator variables is used as an evaluation criterion. Table 6.4 summarizes the baseline solution with respect to land use, income, and product mix. According to the table, the lion's share of production value comes from perennial crops. Family labor is valued at the wage rate only during peak labor seasons, such as land preparation and pepper harvest. Outside peak seasons, labor is idle, which explains its low shadow value and the high average amount of family labor sold off. The amount of cattle is proportional to pasture size and almost insensitive to changes in most product and input prices. Moreover, a real world farm of the size of a group II model farm would rather not establish pastures due to the economies of scale involved in this type of activity. The appearance of pasture is a consequence of the aggregate

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[53] In our case the share of the sample with the lowest degree of market integration (see table 4.2 in section 3.3.2)

nature of the model and shows that cattle production can be a profitable activity in the study area. Due to the unimportance of cattle production for the majority of group II farms, it is not subject to sensitivity analysis.

Table 6.4: 25-year average of selected indicator variables from the group II baseline simulation

Annual non-essential consumption in R$	Annual cash expenses in R$	Value of production from annual crops in R$	Value of production from perennial cash crops in R$	Hired labor in man days/year	Sold off labor in man days/year
4064	8158	2611	7621	7	83
Area under annuals in ha	**Area under high input perennials in ha**	**area under low input perennials in ha**	**area under productive fallow in ha**	**age of productive fallow in years**	**area under pasture in ha**
2.79	0.97	0.03	9.20	4	1.01
Shadow value of initial fallow in R$/ha	**Shadow value of land in R$/ha**	**Shadow value of labor peak month in R$**	**Shadow value of labor outside peak month in R$**	**Area under mulch in ha**	**Area under mechanization in ha**
128	34	184	68	n.a.	n.a.

The results of the sensitivity analysis for the full range of indicator variables are summarized in appendix 9 in the form of quasi-elasticities (see previous section for definition). As the appendix shows, positive changes in the discount factor[54], i.e. the assumption on the time preference of the model farmer, do affect most indicator variables in a negative way. Albeit significant, the changes are rather small as for example in the case of high input perennials, which occupy on average 1 ha of the farm at an annual discount factor of 0.05 as compared to 0.9 ha at an annual discount factor of 0.15. Both the average age of fallow and the coverage slightly increase with the discount rate as a consequence of a reduction in high input perennials and degraded fallows. A high preference for future consumption does therefore not necessarily improve the conservation of natural resources as might be expected in the case of agricultural frontier areas, where high benefits are derived from primary forests, e.g. through the commercialization of hard woods.

Figure 6.3 shows the models sensitivity to changes in input and output prices in terms of land use variables. As expected, increases in product prices reduce the availability of productive fallow on the farm. The area under annual crops increases as the fertilizer price increases mainly due to cassava cultivation, which goes up as fertilizer demanding perennials become less profitable. Increases in both fertilizer price and wage translate into more productive fallows on the model farm. In the case

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[54] In the baseline 0.1 is the assumed annual discount factor.

of the daily wage, this is the consequence of a reduction in hired labor during the slash-and-burn season and an increase in off-farm labor during months of low on-farm

labor demand. As can be seen in the appendix, increasing product prices lead to an increase in non-essential consumption, especially in the case of the price for pepper. Increases in input prices, especially in the wage rate, have a negative effect on income.

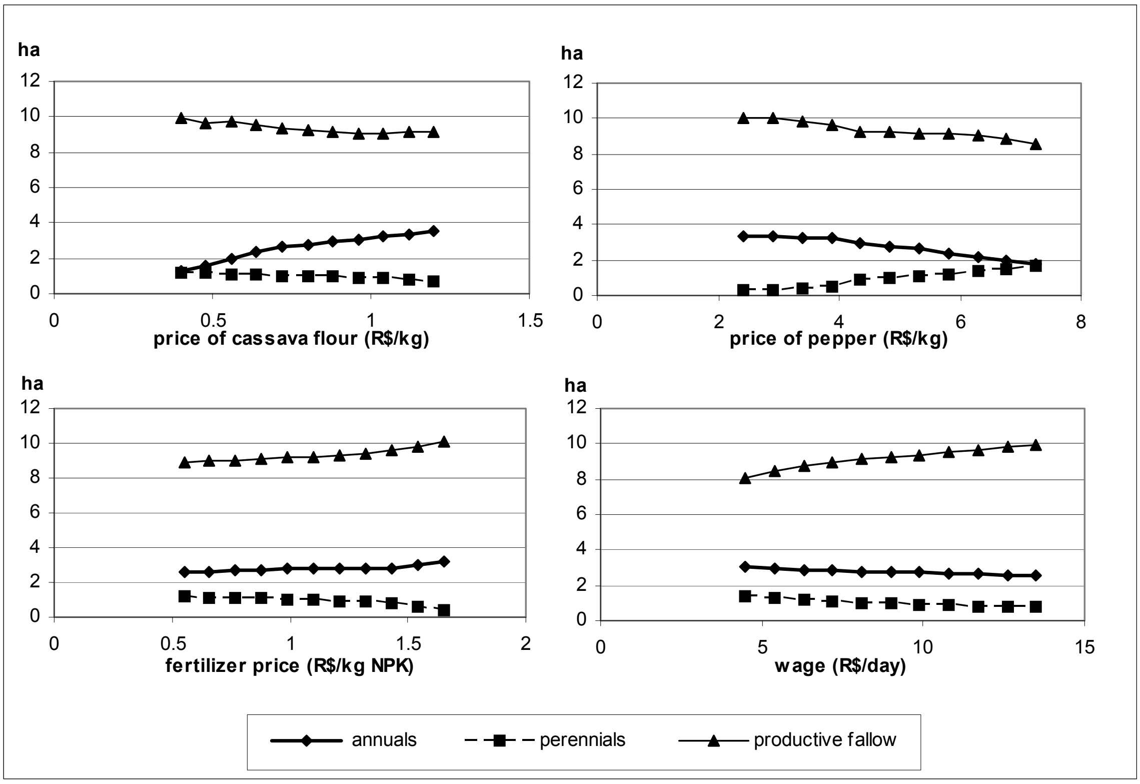

Figure 6.3: Impact of input and output price changes on selected land use variables in the group II baseline

To characterize the effect of price changes on the structure of output supply and factor demand, own and cross price elasticities have been calculated for the most important input (labor) and various output variables. Table 6.5 shows the results based on incremental and equidistant parameter changes of up to +/- 50% of the respective parameter value in the baseline.

Table 6.5: Input demand and output supply elasticities of the group II baseline model

			Prices			
Indicator variable	Fertilizer	Wage	Cassava flour	Bean	Pepper	Passion fruit
Hired labor	**-3.16 (0.029)**	**-4.14 (-1.43)**	**1.22 (1.4)**	0.78	5.99	2.60
Sold labor	1.99	2.13	-0.45	-0.61	-2.08	-0.84
Sold beans	-1.04	-1.27	1.19	0.96	-0.14	-1.61
Sold cassava flour	0.03	-0.12	0.41	0.01	-0.43	-0.04
Sold pepper	-0.44	-0.44	-0.26	0.06	0.64	0.43
Sold passion fruit	-0.53	-0.44	-0.22	0.14	1.38	1.98
Value of production from annuals	**-0.14 (-0.12)**	**-0.28 (-0.004)**	**1.33 (0.12)**	0.35	-0.41	-0.73
Value of production from perennials	-0.47	-0.44	-0.25	0.09	1.60	0.48
Total value of production	-0.38	-0.40	0.16	0.15	1.08	0.36

Values in parenthesis are the corresponding elasticities obtained by Mendoza (2005)

Some of the bold figures in table 6.5 are also directly comparable to the elasticities obtained in Mendoza (2005), as for example the response of annual value of production to changes in the price for labor and fertilizer. The hired labor response to these changes is different in the bio-economic model, because the price of fertilizer and labor directly affects the profitability of perennial cash crops that strongly depend on external inputs. Since Mendoza used a price index to account for all annual crops found on the survey farms, the response of the value of production from annuals (of which the lions' share stems from cassava flour) to changes in the price of cassava flour is more elastic in the bio-economic model than in the profit function estimation. Especially cash crops like pepper and passion fruit have higher own price elasticities than cassava flour. Labor demand is far more responsive to changes in perennial cash crop prices than in the case of annual crops. Finally, the high cross-price elasticity of passion fruit to the pepper price owes to the fact that the model represents the average of the farms in group II. In the real world, farmers tend to specialize in one or another cash crop, and hence, a change in the price of pepper would not as easily affect output of another cash crop as it does in the model. On the model farm, however, an increasing pepper price frees cash that is invested in the expansion of both pepper and passion fruit plantations.

6.3.1 Risk Aversion and Aversion to Income Variation

6.3.1.1 Risk Aversion

The models objective function assumes that the farmer maximizes the value of consumption of non-essential goods and at the same time minimizes the uncertain variation in this value (see also section 3.3.6). This trade-off can be visualized as in the figures 6.4 and 6.5 that show the 25-year net present value of non-essential consumption and the net present value of the mean of total absolute deviations (MOTAD) obtained depending on the degree of risk aversion.

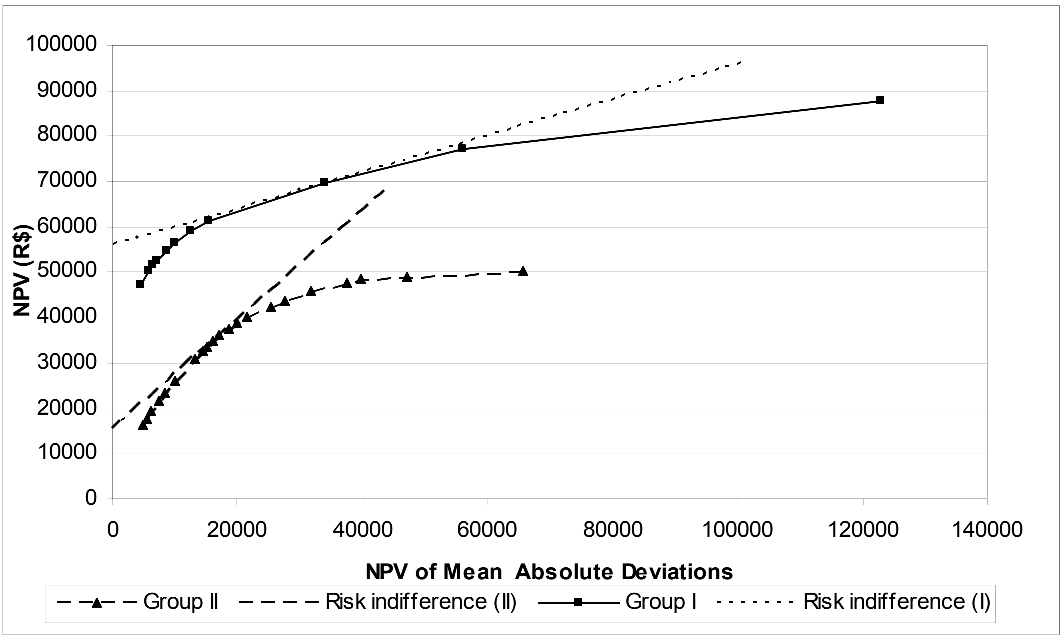

Figure 6.4: Trade-offs between non-essential consumption and MOTAD for group I and II farms

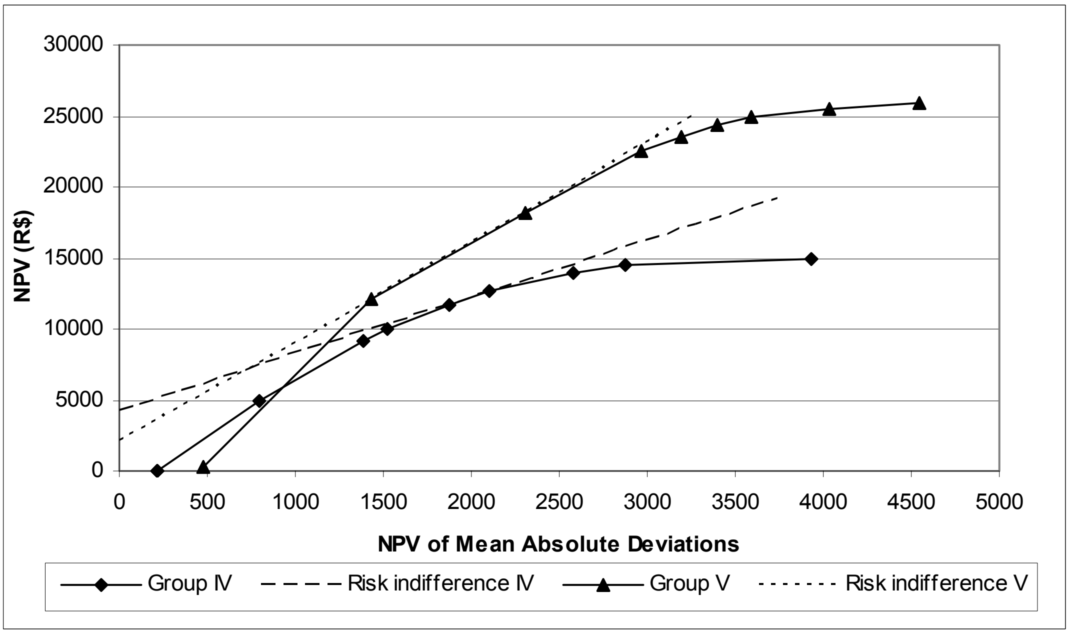

Figure 6.5: Trade-offs between non-essential consumption and MOTAD for group IV and V farms

In the objective function specification, non-essential consumption and MOTAD are linearly connected through the risk aversion factor. A straight line with the slope of the risk aversion coefficient therefore represents a risk indifference line, at which the farmer would trade consumption for MOTAD. At MOTAD = 0, the value at the ordinate represents the certainty equivalent, i.e. the certain amount that the farmer would accept in lieu of the uncertain amount he gets at the point where the risk indifference line is tangent to the respective trade-off curve. The certainty equivalents and the respective risk aversion coefficients[55] for the four representative farm types are summarized in table 6.6.

Table 6.6: Certainty equivalents and corresponding risk aversion factors for farm groups I, II, IV, and V

	Certainty equivalent in R$ (NPV)	Risk aversion factor assumed in the baseline (ψ)
Group I	55971	0.4
Group II	15553	1.2
Group IV	4226	4
Group V	2066	7

The table illustrates once again that the baseline solution for group IV and V farms only corresponds to observed behavior if very high risk aversion is assumed. Especially in the case of group V farms, this is probably not a meaningful assumption. These farmers are relatively well endowed with natural resources and family labor if compared to group IV and even group II farmers. Thus, apart from the distance to market there are few reasons that would explain such a high aversion to risk. As a consequence it is concluded that the present objective function specification is not appropriate to model farms that are more subsistence than commercially oriented, as is the case for most of type V farms.

6.3.1.2 Aversion to variation in non-essential consumption

Figure 6.6 shows the annual consumption of non-essential goods depending on different degrees of aversion to income variation. Without variation aversion, the annual non-essential consumption underlies heavy fluctuations that depend on investment into the reestablishment of perennial plantations, mainly pepper. Appendix 10 demonstrates that the introduction of variation aversion induces a sort of an anti-cyclic investment behavior using cassava cultivation as a buffer activity during the years of plantation reestablishment. This corresponds to the statements of individual farmers and extension officers, who characterize cassava production as a type of basic insurance activity. Cassava can be harvested and processed at any time in the year,

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[55] The MOTAD risk aversion factor is no real measure of constant absolute risk aversion (CARA), but it is reported here to give an idea of the dimension of ψ in the objective function of the different models.

and thus, provides a steady income stream at a comparatively low market risk, especially during years of low returns from other activities.

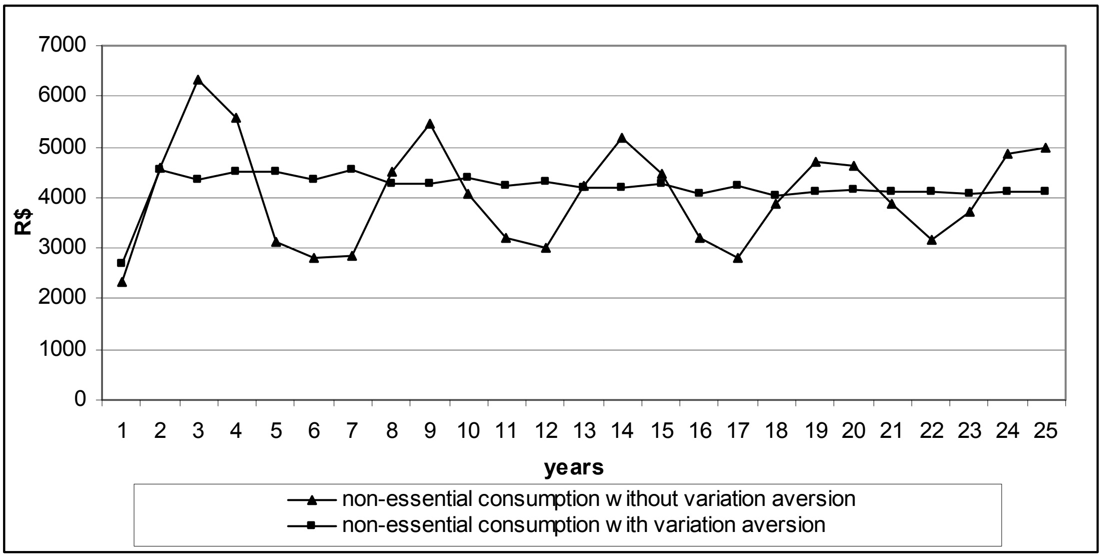

Figure 6.6: The impact of variation aversion on non-essential consumption over 25 years on a group II farm

However, variation aversion has almost no impact on the 25-year average of most indicator variables and it cannot *a priori* be assumed that farmers are variation averse. Hence, as long as variation aversion does not have an impact on the result of policy and technology simulations, it is not further considered below.

6.4 Sustainability of Current Farming Strategies

Based on the assumptions of the model, sustainability is evaluated here using indicators of welfare, environmental degradation, and economic development. Table 6.7 shows the significance of trends in these indicators over the 25-year simulation horizon.

Table 6.7: Estimated baseline long-term trends in sustainability indicators

	Slope	R^2
Welfare		
Non-essential consumption (R$)	3.396	0.00
Environment		
Average fallow age (years)	-0.078 **	0.56
Area under productive fallow (ha)	-0.010	0.08
Below and above ground carbon (t)	-3.843 **	0.61
Economic growth		
Hired labor (days/year)	-0.198	0.06
Product mix		
Value of cassava flour production (R$)	-15.851 *	0.13
Value of bean production (R$)	3.630 *	0.24

N=25

** Significant at the 99% confidence level

* Significant at the 90% confidence level

The results indicate that *ceteris paribus* household income remains constant over time. Also the labor demand is stable, such that the farm does not contribute to economic development in the form of creating new employment opportunities. Meanwhile, average fallow age reduces significantly over time, which confirms the observations made by natural scientists during the years prior to the survey year. As a consequence, cassava flour production becomes less profitable, which is reflected in a slight negative trend in the value of cassava production. Bean production on the other hand, which is less dependent on nutrient inputs from fallow, partly compensates the income loss in the form of a positive trend. Hence, from a private point of view, the farm provides a low but sustainable income, not at least due to the possibility of switching between more and less fallow dependent agricultural activities, such as cassava and bean or perennial production respectively.

The loss of carbon over time is doubtless the most drastic change in environmental indicators. The model farm looses an average of 3.8 tons of below and above ground carbon per year. As figure 6.7 shows, most of the carbon is lost during the first half of the 25-year period of observation. This loss, however, is a cost to the international community in the form of CO_2 emissions and plays no role in decision making at the farm level.

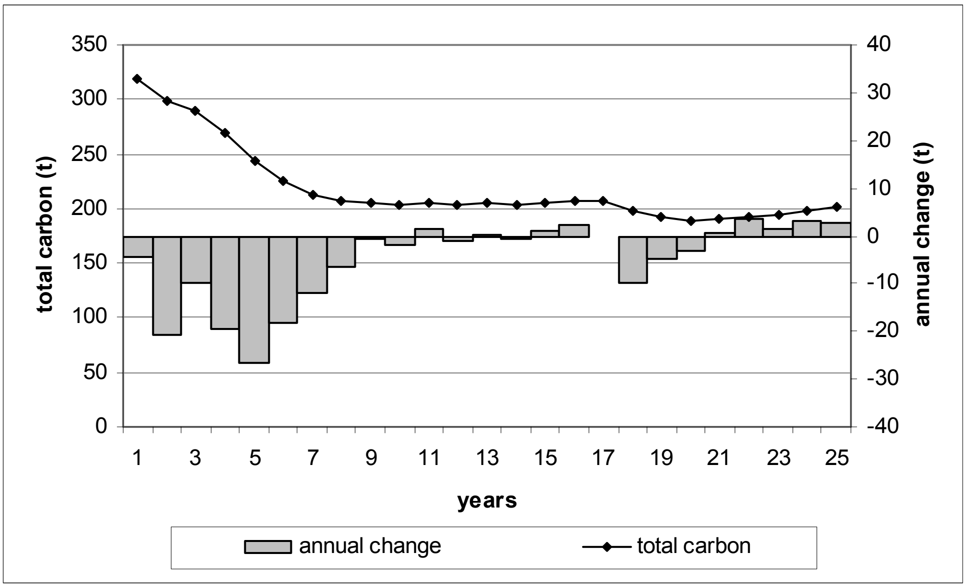

Figure 6.7: Total below and above ground carbon and annual change in the baseline

6.5 Economic and Technological Change: Implications from the Baseline

The baseline and sensitivity results provide some useful hints on how different types of economic and technological change might influence sustainability indicators at the farm level. Actual trends in macro economic conditioning factors are a devaluation of the exchange rate to the US dollar, which affects farmers most in the form of increasing prices for chemical fertilizers. Also relative prices for agricultural and manufactured goods tend to shift in favor of manufactured goods. Both these macro economic trends have a strong negative impact on household income (see also appendix 9). Yet, only an increasing fertilizer price notably affects product mix and environmental indicators in favor of carbon sequestration and fallow conservation. As the group II farm is a net exporter of agricultural goods it will always benefit from increasing product prices. However, income and environmental impacts differ considerably depending on whether perennial cash crop or annual crop prices increase. Increasing perennial cash crop prices lead to a clear reduction in the amount of productive fallow on the farm, whereas the area under degraded (i.e. temporarily unproductive) fallows increases. Yet, the quality of remaining fallows increases with the average age, which is reflected in a slight increase in total carbon. Increasing cassava flour prices on the other hand negatively influence both carbon sequestration and fallow quality. Also the area under fallows goes down and the positive influence on household income and labor demand is less expressed than in the case of increasing prices for perennial cash crops.

Looking at the shadow prices of farm resources (table 6.4) reveals that not all types of technological change can equally contribute to improving household income and environmental indicators. For example, the value of fallow increases with the fallow age, due to its positive impact on the yields of annual crops. Hence, technologies that depend on the conservation of old fallow vegetation, e.g. honey production, non-timber extraction, and some sorts of extensive agro-forestry systems, appear to have few chances to be adopted if they are not at least as profitable as cassava production in the slash-and-burn system.

The value of family labor, especially male family labor, is very high during peak seasons and rather low in other months. Figure 6.8 shows how labor is divided up between production activities during the agricultural year.

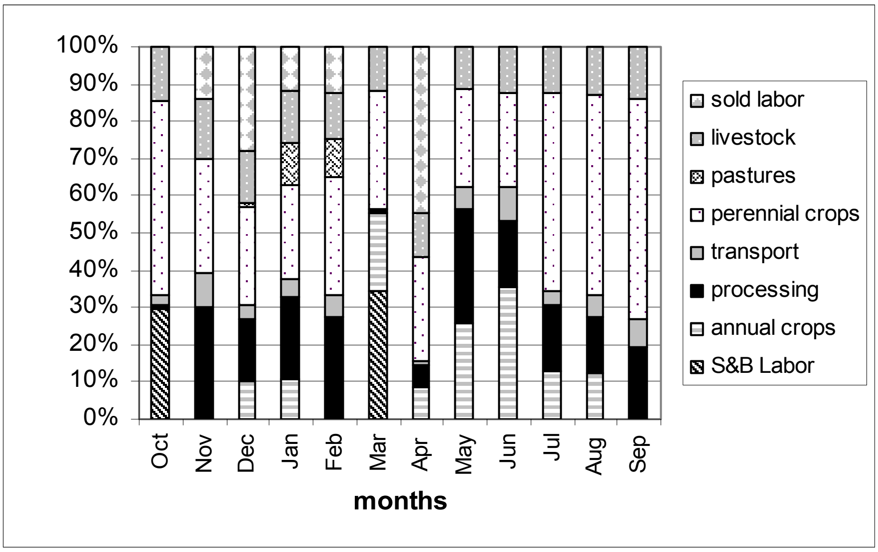

Figure 6.8: Monthly labor allocation to farm and off-farm activities in year 10

Especially the slash an burn season in October falls together with the pepper harvest, which is why labor is valued highest during this month. Consequently, labor is hired at the wage rate. Land preparation technologies are therefore likely to be adopted if they can be accessed at a cost that lies below the cost of preparing a piece of land using hired labor or if they lead to an increased productivity that outweighs the additional cost. Outside peak labor seasons, family labor is valued very low, which is why it is sold off. During these periods labor-saving and capital intensive technologies will rather not be adopted as far as adopting them does not compensate for the opportunity cost of working off-farm. However, technologies that are independent from the agricultural calendar, such as on-farm processing of some local perennial products[56], are likely to be adopted if appropriate marketing channels exist.

The following chapter will explore the impacts of technological change on farm level indicators of sustainability and identify economic and agronomic conditions for adoption.

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[56] Farmers in Castanhal and Igarapé-Açu have made positive experiences with the production of fruit concentrates.

7.0 Induced Technology Change

As suggested by the title, most simulations in this chapter assume that technology change is induced exogenously; or in technical terms, the model now allows for technologies that were not available in the baseline. In fact, this is not an unrealistic assumption, since the two major technologies in question, mechanical plowing and mechanical mulching, are services that are provided (or not) to the farmers depending on the degree of economic development at the district level, the existence of private entrepreneurs, or government action. On-farm processing of perennial crop products requires a good deal of knowledge and experience on the part of the farmer, which depends on the availability and training of local extension agents. The use of fertilizer in annual crop production on the other hand is to a large extent an endogenous decision, which is why it is treated in a separate section.

7.1. Scenarios of Technology Change

Table 7.1 reports the results of the main technology simulations in the form of percentage changes from the baseline. The outcome is then discussed in more detail for each type of technology.

Legend to table 7.1

1. baseline (B) + mulching 100%(M)	The baseline scenario remained unchanged, but the option of mulching at full service costs was allowed.
2. B + M 100% + fertilization (F)	In addition to scenario 1, this scenario allows fertilizing mulched and burned fields to compensate nutrient deficits.
3. B + M 30% + F	Here mulching costs are reduced by 70% as compared to scenario 2.
4. B + M 30% + F + plowing annuals (Pa)	Scenario 3 is modified here to allow for plowing in annual crops.
5. B + M 10% + F + Pa	In scenario 5 mulching costs were further reduced to 10% of the estimated service costs.
6. B + M 10% + F + Pa and perennials (Pall)	This scenario extends the previous one by the option of plowing to prepare for perennial cropping.
7. B + on-farm processing (OFP)	This scenario differs from the baseline by allowing for the on-farm processing of agro-forestry products.
8. B + M 10% + F + Pall + OFP	Here scenario 6 was extended by the option of on-farm processing of agro-forestry products.

Table 7.1: Scenarios of induced technological change

Technology scenarios	**Annual Consumption in R$**		**Annual Cash Expenses in R$**		**Value of Production from Annual Crops in R$**		**Value of Production from Perennial Cash Crops in R$**		**Hired Labor in man days/year**		**Sold off labor in man days/year**	
	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*
1. Baseline (B) + mulching 100%(M)	4150	*2*	8366	*3*	2813	*8*	7769	*2*	5	*-26*	73	*-12*
2. B + M 100% + fertilization (F)	4284	*5*	7719	*-5*	6750	*159*	3748	*-51*	25	*267*	17	*-80*
3. B + m 30% + F	4306	*6*	7899	*-3*	7103	*172*	3676	*-52*	32	*360*	12	*-85*
4. B + M 30% + F + plowing annuals (Pa)	4615	*14*	8589	*5*	8104	*210*	3729	*-51*	65	*835*	4	*-96*
5. B + m 10% + F + Pa	4633	*14*	8730	*7*	8216	*215*	3784	*-50*	66	*847*	4	*-96*
6. B + M 10% + F + Pa and perennials (Pall)	4912	*21*	9115	*12*	8569	*228*	4107	*-46*	70	*906*	4	*-95*
7. B + on-farm processing (OFP)	4603	*13*	8294	*2*	2415	*-7*	11501	*51*	10	*42*	41	*-50*
8. B + m 10% + F + Pall + OFP	4929	*21*	9140	*12*	8516	*226*	4282	*-44*	71	*917*	4	*-95*

	Area under Annuals in ha		**Area under High Input Perennials in ha**		**Area under Low Input Perennials in ha**		**Area under Fallow in ha**		**Age of Fallow in years**		**Area under Pasture in ha**	
	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*
1. Baseline (B) + mulching 100%(M)	2.5	*-12*	1.0	*2*	0.0	*7*	9	*3*	4	*10*	1	*0*
2. B + M 100% + fertilization (F)	4.3	*55*	0.5	*-53*	0.0	*-100*	9	*-1*	3	*-23*	1	*-27*
3. B + m 30% + F	4.6	*64*	0.4	*-55*	0.0	*-100*	9	*-2*	3	*-25*	1	*-36*
4. B + M 30% + F + plowing annuals (Pa)	4.4	*58*	0.5	*-53*	0.0	*-100*	7	*-22*	3	*-18*	1	*-41*
5. B + m 10% + F + Pa	4.6	*63*	0.5	*-52*	0.0	*-100*	7	*-23*	3	*-21*	1	*-41*
6. B + M 10% + F + Pa and perennials (Pall)	4.9	*74*	0.4	*-59*	0.0	*-100*	7	*-24*	3	*-28*	1	*-41*
7. B + on-farm processing (OFP)	2.5	*-12*	0.9	*-8*	0.7	*2676*	9	*-2*	4	*2*	1	*-1*
8. B + m 10% + F + Pall + OFP	4.8	*71*	0.4	*-58*	0.0	*17*	7	*-24*	3	*-27*	1	*-41*

	Shadow Value of Initial Fallow in R$/ha		**Shadow Value of Land in R$**		**Shadow Value of Labor Peak Month in R$**		**Shadow Value of Labor outside Peak Month in R$**		**Area Mulched in ha/year**		**Area Mechanized in ha/year**	
	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*	total	∆ *in %*
1. Baseline (B) + mulching 100%(M)	113	*-12*	30	*-12*	153	*-17*	73	*7*	0.4	*n.a.*	0	*n.a.*
2. B + M 100% + fertilization (F)	283	*121*	83	*142*	214	*17*	121	*77*	0.0	*n.a.*	0	*n.a.*
3. B + m 30% + F	185	*44*	75	*119*	228	*24*	126	*84*	0.8	*n.a.*	0	*n.a.*
4. B + M 30% + F + plowing annuals (Pa)	38	*-71*	44	*30*	235	*28*	145	*113*	0.0	*n.a.*	1.1	*n.a.*
5. B + m 10% + F + Pa	-3	*-102*	21	*-39*	214	*17*	150	*120*	1.1	*n.a.*	1.0	*n.a.*
6. B + M 10% + F + Pa and perennials (Pall)	8	*-94*	23	*-34*	208	*13*	156	*129*	1.9	*n.a.*	1.0	*n.a.*
7. B + on-farm processing (OFP)	110	*-14*	32	*-7*	165	*-10*	83	*22*	0	*n.a.*	0	*n.a.*
8. B + m 10% + F + Pall + OFP	7	*-94*	23	*-33*	209	*14*	156	*129*	2	*n.a.*	1	*n.a.*

7.1.1 The Potential Effect of Fertilizer Use in the Slash and Burn (S&B) System

The second simulation presented in table 7.1 shows the potential effect of fertilizer use in the slash-and-burn system. The word ‘potential’ is used here to point out that the majority of the farmers does actually not use fertilizers on burned cassava fields for reasons that have been discussed in section 4.7.1 and will be taken up again below. However, the potential benefit of fertilizer represents a real opportunity cost as has been shown on experiment stations and under farming conditions. The reason why it is introduced here is that both plowing and mechanical mulching require the use of fertilizers in annual crop production and, hence, need to be evaluated at their full opportunity costs. The first simulation (B+M 100%) shows the models reaction if mulching is allowed without the option of fertilizer use in the S&B system. In this case mulching is adopted at full service costs during the first 10 years of the simulation period (see also next section). However, the use of fertilizer in the S&B system not only eliminates mulching from the optimal solution, it also has a dramatic effect on crop mix and land use. As a consequence of the increased per hectare productivity annual crop production supersedes perennial production as the main income source. The area of annual crops increases by 55% as compared to the baseline causing the average age of fallow to reduce by 23%. The average area under fallow, however, remains constant and total carbon reduces only slightly (from 218 tons in the baseline to 210 tons), because of the reduction in perennial cropping that conserves below ground carbon stocks. Interesting is the positive effect of an increased annual crop productivity on labor demand and supply. The increased amount of available cassava spurs cassava flour processing, which results in a higher amount of family labor employed on the farm even during low peak seasons.

Figure 7.1 illustrates the impact of fertilization in the S&B system on non-essential consumption and natural resource quality measured in the age of fallow vegetation over time.

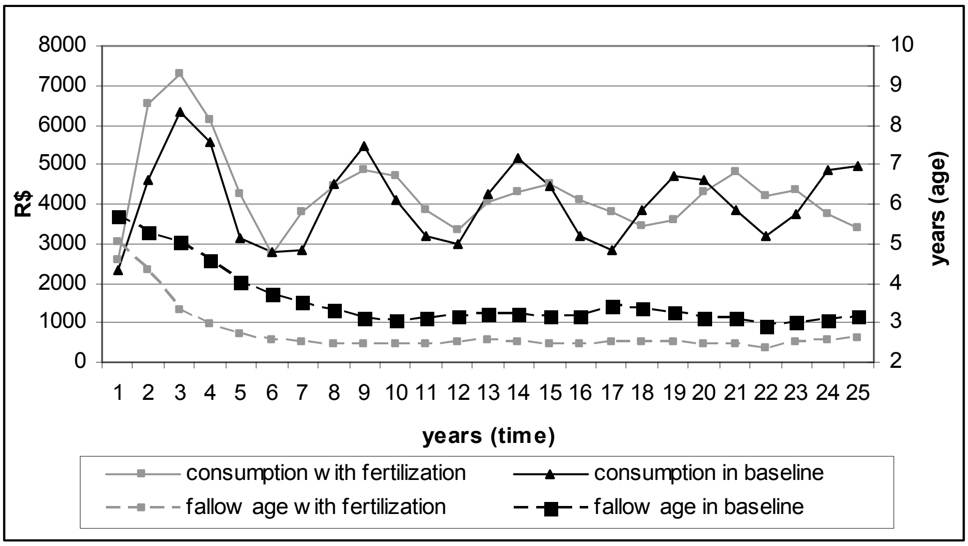

Figure 7.1: The potential impact of fertilizer use in the S&B system

The figure shows that the price to pay for higher consumption in earlier years is a more rapid depletion of fallow quality and a lower steady state fallow age than without fertilization.

Up to this point it has been assumed that the model farm is a price taker, but since it represents more than one half of the survey farms, it is likely that such an enormous increase in cassava flour output puts pressure on the prices of local markets. A sensitivity analysis on the cassava flour price shows that cassava output is very elastic (1.56) for prices ranging between 50% and 80% of the actual price, whereas it becomes completely inelastic for prices ranging between 80 and 150% of the actual price. Very high quasi-elasticities of the shadow prices for land and fallow (1.8 and 2 respectively) indicate that the scarcity of these resources puts a limit on the expansion of cassava production in the face of positive price changes. However, if a productivity increase at the regional scale would push the price down to say 70% of the actual price, the area under annual crops increases by only 22% instead of 55% as compared to the baseline. Hence, the productivity increasing effect of fertilization in the S&B system is prone to be affected by negative feedback effects on local and regional markets (the results of the sensitivity analysis can be found in appendix 11).

7.1.2 Mechanical Mulching

Although scenario number 1 in table 7.1, represents an artificial scenario (i.e. the full opportunity costs of mulching are not taken into account) it provides an interesting insight into the importance of fallow dynamics when it comes to technology adoption (figure 7.2).

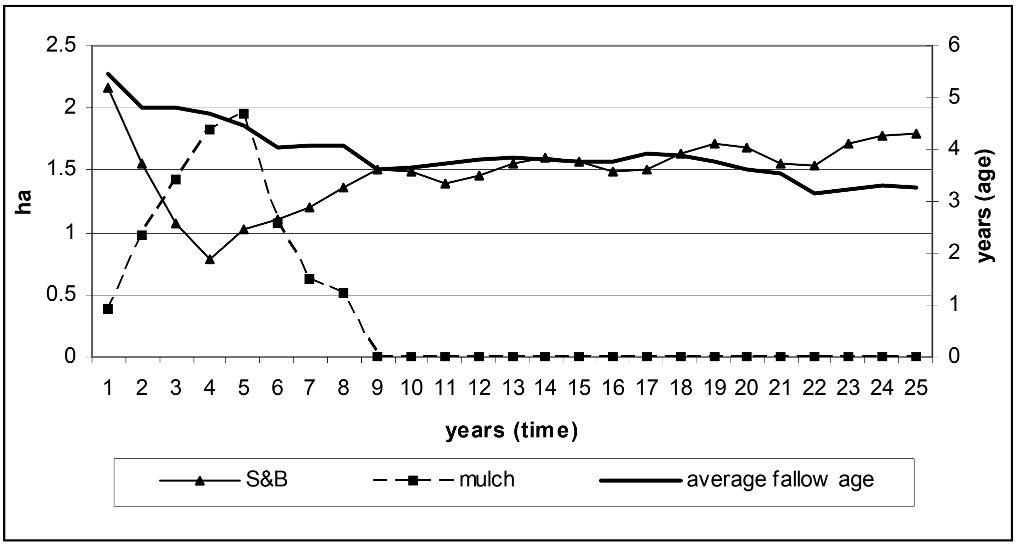

Figure 7.2: Fallow dynamics and technology adoption

The figure shows that mulching is profitable if high quality fallows are available. As fallow age decreases over time, the area under mulch decreases in favor of slash-and-burn. By the end of the simulation period S&B is even further expanded to compensate for the negative yield impact of the decrease in fallow age. Nevertheless, average fallow age (and total carbon) is 10% (7%) higher than in the baseline.

The third scenario in table 7.1 (B + M 20% + F) shows that, only if mulching service costs are reduced by 70%, it is adopted as a land preparation technology in addition to S&B with fertilization. Yet, income gains are very small in comparison to S&B with fertilization even if net present values for the whole simulation period are compared, which is due to the increase in expenditure. As expected, the adoption of mulching frees labor that is used to clear more land such that the average area under annual crops increases by 7%. The additional loss of area under fallow, however, is rather small.

An interesting aspect of the solution is that fields that have been prepared with mechanical mulching are not always used for annual cropping during two cropping cycles; a feature that has been considered one of the main advantages of mulching. This was also observed on trial farms and the bio-economic model offers one out of several possible explanations. Using a field for an additional cropping cycle involves opportunity costs, i.e. cleared area that could go into perennial production or back into the fallow cycle. Depending on the on-farm resource availability at a given point in time, fields that have been cleared by mechanical mulching are occasionally used for other more profitable purposes after the first cropping cycle.

The effect of increasing wage on the adoption of mechanical mulching can, but must not have positive effects on the adoption rate. If wages during peak labor months increase by 20% and remain at their actual level in the rest of the year, the area under mulch increases slightly towards the end of the simulation period if compared to scenario 3. However, the average of the whole simulation period is lower than in scenario 3. The reason is that an increasing wage during the land preparation seasons also requires higher cash outlays for hired labor in perennial crop production. Since perennial production is more profitable than mulching, less cash is available for investments into land preparation. The effect is even more obvious if the general wage level goes up. Apart from increasing opportunity costs of on-farm work, this affects also the productivity of cassava processing in a negative way and results in a reduction of the area under annual crops independent of the type of land preparation technology.

Simulations 4 and 5 confirm the notion that mechanical mulching and plowing are competing technologies. The introduction of mechanical plowing almost eliminates mulching from the optimal solution. A reduction of 90% of the initial mulching cost is necessary in order to make the technology competitive in a scenario of full technology access.

7.1.3 Mechanical Plowing

Mechanical plowing is introduced in scenarios 4,5,6, and 8 and has the most obvious effect on overall household income, environmental indicators, and labor supply and demand. But, increasing income levels and positive impulses on the labor market come at the cost of fallow quality, fallow coverage, and carbon losses. Moreover, the average area under degraded fallows (unproductive fallows in rehabilitation) increases from 1.1 ha in the base line to 2.3 ha in scenario 6.

Interesting is the effect of improved access to mechanical land preparation technologies on the own price elasticity of cassava flour production. Since the introduction of these technologies relaxes virtually all fixed resource constraints (i.e. family labor, fallow vegetation, land), cassava flour production becomes more elastic to price changes above 70% of the cassava price in the baseline (figure 7.3).

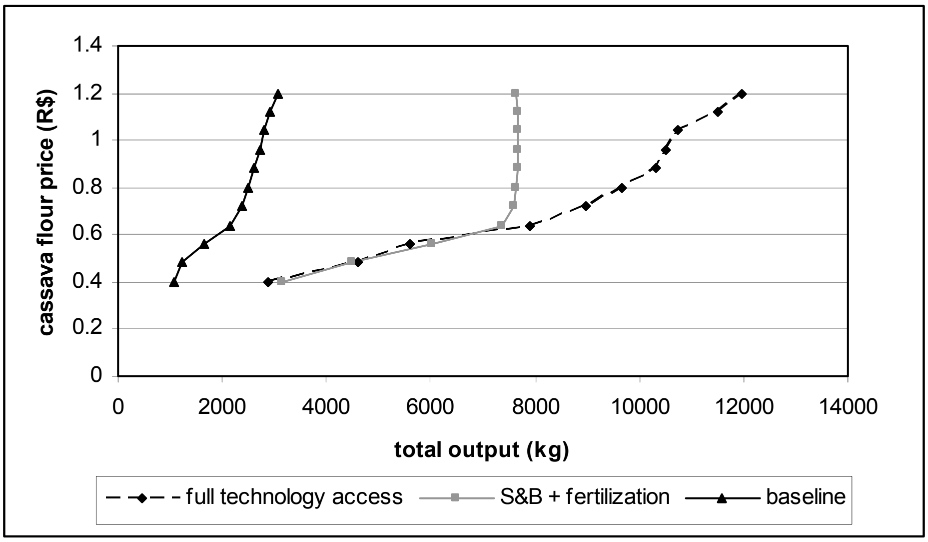

Figure 7.3: Supply response to changes in the cassava flour price depending on technology access

7.1.4 On-farm Processing

On-farm processing is not an additional agricultural activity, but an option to convert the harvest from extensive perennial production into higher value products, such as fruit concentrate. Technical coefficients for this technology were obtained from extension agents and entrepreneurial farmers in Castanhal.

Provided that appropriate marketing channels exist, on-farm processing of agro-forestry products (scenario 7) can improve fallow quality and carbon sequestration (+17%) if compared to the baseline. Although the economic impact is not as strong as in the case of other technologies it is considerable especially in the case of non-essential consumption (+13%). However, at full technology access the opportunity costs of agro-forestry with on-farm processing are too high for it to remain relevant in the crop mix.

7.1.5 Risk Aversion and Fertilizer Use Intensity

For the simulations in this section the “Expected value Variance” (E-V) model has been used as described in 3.3.6.3. The model includes the potential crop yield variation as a function of chemical fertilizer use and was set up to analyze the effect of risk aversion on fertilizer use intensity. The results are shown in figure 7.4 for the baseline scenario and in figure 7.5 for a scenario of full technology access.

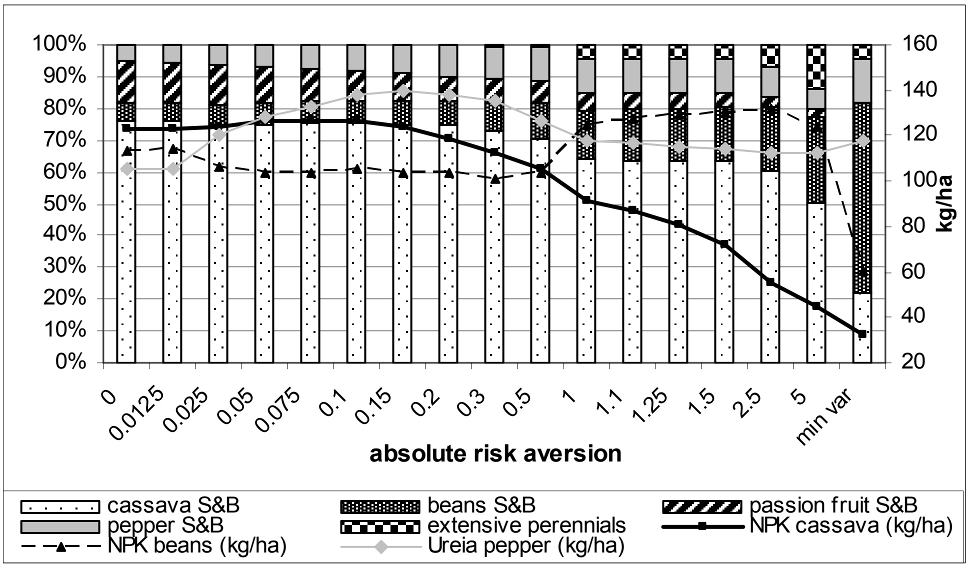

Figure 7.4: Baseline land use mix and fertilizer use intensity at different degrees of risk aversion

In the baseline scenario, where technology access is limited to traditional slash-and-burn, fertilizer use intensity in cassava production and the operational scale (not shown here) go down with increasing risk aversion. As with the MOTAD approach, the share of intensive perennials reduces with risk aversion. Yet, fertilizer use intensity in pepper production is not clearly influenced in a negative way. The area under beans is positively affected by risk aversion and fertilizer use increases with higher levels of risk aversion. Both scenarios explain to some extent, why smallholders in the Bragantina might be reluctant in adopting fertilizers in cassava production, while being relatively open for fertilizer use in perennial crop and bean production (see also section 4.7.1). Due to the relative importance of cassava flour production with fertilization, the variance of household income can be considerably reduced by both reducing the operational scale and the fertilizer use intensity of cassava flour production. At moderate risk aversion levels, the income loss can be compensated by a more intensive production of beans (and pepper in the baseline); crops that require a minimum application of fertilizer to produce reasonable yields.

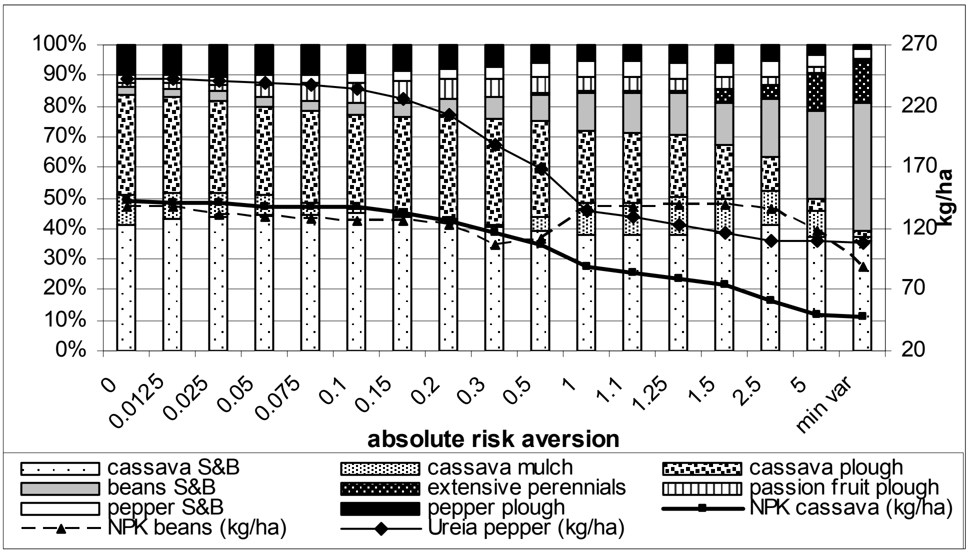

Figure 7.5: Land use mix and fertilizer use intensity under risk aversion and full technology access

The picture is a little different if full technology access is assumed. Here also the fertilizer use intensity in pepper production reduces over time, because the mechanized pepper production activity provides higher (and more uncertain) yields at high intensity levels.

Both simulation results show that more risk averse (and eventually poorer) farmers are less likely to adopt land preparation technologies that require the use of chemical fertilizers, but leave the variance of yields unaffected. However, the reason for that is not necessarily that they face more serious cash constraints than farmers in more favorable economic conditions. Instead the model suggests that the tendency to reduce the uncertain variation of household income makes farmers produce especially cassava flour at low levels of fertilizer use intensity.

7.2 Alternatives to Slash and Burn and the Critical Triangle of Development Objectives

Looking at the results of the technology simulations reveals that considerable trade-offs exist with respect to the economic and environmental benefits and costs of technology change. Figure 7.6 summarizes the main technology options and the respective impact on indicators of household wealth, environmental quality, and local economic growth.

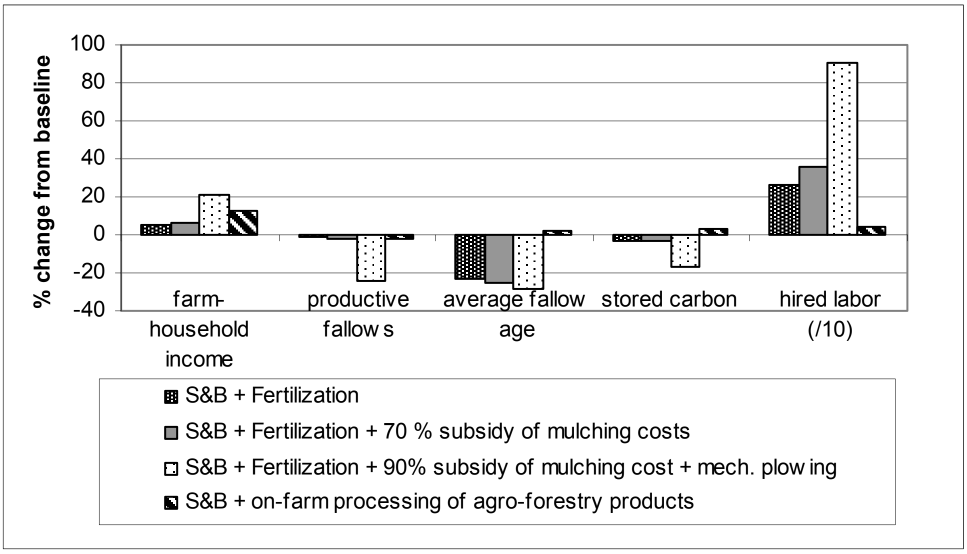

Figure 7.6: Technology change and development objectives

Fertilizer use in combination with mechanical land preparation technologies has clear positive impacts on household income and on-farm employment. Yet, all indicators of environmental sustainability are negatively influenced by improved access to mechanical land preparation. The exception (not shown here) is the rather unrealistic scenario of access to mechanical mulching with fertilization and without the option to apply the fertilizer on fields that have been prepared by slash-and-burn. Apart from a slight increase in household income, this would positively influence total carbon and fallow age. In all scenarios that assume full opportunity costs, mechanical mulching is adopted only at costs lower than 50% of the estimated service costs. A reduction of 90% is necessary for mulching to be competitive with mechanical plowing.

On-farm processing of agro-forestry appears to be a “win-win-win” solution as it positively influences all sustainability indicators, albeit not as strongly as in the case of mechanical land preparation. Despite the necessary economic frame conditions for it to be viable[57] the technology represents a realistic alternative for many smallholders.

The four farm types essentially react in the same way to improved technology access. Exceptions with respect to mulching and on-farm processing of agro-forestry products are the farm types IV and V. Farm type V tends to be less responsive to the option of mulching without fertilization in the S&B system, since it disposes of a large amount of old and

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[57] Very good access to markets and knowledge. Eventually, the existence of a critical mass of adopters at the community level might be necessary to stimulate demand from local traders.

productive fallows that make S&B more profitable than for “natural resource poor” group IV farmers.

For both group V and IV farms, on-farm processing of agro-forestry products appears a profitable alternative in most simulations. However, at least for group V farms in remote areas it remains an unrealistic option in the short-run due to the limited access to markets. The models for group IV and V farms are generally rather inflexible in the response to technological change, which can be attributed to the very high risk aversion assumed.

Income variation aversion has no significant effect on technology adoption, which is why it is not further considered here.

8.0 Policies for Sustainable Development

Apart from pure price policies that have been explored via sensitivity analysis, other policy instruments (or combinations of them) exist that are applicable in the context of the Bragantina and other old colonization areas in the Amazon. This chapter presents results from model scenarios that simulate the impact of some of those policies with respect to land use and technology choice at the farm level. Some of the simulations presented here are scenarios of existing types of policy action, such as credit provision, environmental standards, and the Proambiente program. In addition, taxes, subsidies, and the option of a technology specific crop yield insurance have been explored using the bio-economic model.

8.1 Policy Scenarios

Table 8.1 presents a summary of simulation results in absolute figures and in terms of changes from the baseline.

Legend to table 8.1

1. Improved credit access	This scenario extends the baseline with the option of credit up to R$5000 in five year intervals at an interest rate of 6%.
2. Proambiente	This scenario simulated the introduction of the planned *Proambiente* credit program.
3. Proambiente modified	This scenario represents a modification of the Proambiente rules, such that the unlimited use of fertilizers is possible.
4. Environmental standard (5 ha set-aside)	Here a constraint is imposed on the baseline scenario, such that 5 ha of productive fallow have to be set-aside permanently.
5. Set-aside payment (R$/ha 160)	In this scenario setting aside productive fallow land under baseline conditions is remunerated with R$/ha 160 per year.
6. Set-aside payment with full technology access	In this scenario setting aside productive fallow land under full technology access is remunerated with R$/ha 160 per year.
7. Tax on S&B (R$/ha 300)	Here all technologies are allowed, but a tax of R$/ha 300 is levied on the use of slash-and-burn.

Table 8.1: Selected policy scenarios and their impact at the farm level

Policy scenarios	**Annual consumption in R$**		**Annual cash expenses in R$**		**Value of production from annual crops in R$**		**Value of production from perennial cash crops in R$**		**Hired labor in man days/year**		**Sold off labor in man days/year**	
	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*
1. Improved credit access	4051	*0*	9245	*13*	2674	*2*	7690	*1*	7	*-4*	77	*-7*
2. Proambiente	1772	*-56*	8341	*2*	4891	*87*	1829	*-76*	2	*-73*	191	*129*
3. Proambiente modified	3690*	*-9*	9340	*14*	5167	*98*	5711	*-25*	8	*9*	22	*-74*
4. Environmental standard (5 ha set-aside)	4094	*1*	8304	*2*	2092	*-20*	8242	*8*	5	*-30*	106	*27*
5. Set-aside payment (R$/ha 160)	4549	*12*	8278	*1*	2194	*-16*	8093	*6*	5	*-27*	102	*23*
6. Set-aside payment with full technology access	5103	*26*	8689	*7*	8014	*207*	3941	*-48*	43	*523*	7	*-92*
7. Tax on S&B (R$/ha 300)	4449	*9*	9369	*15*	8279	*217*	4062	*-47*	66	*846*	6	*-93*
** In this case the average is misleading since the npv of non-essential consumption is equal to the baseline*	**Area under annuals in ha**		**area under high input perennials in ha**		**area under low input perennials in ha**		**area under fallow in ha**		**age of fallow in years**		**area under pasture in ha**	
	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*
1. Improved credit access	2.8	*0*	1.0	*1*	0.0	*7*	9	*0*	3	*-5*	1	*0*
2. Proambiente	3.6	*29*	0.2	*-84*	0.1	*163*	9	*2*	5	*46*	1	*1*
3. Proambiente modified	3.9	*40*	0.6	*-39*	0.2	*546*	9	*-4*	5	*34*	1	*-4*
4. Environmental standard (5 ha set-aside)	2.0	*-27*	1.1	*9*	0.0	*4*	10	*7*	8	*136*	1	*0*
5. Set-aside payment (R$/ha 160)	2.1	*-24*	1.0	*6*	0.0	*-4*	10	*6*	9	*146*	1	*0*
6. Set-aside payment with full technology access	4.4	*57*	0.4	*-61*	0.0	*-100*	7	*-19*	11	*196*	1	*-44*
7. Tax on S&B (R$/ha 300)	4.4	*59*	0.4	*-59*	0.0	*-100*	7	*-28*	3	*-6*	1	*-19*
	Shadow value of initial fallow in R$/ha		**Shadow value of land in R$**		**Shadow value of labor peak month in R$**		**Shadow value of labor outside peak month in R$**		**Area mulched in ha/year**		**Area mechanized in ha/year**	
	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*	total	Δ *in %*
1. Improved credit access	118	*-8*	30	*-11*	171	*-7*	68	*0*	0	*n.a.*	0	*n.a.*
2. Proambiente	65	*-49*	26	*-23*	126	*-31*	69	*1*	3.3	*n.a.*	0	*n.a.*
3. Proambiente modified	183	*43*	83	*143*	157	*-15*	99	*45*	3.9	*n.a.*	0	*n.a.*
4. Environmental standard (5 ha set-aside)	304	*138*	39	*15*	163	*-11*	65	*-5*	0.0	*n.a.*	0	*n.a.*
5. Set-aside payment (R$/ha 160)	432	*238*	39	*15*	158	*-14*	65	*-5*	0.0	*n.a.*	0	*n.a.*
6. Set-aside payment with full technology access	370	*190*	52	*54*	184	*0*	139	*104*	2.8	*n.a.*	1.1	*n.a.*
7. Tax on S&B (R$/ha 300)	-23	*-118*	33	*-3*	210	*14*	145	*112*	1.1	*n.a.*	1.2	*n.a.*

8.1.1 Improved Access to Credit

Although any smallholder in the Bragantina can theoretically draw on credits under the FNO or from the *Banco do Brasil*, only a few farmers actually make use of this option. This is partly due to the extraordinary high interest rates charged by regular banks and partly to the bad reputation of early FNO projects. In addition, it is often necessary for farmers to be in contact with extension officers either as sureties[58] or for assistance with administrative issues.

In the scenario presented here it is assumed that credits of any size up to R$5000 can be taken by any farmer at low transaction costs and at conditions equal to the FNO credit scheme (6% interest rate). Credits can be taken every five years provided they have been fully amortized before and they are not linked to specific production activities.

Table 8.1 shows that neither land use nor technology choice is significantly affected by the improved access to credit. Only the average area under beans increases by 10% (not shown) as a consequence of the relaxed cash constraint.

A look at the consumption of non-essential goods over time reveals that the credit option mainly affects consumption patterns as it allows consuming cash that has previously been invested into agriculture (figure 8.1). The figure shows that on average 80% (R$4000 negative savings) of the total value of the credit is consumed in the year when the credit is taken, while the rest goes into the stock of working capital.

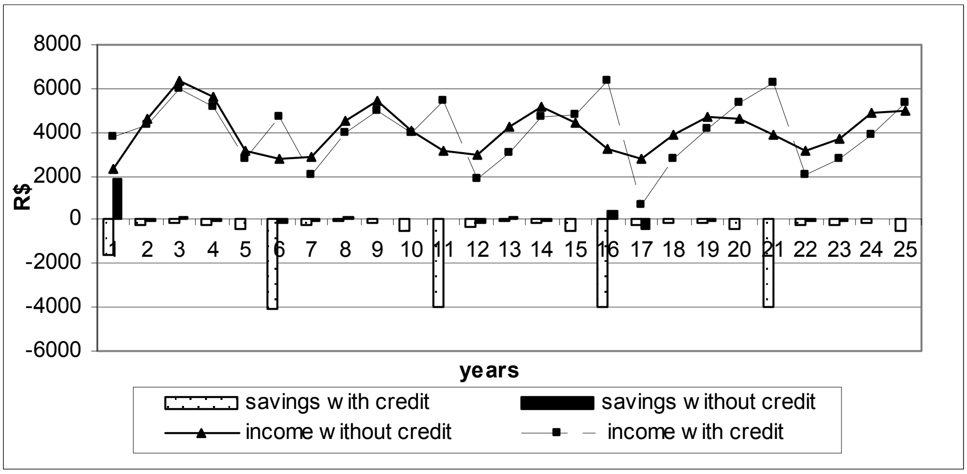

Figure 8.1: Non-essential consumption and savings with and without credit

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[58] Extension officers are not sureties in the true meaning of the word; they rather serve as a reference person.

The result, however, uncovers one of the weaknesses of the model with regard to simulating investment behavior. Since, it allows for investments to be infinitely small, capital intensive investments into perennial plantations can be divided up into several small annual investments according to the availability of working capital and other resources. Although this behavior has been observed on some farms in the study area, e.g. smallholders eventually expand pepper plantations annually; many plantations are established all at once. Hence, it might be argued that the model should require a minimum acreage for the initial establishment of perennial plantations. Technically, this is only possible using mixed-integer programming, which comes at the costs discussed in chapter 3. Yet, for the purpose of determining the value of credit in the face of non-separable investments an auxiliary measure can be used. For example, a lower bound of 0.3 ha for the establishment of passion fruit plantations in year 1 without access to credit will come at a shadow cost of R$1893. With access to credit the shadow cost reduces to R$426 leaving a net gain of R$1147, which is due to the availability of credit.

In summary, improving credit access appears to be a useful instrument to enhance investments into indivisible capital intensive activities, but has little impact on income and environmental indicators.

8.1.2 The Example of Proambiente

The Proambiente approach (see section 4.11.1), although mainly credit based, is different in that it includes a subsidy component in combination with environmental standards regarding the choice of production technologies. A Proambiente-like scenario has been constructed here by allowing for credit as described in the previous section. In addition, only 60% of the original size of the credit needs to be paid back after 5 years, while only mulching and extensive perennial production are eligible technologies. Despite the strict formulation of the Proambiente principles that require farmers to go without chemical fertilizer, the use of NPK to avoid nutrient immobilization under mulch has been tolerated during the pilot phase and so is here. Model runs without the option of mulching turned out to be infeasible, because the minimum consumption requirements of the farm-household could not be met with the available production activities. The Proambiente-scenario clearly influences fallow age and area in a positive way, while average total carbon is about 40% higher than in the baseline. However, average non-essential consumption drops dramatically, which indicates that the average farm-household would not be able to maintain its living standard if it would stick to the Proambiente regulations.

The modified Proambiente (scenario 3) shows that it is possible to maintain income levels at their actual level if chemical fertilizer use would be allowed in combination with a 30% reduction of mulching costs. The negative impact of fertilizer use on the observed environmental indicators is relatively small if compared to the original Proambiente if mulching would be declared the only eligible land preparation technology for all cropping activities. The improvement in carbon sequestration in the modified Proambiente scenario is 30% if compared to the baseline, i.e. only a 10% loss due to the additional option of fertilizer use.

8.1.3 Environmental Standards, Subsidies and Taxes

Environmental standards, subsidies and taxes are the most typical policy instruments that are used in agro-environmental policy making. Like most other policy instruments they require a minimum institutional infrastructure to allow for monitoring and enforcement. Depending on the policy target modern technologies, such as remote sensing, can be used to reduce monitoring costs. Since one of the main objectives of environmental policy in old Amazonian colonization areas is the conservation of secondary vegetation, directly targeting secondary vegetation might be a more reasonable and technically feasible approach than the promotion of selected technologies. The legal reserve (section 4.11.1) is such an attempt, but it is probably too ambitious to expect smallholders in the Bragantina to set aside 50% or even 80% of their property. Nevertheless, at a first glance scenario 4 shows that setting aside a minimum of 5 ha hardly affects the baseline consumption levels of group II farms, while fallow age as well as area and carbon are positively affected. Due to the set-aside requirement, annual production becomes less profitable and the income loss is compensated by intensive perennial production. Yet, the switch in product mix comes at the cost of increasing market risk, which can be expressed in NPV of non-essential consumption using the risk indifference line in figure 6.4. According to the risk indifference line for a group II farm, this corresponds to a consumption loss of R$1514 (-4% as compared to the baseline) over the 25 year simulation horizon. This loss could theoretically be compensated through transfer payments.

Another more flexible option to conserve secondary vegetation is a permanent subsidy on areas that are taken out of the fallow cycle (scenario 5). The size of the subsidy could be determined depending on farm size to avoid that large farms benefit more than small farms. The scenario shows that a subsidy of at least R$/ha 100 is necessary to induce a group II model farm to set aside 0.36 ha of land for conservation. Overall effects on income and environmental indicators are positive and the amount of land set aside is economically optimal, which is not necessarily the case in the previous scenario. Figure 8.2 shows that below R$/ha 150, the annual set-aside payments necessary to induce forest conservation are lower in a scenario of full technology access than in the baseline. This is a consequence of the reduced value of forest in these scenarios, which has been shown in the previous chapter. The introduction of set-aside payments also increases the area under mulch, since mulching allows to use fallow vegetation more efficiently. However, in the range of simulated set-aside payments mulching continues require a cost reduction of at 50 to 90% depending on the size of the set-aside payment.

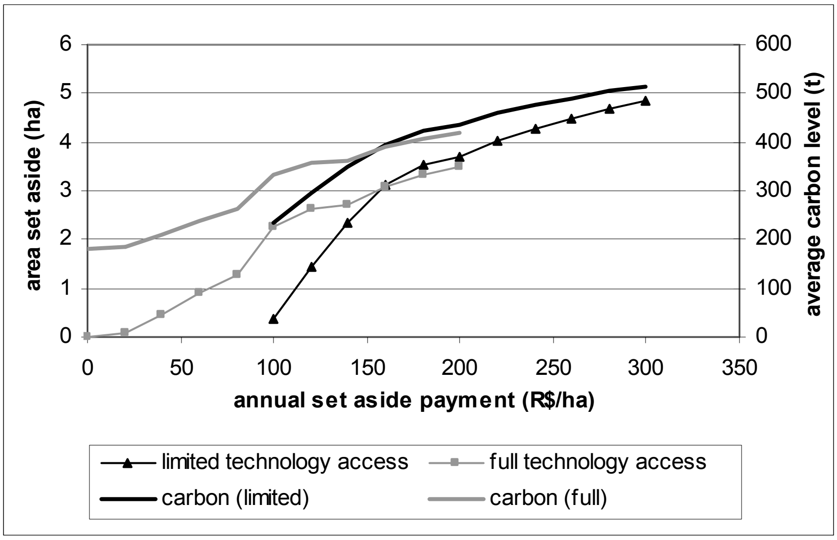

Figure 8.2: Set-aside payments and carbon sequestration under different scenarios of technology access

If the policy objective is to reduce greenhouse gas emissions and other external costs of the slash-and-burn practice in addition to the conservation of secondary vegetation, technology promotion[59] could be coupled with a tax on the use of slash-and-burn for land preparation. The potential effect of such a measure in combination with a 60% subsidy on mechanical mulching is summarized in scenario 7. The tax siphons off some of the profits that are generated through improved technology access, but the income gain remains positive if compared to the baseline. However, the indicators of environmental sustainability improve only if compared to full technology access without additional policy action (table 7.1). For the tax to enhance carbon sequestration beyond the baseline average carbon level, higher tax rates are necessary, which involves trade-offs with regard to the tax income (figure 8.3). The model suggests that even at a tax of R$/ha 500, household income is higher than in the baseline given full technology access.

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[59] Technology promotion is understood here as a government effort to establish the necessary frame conditions for the effective provision of technology services (e.g. tractors and machines that can be contracted at full or subsidized service costs) and agricultural extension.

With increasing tax rates, the size of the subsidy necessary to make mechanical mulching profitable reduces. At a tax of R$/ha 500, mechanical mulching is adopted at 70% of the calculated service costs.

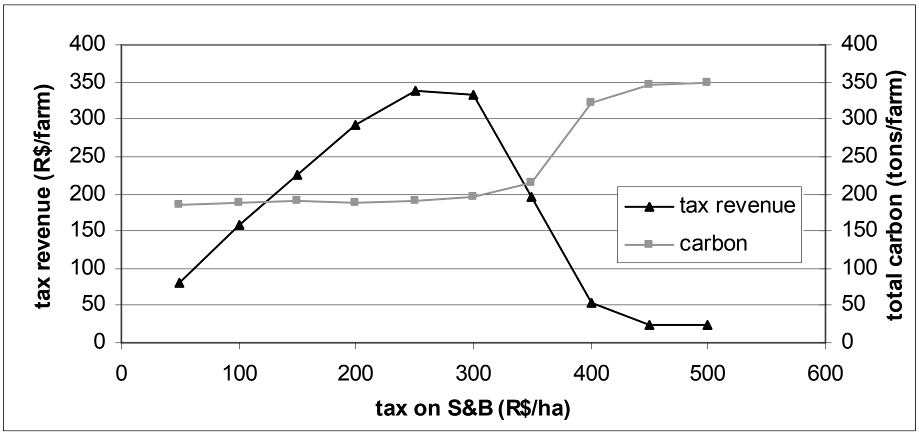

Figure 8.3: Tax revenue and carbon sequestration depending on the tax rate

8.1.3 Crop Yield Insurance for Technology Promotion

Model test runs with minimum prices and/or yield insurance schemes have shown that fertilizer use intensity generally increases as a consequence of reduced price/yield variation. However, with the fertilizer use intensity also the operational scale goes up especially in the case of annual crops, which has negative impacts on environmental indicators. Minimum prices for perennial cash crops can have positive impacts on income and environmental indicators, but since many cash crops are export products, establishing minimum prices can come at high costs and eventually violate WTO rules.

Since mulching has shown the potential to positively influence environmental indicators if it substitutes conventional technologies, the effect of a technology specific crop yield insurance has been tested in a “full technology access” scenario using the E-V model (section 3.3.6.3). Figure 8.4 shows the principle of the crop yield insurance in the form of cumulative distribution functions of a simplified cassava flour production activity using either S&B or mulching with and without crop yield insurance.

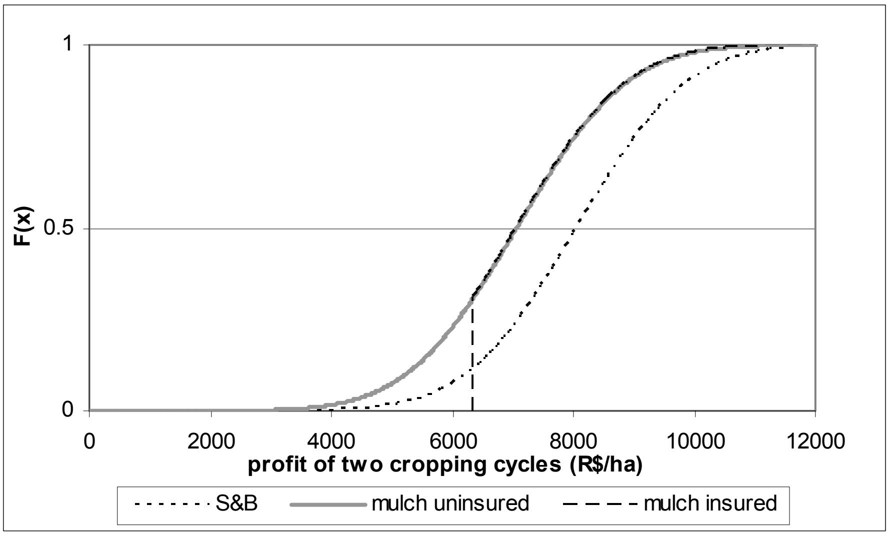

Figure 8.4: Cumulative distribution of the profits of two consecutive cropping cycles

It is assumed that mulching is provided to the farmer at full estimated service costs that include the insurance premium as a subsidy component; i.e. the farmer does not have to pay an additional fee for the crop yield insurance. If the yield on the mulched field falls below 90% of the expected yield (E(y)), the difference to E(y) * 0.9 multiplied with the cassava price will be reimbursed by the insurance fund.

The figure clearly demonstrates that the S&B activity first and second-degree stochastically dominates the uninsured mulching activity. But especially in the presence of risk aversion the first and second-degree stochastic dominance rules are not clear about the preference between S&B and mulching with crop yield insurance.

Table 8.2 shows the expected values and standard deviations for the three example activities. While these are known in the case of S&B and mulching without insurance it is necessary to estimate the two central moments of the truncated cumulative distribution function of the profits of mulching with insurance (appendix 12).

Table 8.2: Example calculation on the impact of a crop yield insurance for two consecutive cropping cycles

	S&B	**Mulch without insurance**	**Mulch with insurance**
	R$/ha	R$/ha	R$/ha
Expected profit	8062	7062	7355
Standard deviation	1432	1432	1064
Expected compensation			293

As figure 8.5 demonstrates, the crop yield insurance leaves overall fertilizer use intensity almost unaffected, but has a strong positive effect on the adoption of mechanical mulching when risk aversion increases. The area under mulch increases at the expense of area under both mechanical plowing and S&B and leaves the area under fallow almost unaffected.

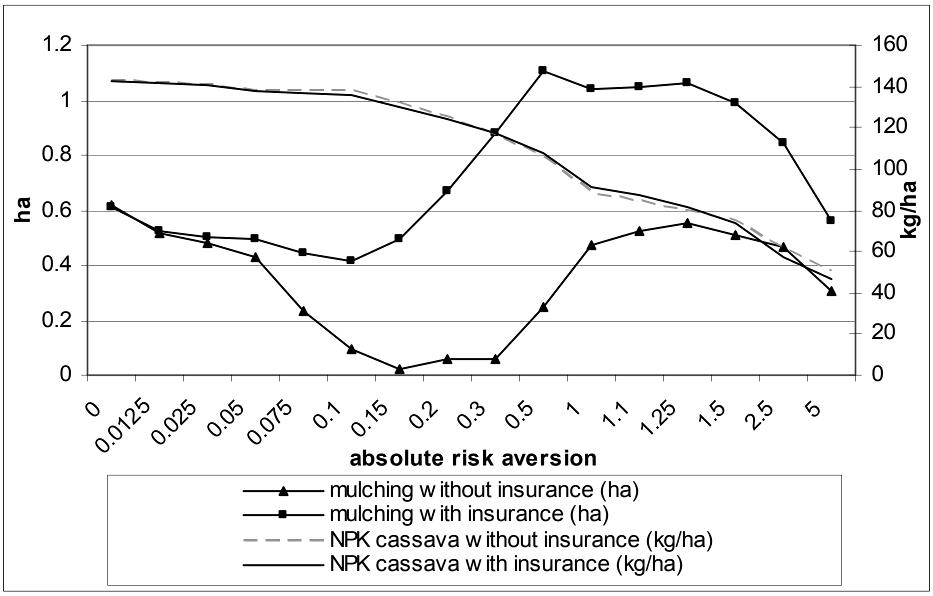

Figure 8.5: Mulching and fertilizer use intensity with and without crop yield insurance

The insurance leaves income and environmental indicators almost unaffected, but leads to a slight decrease of the area under degraded/unproductive fallow, the area under S&B, and the area under plowing in ranges of moderate risk aversion. Hence, the overall benefits do not necessarily accrue at the farm level, but in the form of reduced emissions of non-carbon greenhouse gas and potential damages from accidental fires.

9.0 Conclusions and Research Questions

The study was motivated by the observed need to answer questions related to the future prospects for smallholder livelihoods and the natural resource base at today's agricultural frontiers in the Amazon (see introduction). Frontier agriculture is characterized by very high deforestation rates and wide areas left covered by secondary vegetation, pastures, and agricultural crops.

Instead of focusing on areas currently undergoing rapid land cover changes, this study concentrates on an old colonization area, the Zona Bragantina. Smallholder agriculture has already transformed the landscape of the Bragantina into a patchy mosaic of agricultural crops and fallow vegetation[60]. This allows for the analysis of welfare and environmental effects of economic and technological change in a steady state type of situation not affected by rapid changes in the natural resource base. Such an analysis can provide clues as to how agricultural frontiers might develop where primary forests disappear, and whether and how primary and secondary forests can be conserved for the provision of global benefits without sacrificing rural welfare.

An additional motivation for the study was the emergence of technological alternatives to slash-and-burn for land preparation. Some of these alternatives appear promising in that they could reduce the social costs of traditional land preparation methods, mainly greenhouse gas emissions and material damages from accidental fires. However, in order to evaluate the costs and benefits of technological change it is necessary to analyze whether and how the technological alternatives are likely to be integrated into the existing technology mix at the farm level and what the potential impacts on household wealth and the environment will be.

The study does this by adopting a theoretical framework of household behavior. It starts off with a theoretical discussion of the implications of potential methodological approaches and a detailed description of the assumptions that underlie the final choice of methodology (part I). An extensive descriptive analysis in part II provides a background on the socio-economic and bio-physical frame conditions of smallholder agriculture in the study area. This information is necessary to establish a meaningful context for the development of policy and technology

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[60] Apart from smallholdings larger-scale commercial farms exist that engage in cattle holding and intensive perennial cropping.

scenarios in part III of the study that presents the results of simulations using a farm-household bio-economic model.

In the introduction, a set of research questions and hypotheses was formulated to guide the analyses in part II and III. These questions are picked up below and serve as a structure for the interpretation of the results.

Introductory research questions

1. **What are the major ecological and socio-economic peculiarities of smallholder development in the Bragantina?**

The colonization of the Bragantina region took place long before large infrastructure investments and economic incentives made it easier for commercial agriculture and industry to establish itself in the Amazon and encroach on land previously farmed by smallholders. This in combination with a close and stable outlet market in the nearby urban center Belém contributed to the development of a large smallholder sector with relatively strong social structures and a vital community life. Due to the relatively high returns to agricultural activities, e.g. intensive cash crop production and cassava processing, small-scale extensive pasture and livestock activities are less common on typical smallholdings than at the agricultural frontiers in the western Amazon. Large-scale commercial farms, however, continue to engage in cattle holding in many districts throughout the region.

The climate in the northeast of Pará is more favorable for agriculture than in many other parts of the Amazon due to the existence of short dry seasons that contribute to the development of deep rooting forest and fallow vegetation that provide a variety of agronomic benefits. However, annual rainfall is distributed unevenly over the Bragantina with negative agronomic implications for the eastern part of the region. Soils have good physical, but poor chemical properties, which makes external nutrient inputs necessary for many agricultural production activities.

The average size of smallholdings is lower than on more recent agricultural frontiers and the population density is comparatively high, such that the relative resource endowment is quite different from that of farms in the western Amazon or at the *Transamazônica*. Asset components of poverty and access to markets as well as extension service are unevenly distributed in the Bragantina and, with the exception of land and area under fallow, follow a negative gradient from west to east. As a consequence, many farm-households in the eastern Bragantina show signs of investment poverty, which is reflected in the use of more traditional production technologies.

Agro-industry development and the availability of other off-farm labor activities tend to follow the west-east gradient observed in farm-household data. The regional transport infrastructure, albeit far from being optimal, is of a better quality than elsewhere in the Brazilian Amazon.

2. **What is the role of fallow in a production system without primary forests?**

The deep rooting of fallow vegetation allows it to fulfill a variety of important agronomic functions, e.g. water and nutrient recycling from the subsoil. This is reflected in its high economic contribution to the value of annual crop production (22% of profits/ha, Mendoza 2005). The average fallow period for annual crops in the Bragantina lies between 7 and 10 years as opposed to 3 years on more recently cleared areas in the western Amazon (Vosti et al. 2002). This shows that farmers have adapted to the reduction of fallow re-growth capacity that natural scientists have identified to be the consequence of repeated slash-and-burn cycles.

Due to a lack of consistent time series data it was not possible to estimate the long-term impact of repeated slash-and-burn cycles on the soil productivity in the Bragantina. Nonetheless, it can be expected that it is at least not positive. That the average yield level in the region has remained relatively constant during the last 50 years suggests that two opposing forces have been at work. One the one hand, soil productivity was affected negatively by a slowly increasing degradation of fallow vegetation, but on the other hand, it was enhanced through the use of external nutrient sources. In the short-term it could be shown in both field experiments and farm data analysis that the length of the fallow period has a clear impact on the profits obtained in annual crop production.

The model simulations indicate that smallholders in the Bragantina are risk averse with respect to investments that increase market and production risk, e.g. fertilizer use in annual crop production and intensive perennial cash crop production. Thus, fallow as a natural nutrient source will continue to play an important role at least in annual crop production. Moreover, it was shown that technological change that increases the dependence on external nutrient supply necessarily increases the degree of uncertainty involved in agricultural production. For a risk averse farmer to benefit from technological change, this means that the increase in uncertainty has to be compensated by an increase in expected returns to a degree that depends on his/her individual risk indifference line (see section 6.3.1).

3. Do some smallholders exploit their resource base more than others? If yes, why?

Although regional differences exist in the quality of soils and in the amount of fallow available relative to the farm size, the differences are small and not always significant. Interestingly, better soil quality does not necessarily go hand in hand with higher productivity per ha, which shows that the land productivity depends more on the type of management than on the quality of soils.

Farms that have better soil quality and a higher share of fallow vegetation are typically larger than the average, but not necessarily wealthier in terms of income and household durables. Quite a number of low-income farm-households in the eastern part of the Bragantina (about 10% of the sample farms) are relatively well endowed with natural resources, but lack access to markets, information, and credit to use them more intensively. In the western part of the Bragantina the majority of farm-households engage in intensive perennial production and family members are involved more often in off-farm activities than the eastern counterparts. This reduces the pressure on natural resource use and could help explain why the degree of resource exploitation is rather homogeneous in the study area.

4. What are the external costs of using fire for land preparation?

Material damages from uncontrolled land preparation fires are lower than on the forest margins, but still significant in the years between 1997 and 2002. Farmers reported that on average R$/farm 50 (25% of the estimated damage on smallholdings at the forest margins) are lost every year due to accidental fires. However, the figure is subject to large variations depending on the location of farms and the value of standing crops, i.e. perennial crops are valued higher than annual crops. Usually, the farmers are not compensated for the loss, even though it is not self-inflicted in most cases. Health costs measured in the cost of medical treatment and the value of lost working days appeared to be negligible.

Additional external costs accrue in the form of greenhouse gas emissions, but a quantification of these costs appears speculative in the absence of a market for emissions from agriculture.

5. What type of policy action has proven successful in conditioning land use decisions and technology choice?

Most successful in influencing land use decisions and technology choice in the past, have been regional economic integration, infrastructure improvements, and policy induced agro-industry development. Also the FNO credit scheme had an impact on the crop and technology mix on smallholdings. Local efforts to improve access to extension service and mechanical land preparation may or may not be successful, depending on the capacities of local governments to acquire and maintain the necessary equipment and adequately administer the service.

Not all types of policy action shows equally positive effects on poverty alleviation and the conservation of environmental quality. In fact, existing environmental policy measures, for example the minimum forest conservation requirement, are far too ambitious and not enforced.

Especially in the eastern part of the region, some farmers are virtually excluded from policy measures that affect farm level supply, e.g. credit schemes, co-funding of local infrastructure projects and minimum prices, because government organizations and extension services lack the capacity to overcome information asymmetries or establish transparent administrative standards.

Model related research questions

1. **Is the existing dominant land use system environmentally and economically sustainable?**

The model baseline confirms the **steady-state hypothesis** for the average smallholding in the Bragantina only partially. While non-essential consumption, and hence income, shows to remain stable over time, especially fallow age (i.e. quality) and total sequestered carbon decrease during the first half of the 25 year simulation period. Access to mechanical land preparation technologies positively alters the steady-state of household non-essential consumption, but accelerates the degradation of natural resources during the first half of the simulation period. Natural resource degradation mainly influences the profitability of annual crops in the slash-and-burn system, which tends to be compensated through a slight extension of perennial cropping. Although this crop mix change exposes the household to increasing market risk the measured increase is not statistically significant. Varying the underlying assumptions[61] with regard to the substitutability of natural and physical capital alters the level of the steady state, but does not affect its stability. Hence, the existing land use system can be characterized as economically sustainable at least in the weak sense of sustainability (see section 3.3.7).

2. **What are the major constraints on current land use and intensification strategies?**

The shadow prices of the baseline model run partially confirm **hypothesis 1**. Labor is in fact more abundant in the Bragantina than in most other rural areas of the Amazon region, which allows for the widespread adoption of labor intensive cash crops. However, during peak labor

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[61] E.g., the amount of fallow rehabilitation years necessary for fallow to return to the productive cycle.

months, labor becomes scarce and can be a limiting factor on farms without access to mechanical land preparation technologies.

Land is only scarce as far as its potential for fallow re-growth is concerned, which is reflected in the high shadow value of fallow as opposed to the low value of land. However, the use of mechanical land preparation, e.g. plowing, increases the operational scale of annual cropping and reduces the value of fallow vegetation, since it no longer provides nutrients and other agronomic services. Consequently, the shadow value of fallow reduces as opposed to the value of land.

Hypothesis 2 has to be rejected as cash availability does not seem to be a limiting factor as far as divisible investments, e.g. fertilizer, are concerned. In the case of divisible investments, credit scenarios show that credit access considerably reduces the shadow costs of investments. This leads to the conclusion that cash constraints do not represent an insurmountable barrier to land use and technology change. They merely contribute to slowing down investment that would take place more rapidly over time if access to credit were easier.

3. **To what extent do these constraints play a role in the adoption of alternatives to slash-and-burn, such as conventional mechanical land preparation or mulching?**

With respect to **hypothesis 1** the model suggests that the effect of increasing wages on the adoption of mechanical land preparation technologies is ambiguous. If wages increase only during land preparation seasons, the area under mulch increases only slightly towards the end of the simulation period. On average, however, less area is prepared mechanically, because cash requirements for hiring labor in perennial production increase together with the opportunity costs of on-farm labor. A general increase in the wage level has a clear negative impact on the adoption of mechanical land preparation for annual cropping as it also affects the productivity of cassava flour production in all months of the year.

The technology simulations confirm **hypothesis 2** as mulching only becomes a competitive land preparation technology if the service costs are about equal to the costs of mechanical plowing or if a tax is imposed on the use of S&B[62]. Also set-aside payments and a technology specific crop yield insurance positively affect the adoption of mulching as opposed to all other land preparation technologies.

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[62] S&B is necessary in regular intervals even in systems of mechanical land preparation.

Technology scenarios also clearly confirm **Hypothesis 3**. Both mechanical mulching and plowing relax labor and fallow constraints, thus leading to an increase in the operational scale of annual crop production. Yet, small negative changes in the cassava flour price, e.g. as a consequence of a positive regional supply shift, are likely to only partially off-set the scale increasing effect of technological change. This is a result of a sensitivity analysis that shows cassava supply to be very elastic in lower price ranges and inelastic in higher price ranges.

4. What is the impact of risk aversion on product mix?

As expected, increasing risk aversion induces farmers to change the crop mix in favor of annual crops and extensive perennial production, because prices tend to fluctuate less for these activities than for intensive perennial cash crops. Among these, passion fruit dominates the crop mix of a risk neutral farmer and gets partly displaced by pepper with increasing risk aversion. For annual crops, increasing aversion to market risk leads to a reduction of the area under beans that is compensated by additional cassava flour production. Including aversion to production risk changes the picture only with respect to the relationship between these two annual crops because the unknown variation is higher in cassava than bean production.

5. What is the impact of risk aversion on technology choice?

As a consequence of the previous result, the adoption of technologies for annual and extensive perennial cropping generally increases with risk aversion. Without policy action, e.g. in the form of technology specific crop yield insurance, the results of the technology simulations remain unaffected by increasing risk aversion. Nonetheless, the **hypothesis** established for this research question holds with regard to input use. Fertilizer use intensity in cassava production goes down with increasing risk aversion, while the effect in the case of perennial cash crop and bean production is ambiguous. Although it would go too far to attribute the low adoption of chemical fertilizer in cassava production solely to risk averse behavior, it can be concluded that risk aversion is an important contributing factor.

6. If not privately, but socially profitable, what types of incentives are necessary to induce a given level of technology adoption? (see also next question)

The technology simulations show that all technological alternatives in question, except for mechanical mulching, are privately profitable without specific policy action. However, the precondition is that technology and market access (for on-farm processing products) is possible at reasonably low transaction costs, which is not the case in most of the districts in the study area. As stated in the **hypothesis**, with the exception of on-farm processing of agro-forestry products, the mere provision of technology access tends to affect indicators of environmental sustainability in a negative way. Only if access to new technologies is coupled with environmental standards on technology use, taxes on S&B, set-aside payments, or a technology specific crop yield insurance does it appear possible to enhance farm household income, fallow conservation, and carbon sequestration.

Mechanical mulching has a higher potential than plowing when it comes to reducing the social costs of land preparation in the study area. But especially if farmers have full technology access, the 90% subsidy necessary to make mulching competitive with mechanical plowing greatly exceeds the potential reduction in social costs associated with fire. Hence, further cost reducing technology development is necessary if mulching is to be a realistic option for reducing the social costs of traditional land preparation practices. Possible cost reducing modifications include, for example, the use of less powerful mulching equipment in combination with young fallow vegetation on areas that have long been cleared from primary forest. In addition, it is possible to reduce the number of treatments per plot from two to one, which would increase the size of the mulch particles. The combination of these measures could reduce the estimated mulching costs by up to 40%. In some policy scenarios, e.g. the tax on slash-and-burn and the technology specific crop yield insurance, this cost reduction would make an additional subsidy of mulching service costs superfluous.

7. **Do policy-technology combinations exist that can simultaneously reduce environmental degradation and poverty in the region?**

Only a few scenarios show a clear improvement of welfare and environmental indicators compared to the baseline. It is, however, likely that the baseline is too conservative with respect to technological change. Although new technologies will probably not disseminate as fast as the technology simulations suggest (the social aspects of technology simulations have not been considered in the model) it is realistic to expect that more and more farms will engage in mechanical plowing and more intensive fertilizer use in the near future. Consequently, average fallow age, fallow area, and total carbon might decline more rapidly over time than in the model baseline. It is therefore reasonable to think about options for cushioning the negative impact of technological change on the environment through the use of appropriate policy measures.

A promising example in this regard is the option of taxing S&B while providing appropriate access to alternative land preparation technologies. It was shown that an annual tax revenue of up to R$340 per average farm type could be collected, while simultaneously increasing household income, fallow quality and carbon sequestration. Moreover, increasing the tax rates also reduces the size of the subsidy necessary to make mechanical mulching competitive, such that at a tax R$500 per ha prepared by S&B, mulching is adopted at 70% of the full service costs. A tax without improving technology access is not recommended as it would have serious negative impacts on household income.

Set-aside or fallow conservation payments are policy options that improve both household income and carbon sequestration. Yet, from the point of view of a policy maker facing a tight budget, such options appear less attractive due to their additional financial burden not directly compensated through tax revenues.

8. **What is the effect of policy instruments in reducing market and production risk?**

The model suggests that market risk reducing policies, such as minimum prices, have a potential to improve the income of risk averse households. However, regardless of the type of product targeted by this policy, environmental indicators are negatively influenced.

A reduction of production risk has essentially the same effect, as long as it is not technology specific. For example, if only the yields of mulched fields are covered by crop yield insurance, the overall effect on the environment is positive. The crop yield insurance shifts the expected return to mulching upwards and the technology is adopted at a higher rate than without the insurance. At the same time the area under both slash-and-burn and plowing goes down, which leads to a higher amount of productive fallow on the average smallholding. An additional positive off-farm effect would be a reduced amount of mainly non-carbon greenhouse gas emissions and material damages from accidental fires.

9. **What are the impacts of shifts in product and/or input prices on land use and technology choice and the performance of policy instruments?**

Increases in product prices generally have positive impacts on household income and, with the exception of the price of extensive perennials, negative impacts on fallow conservation and carbon sequestration. Rising input prices negatively affect household income, while increasing carbon sequestration, fallow area, and average fallow age. Technologies that strongly depend on the input of external nutrients, such as intensive perennials and mechanical plowing, become less attractive in the face of rising fertilizer prices. For the average type of farm-household increasing wages negatively influence household income. For the farm types identified in the eastern Bragantina the effect if in creasing wages depends on the existence of off-farm labor opportunities. If off-farm opportunities are available, higher wages can have positive welfare effects as these farms are less dependent on hired labor for cash crop production.

10. To what extent are the results valid beyond the borders of the study region?

In terms of the combination of relatively good market access and a regional infrastructure including transport facilities and agro-industry, the Bragantina case is probably unique in the Amazon at this point in time. However, urban centers in the south of Pará and in the Western Amazon are growing and becoming increasingly connected at the national and international level. In this context the Bragantina can serve as a reference scenario for future development in more recent settlement areas hosting a large number of smallholders.

Smallholdings in these areas are typically larger than in the Bragantina*,* and hence, dispose of a larger area under productive secondary vegetation or even primary forests. The lessons from the Bragantina case indicate that, given the abundance of productive fallow land, annual crop production will continue to be profitable even in the presence of technological alternatives. Meanwhile, mechanical land preparation might be even more attractive to smallholders that face more serious labor constraints than farmers in the Bragantina. This implies that carbon sequestration and natural resource degradation are likely to continue even if primary forest clearing comes to a halt.

Independent of the choice of land preparation technology that dominates the technology mix, the Bragantina case demonstrates that an economically sustainable steady state with respect to natural resource use is possible on archetypical smallholdings. The quality and level of this steady state depends critically on the type of policy environment encountered by smallholders, but also on the agronomic suitability of climate and vegetation that have shown to be quite heterogeneous in the Amazon region. Subsidy and tax schemes that directly target broad land use categories, such as fallow or secondary vegetation of different age classes, are likely to be successful on agricultural frontiers as well. Vosti et. al (2002), for example, have shown that the amount of set-aside payments necessary to induce forest conservation in Acre and Rondônia is not much different than in the Bragantina case.

9.1 Policy Messages

This section addresses decision-makers in government and non-government organizations at the local, regional, national, and international level, whose interests are not always in line. While many international organizations represent the interests of the global community with respect to the conservation of globally relevant natural resources, local policy makers in urbanized districts have to attend the needs of the urban population, and the mayors of rural districts are concerned with raising tax incomes, e.g. through the promotion of agricultural intensification.

However, the analysis using the bio-economic model has underlined that focusing on natural resource conservation alone is very likely to imply costs with respect to economic development and rural welfare and *vice versa.* Policy action is therefore more likely to raise long-run sustainability if it tries to simultaneously address development objectives. Promising examples in this regard can be found in the actual Amazonian policy landscape, which is why the policy messages from this study are divided into recommendations for the improvement of existing policy action and additional implications from the study.

Recommendations for Existing Policy Action

1. Promotion of technological change

The promotion of technological change in agriculture is more common in districts that have higher tax incomes from the urban population. It is typically done by providing subsidized access to mechanical land preparation in combination with agricultural extension services. Unfortunately, not all farmers benefit equally from the service provision due to a lack of transparency in the process of contracting the service. The model simulations and field experiences indicate that it is not necessary to subsidize the access to mechanical plowing as it is contracted even at the price of private suppliers. In fact, it is even possible to levy a tax in the range of R$/ha 200 – 300 on the undesirable exercise of S&B on farms that benefit from improved technology access without affecting household income in a negative way. Without such a measure, S&B and mechanical land preparation will coexist with negative impacts on the environment.

The technological option of agro-forestry and on-farm processing should receive more attention when it comes to promoting technologies at the local level at least in districts with good marketing opportunities. Apart from vitalizing the local labor market and improving household income at low investment cost, this could have positive impacts on environmental indicators without requiring countervailing policy measures.

The promotion of mulching can only be recommended if real service costs can be reduced by more than 50%. As with plowing, a promotion of the mulching technology needs to be combined with additional measures to avoid negative impacts on the environment. Set-aside payments in the range of R$/ha 100 -150, a tax as proposed above, or a technology specific crop yield insurance appear to be promising candidates in this regard. From an ecological point of view mulching is to be preferred to plowing as it maintains below ground carbon, fallow re-growth capacity, and completely avoids the external costs of the use of fire for land preparation.

A system-inherent problem arises from the competitive nature of mechanical mulching and plowing as long as mulching is more expensive for service providers. If the acquisition of tractors for public service provision is subsidized as in the case of the *patrulha mecanizada*, these tractors are more likely to be used for plowing than for mulching. Hence, if the objective is to promote mulching, the institutional framework with respect to monitoring and enforcement of service provision regulations would need to be much better developed.

2. Proambiente and Smallholder Credit Schemes

The Proambiente approach started off with the aim of promoting rural welfare and environmental protection simultaneously through the provision of subsidized credit for farmers that switch to more environmentally friendly production technologies. It is, however, unlikely that farmers will voluntarily enter the program if the proposed ban on chemical fertilizers is fully enforced. Model simulations suggest that not using chemical fertilizers implies extremely high opportunity costs for farmers that engage in intensive perennial production. A more realistic scenario would be to promote the on-farm processing of agro-forestry products along with mechanical mulching as the only eligible land preparation technology for both perennial and annual crops. Fertilizer use should not be affected by the program regulations as it represents the only viable means to produce important cash crops, such as passion fruit and pepper, apart from being a necessary supplement of the mulching technology. If the real service costs of mulching cannot be reduced through further technology development, a subsidy of at least 40% of the mulching costs is necessary to maintain the income level of an average type of farm-household under the modified Proambiente scenario.

The combination of mulching (at reasonable service costs) and agro-forestry bears the potential to provide positive synergistic effects at a local and regional scale. The reason is that agro-forestry, more than many other perennial crop operations, represents a long-term investment. The risk of being damaged by accidental fires from slash-and-burn operations increases with the lifespan of the activity. The use of fire-free land preparation technologies in the neighborhood would therefore increase the expected return from agro-forestry plantations.

3. Minimum Prices

The model suggests that the actual level of minimum prices for annual crops hardly affects the production decisions of a typical risk averse farmer in the study area. Increasing minimum prices does not seem to be the first best measure to combat rural poverty and exposure to market risk. Since such a measure positively affects expected revenues it tends to increase the operational scale of agricultural activities, which would improve welfare indicators at the cost of reduced fallow quality, fallow area, and carbon sequestration.

Policy measures with the single purpose of addressing rural welfare should rather affect household income directly as in the case of pension payments and school grants that enhance consumption without affecting production in a specific way. This avoids negative impacts on carbon sequestration and fallow conservation that accompany an expansion of annual cropping.

Additional Policy Implications

1. Technological and economic change

Even without the official promotion of technological change, the trend towards the mechanization of land preparation on smallholdings in the Bragantina and in other parts of the Amazon is likely to continue. This study indicates that mechanical land preparation will not substitute for the use of fire for land preparation. Instead it suggests that farms that have access to mechanical land preparation will increase their operational scale, causing considerable losses of below and above-ground carbon and a reduction of the total area under secondary vegetation and remaining primary forests. Conventional mechanical land preparation comes with a more intensive use of external inputs, such as chemical fertilizers and other agrochemicals. Apart from the short-term irreversible loss of productive fallow vegetation this will increase household wealth, but also expose farmers to higher production and market risks. Moreover, it will increase the pollution of groundwater and river streams that still serve as the primary source of drinking water for the rural poor. Along with addressing the social costs of slash-and-burn, avoiding the negative environmental consequences of the mechanization of land preparation is likely to represent the major challenge for the design of agro-environmental policies in the near future.

Several potential counteracting policy instruments were tested in model simulations. A tax on S&B for farms that benefit from improved technology access and the option of set-aside payments appeared to be reasonable measures for conserving below and above-ground carbon and reducing the external costs of the slash-and-burn practice. The results provide an indication of the degree of intervention necessary to induce a given level of natural resource conservation on a typical smallholding (chapter 8).

2. Regional Heterogeneity

Especially smallholders in the eastern part of the Bragantina represent a group of farm-households that does not benefit as much from technological change as their western counterparts. The reasons for that are many and certainly not all related to the distance to the urban center Belém. However, if technological change continues to take place at different paces these farmers will increasingly suffer from a comparative disadvantage. Since they depend mainly on annual crop production, they are more vulnerable to negative changes in cassava flour prices - a likely consequence of improved access to mechanical land preparation in the rest of the Bragantina. In the absence of technological alternatives to slash-and-burn this can be expected to affect both welfare and environmental indicators negatively as low-income households will have to increase the operational scale of farming activities to meet consumption requirements.

Regional development strategies should therefore seek to offset regional comparative disadvantages with respect to technology access. The tax option appears most promising in this regard as it would allow re-investing tax revenues from economically well-off districts into technology promotion or set-aside payments in underprivileged areas.

3. Risk reduction

Engaging in new agricultural activities or switching from one to another land preparation technology is always a risky business. Often the use of a certain technology appears to be desirable both privately and from a society's point of view, but farmers remain reluctant. In these cases technology specific crop yield insurance schemes including subsidized insurance premiums appear to be a cost effective alternative to subsidizing the costs of the technology. As opposed to the direct subsidy, the insurance only involves costs for the provider if technology performs worse than expected, whereas the subsidy has to be paid even if the beneficiary increases his/her profits through the use of the technology.

4. Credit

Credit has shown the potential to serve as a catalyst especially for investments of an indivisible character. The model suggests that taking credit is profitable for smallholders even at relatively high interest rates (up to 15% real interest rate). In view of the low repayment rates of large amounts of credit for smallholders it is proposed to alleviate cash constraints through the provision of micro-credits. A necessary precondition is that micro-credits can be accessed at reasonably low transaction costs, which would be possible, for example, if credits could be provided to the farmers through the local trade unions. Most trade unions are known, trusted, and frequently visited by many smallholders and are experienced in the administration of pension payments. This makes them a better facilitator for credit than, for example, extension services or the banks themselves.

5. Agro-industry development off and on-farm

Agro-industry can provide rural off-farm employment opportunities and model simulations have shown that, depending on the type of industry, this can take pressure off natural resource use in annual production. In fact, agro-industry that provides a secure outlet market for perennial crop production is likely to enhance the conservation of secondary vegetation, carbon sequestration and smallholder income simultaneously. Some types of product conversion can be done on farm, while more complex processes require the establishment of larger scale individual production plants. Developing appropriate marketing channels and strategies for processed agro-forestry products can be a first step towards sustainable resource use and poverty alleviation in areas that are well connected to the local and regional market.

9.2 Implications of Model Assumptions on the Interpretation of Results and Future Research

This section briefly reviews the main assumptions made in the farm-household modeling exercise and provides some indication as to how interpretations might change if the assumptions were violated. Since some of these assumptions had to be made in lieu of information for a more accurate representation of real world relationships, implications for future research are derived whenever possible.

Strong and Weak Sustainability

In the absence of reliable bio-physical and agronomic data, an assumption had to be made with regard to the possibility of substituting agronomic fallow services with an external supply of soil nutrients and organic matter. The assumption represents the best possible guess based on expert opinions, but cannot be taken for granted. For example, very little is known about the impact of repeated mechanical land preparation on long-term soil productivity. Assuming an irreversible and strong negative impact would alter the model results considerably in favor of slash-and-burn and perennial cropping. Assuming a lower potential substitutability of natural and physical resources also affects conclusions with regard to the long-run sustainability of slash-and-burn agriculture. If repeated slash-and-burn cycles exhaust soils and fallow vegetation such that productivity cannot be maintained through external nutrient supply, smallholders will have to switch to other eventually more risky crop mixes that are dominated by perennial cash crops. The welfare implications of such changes are typically not reflected in official statistics that report only the expected value of farm income. However, it has been shown in section 6.3.1 that a risk-induced increase in income variation represents real income losses for risk averse farm-households (depending on the slope of the risk indifference line). Thus, such a scenario would have to be interpreted as a welfare loss.

Under such circumstances it is unlikely that a tax on the use of slash-and-burn would bring about the desired positive impact on fallow conservation without negatively affecting household income. Moreover, higher fallow/forest conservation payments would be necessary to avoid the more intensive use of fallow vegetation, especially in areas where farm-households depend more on annual cropping (e.g. in the eastern Bragantina).

Hence, more explicit conclusions with regard to the long-term sustainability of agriculture in the area require more precise knowledge of the long-term impact of alternative land preparation technologies on soil productivity characteristics and yields. Of particular interest from an economic point of view is the impact of land preparation on labor requirements for weeding as these appear to be related to the existence and length of fallow periods.

Stability of Farm and Family Size

The model assumes that farm size as well as family size and composition remain constant over time. This might be a reasonable assumption as farm sizes and population density have shown little changes in the past and the model is used to represent an average type of smallholder. However, land use mix and technology choice of an individual farm-household will differ considerably in response to the demographic changes a family and its community undergo over time. In order to simulate these phenomena it is necessary to represent the region spatially more explicitly in a multiple-agent approach. Such an approach would allow a more explicit analysis of the social determinants of technology adoption and smallholder development at the regional scale.

Farm-household objectives (utility)

The model results were generated assuming that the farm-household maximizes consumption and minimizes risk-induced income variation. Changing this assumption can, but needs not change the baseline results. Yet, it surely has far-reaching consequences for some technology and policy results. For example, if the main household objective was the minimization of family labor (measured in days or subjective values) subject to minimum consumption requirements, a similar baseline solution would emerge. Yet, the introduction of chemical fertilization or mechanical land preparation would affect the operational scale of annual production much less than in the actual baseline. Instead, technological innovations would be evaluated much more with regard to their contribution to saving family labor than to maximizing household income. For both chemical fertilizers and labor saving mechanical land preparation technologies this implies that they would be adopted in order to reduce the scale of agricultural operations as far as this would allow meeting family consumption needs at lower labor inputs. Moreover, for net food importing farm-households, the changed assumption implies that they would increase their operational scale if prices of food and other consumption goods increase. A better understanding of these processes requires more accurate knowledge about the returns to scale of agricultural activities and the dynamics of local labor markets, since these will be the main factors determining land use decisions and technology choice of labor minimizing households.

Appendices

Appendix 1

1. The Wealth Index

Since neither the quality nor the price of the household and agricultural assets is known, assigning value-based weights is not possible. Instead of defining objective weights, principal component analysis PCA can be used to assign weights based on the structure of the data. Following Sahn and Stifel (2000) the wealth index is constructed by extracting the first principal component from the data set that consists of dummies indicating whether a household owns the respective item or not. The result of the PCA is a scoring factor *f* for each asset type that can be used to calculated the wealth index *WIj* such that:

$$WI_j = f_1 \times \frac{\left(a_{j1} - \bar{a}_1\right)}{s_1} + \ldots + f_n \times \frac{\left(a_{jN} - \bar{a}_N\right)}{s_N} \qquad (1)$$

Where a_{j1} is the *j* th household's value for the first asset and a_1 and s_1 are the mean and standard deviation of the first asset variable over all households.

2. The distribution of the wealth index for household assets

Using the index, each household is assigned to the bottom 20%, the middle 60% or the top 20%. The three last columns of table 1 and table 2 represent the percentage of households that own a given asset. Because the asset variables only take the values 0 and 1 (yes or no), the weights are easy to interpret. For example, owning a refrigerator increases the index by 0.33 and using fire wood for cooking lowers the index by 0.13.

Table 1: Wealth index distribution and coherence for household assets

Assets	Scoring factors	Mean	Std.Dev.	scoringf/ std.dev	Poorest 20%	Middle 60%	Richest 20%
Water connection	0.28	0.38	0.49	0.57	0.000	0.193	0.833
Sound system	0.23	0.30	0.46	0.50	0.037	0.147	0.741
Bath room	0.25	0.30	0.46	0.54	0.037	0.138	0.815
12 V battery	-0.05	0.20	0.40	-0.12	0.185	0.284	0.148
Bike	0.15	0.87	0.33	0.45	0.648	0.890	0.981
Truck	0.10	0.03	0.16	0.62	0.000	0.009	0.093
Car	0.17	0.08	0.28	0.61	0.000	0.018	0.352
Stone house	0.23	0.33	0.47	0.49	0.000	0.211	0.704
Mud hut	-0.20	0.66	0.48	-0.42	0.926	0.771	0.296
Frame house	0.08	0.11	0.31	0.26	0.056	0.083	0.222
Electricity	0.29	0.62	0.49	0.59	0.148	0.505	1.000
Rifle	-0.03	0.46	0.50	-0.06	0.481	0.486	0.519
Water filter	-0.09	0.41	0.49	-0.18	0.519	0.495	0.259
Electric iron	0.07	0.01	0.10	0.70	0.000	0.000	0.056
Gas-fired stove	0.23	0.83	0.37	0.62	0.370	0.899	1.000
Wood-fired stove	-0.13	0.87	0.33	-0.39	0.963	0.917	0.630
Fridge	0.33	0.49	0.50	0.66	0.000	0.303	1.000
Sewing-machine	0.18	0.35	0.48	0.38	0.019	0.339	0.685
Camera	0.09	0.11	0.31	0.29	0.000	0.110	0.204
Washing machine	0.08	0.02	0.13	0.62	0.000	0.000	0.074
Motor-bike	0.11	0.14	0.34	0.32	0.000	0.119	0.259
Motor	0.10	0.11	0.31	0.32	0.019	0.101	0.241
Furniture kitchen	0.18	0.87	0.34	0.53	0.556	0.927	1.000
Furniture dormitory	0.19	0.89	0.31	0.61	0.593	0.936	1.000
Furniture living room	0.25	0.70	0.46	0.54	0.204	0.706	0.981
Satelite dish	0.26	0.28	0.45	0.58	0.000	0.110	0.759

Assets	Scoring factors	Mean	Std.Dev.	scoringf/ std.dev	Poorest 20%	Middle 60%	Richest 20%
Brunnen	0.03	0.03	0.16	0.19	0.000	0.046	0.037
Drinking water pot	0.01	0.02	0.15	0.07	0.000	0.028	0.019
Radio	0.05	0.53	0.50	0.10	0.444	0.541	0.556
Television	0.31	0.61	0.49	0.63	0.037	0.532	1.000
Wealth Index Status		***0.00***	***2.38***		***-2.40***	***0.83***	***2.21***

Source: SHIFT/NAEA field data 2002/3

Looking at the last three columns of the table shows that the procedure assigns reasonable weights to the respective assets. For example, only 3.7% of the least wealthy households have a toilet comparing to 82% of the wealthiest and 0% of the least wealthy own a car, as opposed to 35% of the wealthiest.

2.3 The distribution of the wealth index for agricultural assets

Table 2 presents the results of repeating the analysis for agricultural assets. The lower standard deviation indicates that the distribution of agricultural assets is less heterogeneous than in the case of household durables. Nevertheless, this index is also internally coherent.

Table 2: Wealth index distribution and coherence for agricultural assets

Assets	Scoring factors	Mean	Std.Dev.	scoringf/ std.dev	Poorest 20%	Middle 60%	Richest 20%
Fixed weir	0.16	0.04	0.21	0.76	0.000	0.009	0.167
Watering place	0.05	0.01	0.09	0.56	0.000	0.000	0.037
Pepper processing plant	0.23	0.05	0.22	1.05	0.000	0.000	0.222
Ox	0.10	0.01	0.09	1.11	0.000	0.000	0.037
Hand barrow	0.36	0.44	0.50	0.72	0.034	0.250	0.963
Cassava flour processing plant	0.19	0.48	0.50	0.38	0.190	0.473	0.778
Digger	0.30	0.57	0.50	0.60	0.086	0.536	0.926
Stable	0.20	0.06	0.23	0.87	0.000	0.018	0.185
Digging device	-0.04	0.02	0.13	-0.31	0.034	0.018	0.000
Large knife	0.20	0.94	0.23	0.87	0.776	0.982	1.000
Pruning knife	0.26	0.71	0.45	0.58	0.310	0.723	0.944
Barn	0.20	0.10	0.30	0.67	0.017	0.018	0.333
Tool	0.23	0.01	0.10	2.30	0.000	0.000	0.056
Mattock	0.23	0.77	0.42	0.55	0.466	0.795	0.926
Hammer	0.00	0.00	0.06	0.00	0.000	0.009	0.000
Chain saw	0.17	0.07	0.25	0.68	0.000	0.018	0.185
Pick axe	0.01	0.01	0.09	0.11	0.000	0.009	0.000
Planting device	0.25	0.33	0.47	0.53	0.052	0.241	0.648
Pig pen	-0.01	0.08	0.27	-0.04	0.121	0.071	0.056
Pulverizer	0.33	0.37	0.48	0.69	0.034	0.205	0.815
Storage barrel	0.31	0.31	0.46	0.67	0.034	0.170	0.796
Tractor	0.24	0.02	0.13	1.85	0.000	0.000	0.093
Wealth Index Status		***0.00***	***1.80***		***-1.46***	***0.28***	***1.36***

Source: SHIFT/NAEA field data 2002/3

Appendix 2

All figures (except superscripts) in the table are standard deviations.

Table 1: Standard deviations and mean t-test results at the 95% significance level

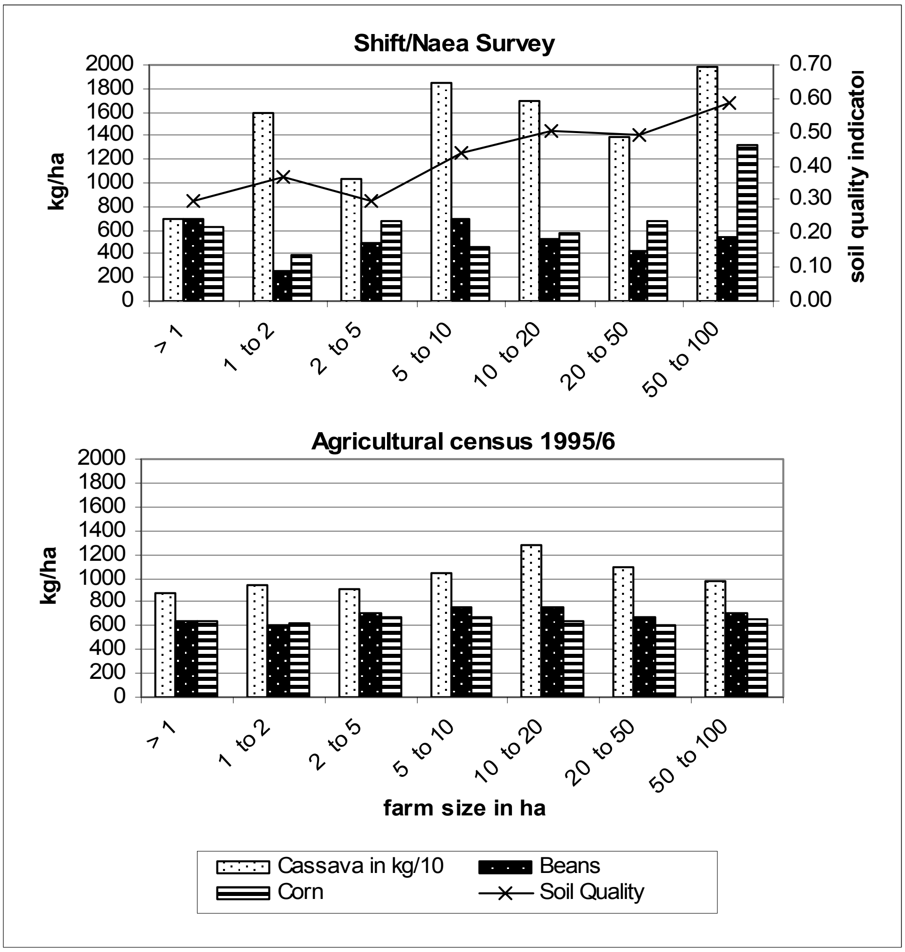
	1. Quartile	2. Quartile	3. Quartile	4. Quartile	Means
Total per capita income	***147^{234}***	***170^{34}***	***423^{4}***	***14462***	***7787***
Agricultural per capita income (R$ year -1)					
Crop production	139^{234}	284^{34}	607^{4}	7204	4066
Livestock production	54	141	113	12977	6519
Total agricultural production	153^{234}	281^{34}	606^{4}	14358	7658
Share of commercialized production value (%)	28^{234}	27^{4}	29^{4}	27	29
Off-farm per capita income (R$ year -1)					
Non agricultural off-farm employment	122^{34}	155^{4}	192^{4}	413	254
Remittances	23	24	41	41	33
School grants	19	17	16	14	16
Old age grants	98^{234}	263^{34}	375	705	447
Agricultural off-farm employment	59	44	116	138	97
Physical endowment (ha)					
Total farm land	21.0^{4}	29.8^{4}	16.7^{4}	38.3	28.3
Old fallows in % of farm land (average age)	19.6^{4} (9^{34})	19.4 (9^{4})	18^{4} (11^{4})	19.9 (12)	19.3 (10)
Young fallows in % of farm land (average age)	64.7^{3} (4)	30.6^{3} (4)	27.1 (4)	25.5 (4)	40.1 (3)
Cropland	1.9^{234}	2.3^{4}	2.9^{4}	7.9	4.7
Soil quality	0.93*	0.96	0.92	0.77	0.69
Wealth index (agricultural assets)	1.23^{234}	1.46^{34}	1.58^{4}	2.05	1.80
Wealth index (household assets)	2.20^{234}	2.01^{4}	2.27^{4}	2.23	2.38
Labor use					
Familiy labor (adult equivalent)	1.5^{34}	1.5	1.7	1.3	1.5
Hired labor (man days year $^{-1}$)	35^{34}	55^{4}	70^{4}	98	78
Household composition					
Familiy size	3.0^{234}	2.8^{4}	2.5^{4}	1.8	2.7
Number of childern (< 16 years)	2.2^{234}	1.7^{4}	1.8^{4}	1.4	2.0
Education of the head of the household (years)	2.3^{4}	2.6^{4}	1.8^{4}	3.3	2.6
Location					
Castanhal (west)	11	19	24	36	90
Igarapé-Açu (center)	18	25	25	22	90
Bragança (east)	39	24	18	10	91
Total N	68	68	67	68	271

2,3,4 significantly different from the 2nd, 3rd, 4th quartile mean at the 95% confidence level

* mean is significantly different from the 2nd and 4th quartile only at the 88% confidence level

Source: SHIFT/NAEA survey 2002/3, IBGE agricultural census 1995/6

Figure 1: Yields and farm size



Source: SHIFT/NAEA field survey 2002/3, IBGE agricultural census 1995/6

Appendix 3

Probit estimates of the determinants of fertilizer use

	Probit Model Fertilizer Use (yes/no)			
	coefficients	**z-value**	**marginal effect**	**z-value**
Farm-HH characteristics				
Net per capita income (R$/year)	0	(1.62)	0.000	(1.57)
Family labor units	-0.003	(-1.02)	-0.001	(-1.01)
Age of HH head (years)	-0.01	(-1.32)	-0.002	(-1.31)
Dummy participation in cooperation	0.402	(1.58)	0.080	(1.75)
Dummy machinery access to plot	0.645	(1.13)	0.107	(1.61)
Dependants in the HH (number)	-0.051	(-0.85)	-0.011	(-0.85)
Distance to community center (minutes)	-0.009	(-1.56)	-0.002	(-1.57)
Soil quality*	-1.22	(-1.70)	-0.266	(-1.74)
Main crops				
Dummy beans	2.525	(9.97)**	0.777	(14.18)**
Dummy cassava	-0.1	(-0.21)	-0.023	(-0.2)
Dummy maize	-0.001	(-0.01)	0.000	(-0.01)
Dummy sweet cassava	-0.121	(-0.32)	-0.025	(-0.34)
Dummy gherkin	1.645	(3.08)**	0.566	(3.11)**
Dummy watermelon	1.241	(3.29)**	0.408	(2.77)**
Location				
Dummy Igarape Acu	-0.624	(2.48)*	-0.119	(-2.77)*
Dummy Bragança	-0.808	(2.82)**	-0.159	(-3.1)*
Constant	-0.15	(-0.15)		
Observations	400			
Absolute value of z statistics in parentheses				
* Significant at 5%; ** significant at 1%				
Pseudo R2	0.5185			
Log likelihood	-108.30864			

The price of fertilizer has not been included here as only marginal differences exist between districts. Price differentials might arise from transport cost, but were not considered here since farmers regularly visit urban centers to sell produce. Transport costs would then accrue on the way back home in the form of a fee per bag, which depends on the distance to the market. To avoid collinearity problems only the distance to market proxy has been used as an independent variable. Marginal effects can be interpreted as follows: A unitary increase in an independent variable increases the probability of using fertilizer by (marginal effect * 100)%. The estimation was done using data from 400 plots in the three survey districts that were planted with annual crops. Cassava was the most common main crop in all districts. Since only typical annual crops have been considered, the selection is not biased in terms of crop mix.

Appendix 4

Correlation structure of variables for the farm-household classification

	RT	DIST	PRECIP	AVBIOMAS	VALRES	TRAC	OFFINC	CROPLAND	EDUMEAN	PERM
RT	1									
DIST	-0.1827*	1								
PRECIP	0.3643*	-0.2945*	1							
AVBIOMAS	-0.1604*	0.4432*	-0.2431*	1						
VALRES	0.2712*	-0.1506*	0.2963*	-0.1051	1					
TRAC	0.3275*	-0.2393*	0.4051*	-0.1237*	0.3501*	1				
OFFINC	0.1121				0.1363*		1			
CROPLAND			0.1658*	0.1228*	0.1979*	0.2688*		1		
EDUMEAN	0.1447*	-0.2456*	0.2380*		0.4216*	0.2193*	0.2538*	0.1570*	1	
PERM	0.2388*	-0.2598*	0.3087*		0.2926*	0.1891*	0.1076		0.1924*	1

Correlations at 10% siginificance level, * at 5% significance level

Validation of PCA (split sample)

Test Scores and Rotated Component Matrix (I)

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.674
Bartlett's Test of Sphericity	Approx. Chi-Square	74.911
	df	10
	Sig.	.000

Rotated Component Matrix[a]

	Component	
	1	2
Zscore: SMEAN(RT)	7.798E-02	.808
Zscore: SMEAN(PERM)	.367	.492
Zscore: SMEAN(TRAC)	9.209E-02	.728
Zscore: SMEAN(VALRES)	.799	.239
Zscore: SMEAN(EDUMEAN)	.841	3.375E-02

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Test Scores and Rotated Component Matrix (II)

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.694
Bartlett's Test of Sphericity	Approx. Chi-Square	124.412
	df	10
	Sig.	.000

Rotated Component Matrix[a]

	Component	
	1	2
Zscore: SMEAN(RT)	.869	-6.52E-02
Zscore: SMEAN(PERM)	.626	.303
Zscore: SMEAN(TRAC)	.580	.450
Zscore: SMEAN(VALRES)	.409	.734
Zscore: SMEAN(EDUMEAN)	-1.25E-02	.870

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

[a] Rotation converged in 3 iterations.

Validation CA (split sample, standardized variables)

Group size and final cluster centers (I)

Number of Cases in each Cluster

Cluster	1	16.000
	2	66.000
	3	4.000
	4	32.000
	5	18.000
Valid		136.000
Missing		.000

Final Cluster Centers

	Cluster				
	1	2	3	4	5
Zscore: SMEAN(OFFFINC)	1.41453	-.32028	-.43374	-.15779	-.12212
Zscore: SMEAN(CROPLAND)	.11716	-.13421	3.97057	-.15591	-.01273
Zscore: SMEAN(DIST)	.07675	-.20408	-.22184	-.49462	2.39910
Zscore: SMEAN(PRECIP)	.70718	.65613	.62215	-1.34432	-1.34432
REGR factor score 1 for analysis 1	.38323	.19604	1.03993	-.69257	-.18086
REGR factor score 2 for analysis 1	1.42767	-.07965	.67548	-.15580	-.91747
Zscore: SMEAN(AVBIOMAS)	-.05731	-.35080	.10395	.08563	1.07508

Group size and final cluster centers (II)

Number of Cases in each Cluster

Cluster	1	18.000
	2	71.000
	3	6.000
	4	27.000
	5	10.000
Valid		132.000
Missing		.000

Final Cluster Centers

	Cluster				
	1	2	3	4	5
Zscore: SMEAN(OFFFINC)	1.97183	-.23612	.27652	-.19375	-.30606
Zscore: SMEAN(CROPLAND)	-.04892	-.19004	3.46690	-.30155	-.16438
Zscore: SMEAN(DIST)	-.43748	-.28517	-.08913	-.42504	2.42122
Zscore: SMEAN(PRECIP)	.33382	.65790	.85600	-1.34432	-1.24866
REGR factor score 1 for analysis 1	.76244	.26727	.05246	-.71747	-.75771
REGR factor score 2 for analysis 1	1.07016	-.34616	1.64458	-.10344	-.45883
Zscore: SMEAN(AVBIOMAS)	-.29492	-.17148	.16374	-.02055	1.57170

Within cluster standard deviations and difference of means test results of the farm-household classification

	N	Land use intensity	% of area under perennials	Tractor use	Value of residence bulidings	Average hh education level	Off-farm income	Area under crops	Soil fertility	Distance to market	Dry season intensity
sd Group 1	*32*	16	33.8	1.1	9669	2.6	3055	2.2	0.34	14	70
sd Group 2	*139*	18	29.3	1.1	3681	1.6	827	2.1	0.55	13	74
sd Group 3	*11*	23	31.9	1.6	6238	1.2	1845	4.8	0.58	9	77
sd Group 4	*59*	13	7.4	0.7	2817	2.1	1230	2.3	0.78	14	12
sd Group 5	*27*	8	13.1	0.3	3784	1.5	1490	2.3	0.56	16	14
Means tests											
Mean Group 1		*245*	*245*	*245*	*245*	*245*	*2345*	*3*	*35*	*45*	*45*
Mean Group 2		*45*	*45*	*345*	*345*	*35*		*3*	*345*	*45*	*45*
Mean Group 3		*45*	*45*	*45*	*45*	*45*		*45*	*5*	*5*	*45*
Mean Group 4			*5*			*5*			*5*	*5*	
Mean Group 5											

2 cluster mean is different to the cluster mean of group 2 at 95% confidence level
3 cluster mean is different to the cluster mean of group 3 at 95% confidence level
4 cluster mean is different to the cluster mean of group 4 at 95% confidence level
5 cluster mean is different to the cluster mean of group 5 at 95% confidence level

Appendix 5

Linear Engel curves regression results

	Rice kg/cap/month	**Beans kg/cap/month**	**Cassava flour kg/cap/month**	**Fruits kg/cap/month**	**Other R$/cap/month**
Income coefficient	1.62E-04	-4.37E-05	-9.86E-05	1.93E-04	1.66E-02
	(3.16)*	-2.19	(2.97)*	(4.26)**	(6.25)**
Minimum requirement	3.57	1.41	3.32	1.83	80.04
	(16.80)**	(17.13)**	(24.19)**	(9.76)**	(7.28)**
Observations	10	10	10	10	10
Adjusted R-squared	0.5	0.3	0.47	0.66	0.81

Absolute value of t statistics in parentheses

* significant at 5%; ** significant at 1%

Appendix 6

The estimation of the service costs of mechanical mulching is based on data from Michelotti (2002) and Bevilaqua (2003).

Assumptions	
annual operation hours	1500
total hours of operation (chopper)	6000
total hours of operation (tractor)	10000
project lifespan based on tractor operation hours	6.667
interest rate (i)	10%
annuity factor (af)	0.2126406

$$af = \frac{(i+1)^T (i+1)}{((i+1)^T - 1)}$$

Table 1: Costs per operation hour

Type of Investment	Cost in R$ (based on Michelotti 2002)	Life span in years (based on Michelotti 2002)	Invest-ments during project	Residual Value in R$ x	NPV in R$ y	Annual Cost in R$ x+y*af
Support						
Buildings	5000.00	25.00	0.27	-1942.32	5000.00	650.19
Tools	250.00	5.00	1.33	-88.29	405.23	67.39
Support Car	16000.00	5.00	1.33	-5650.38	25934.74	4313.28
Fuel Storage	300.00	5.00	1.33	-105.94	486.28	80.87
Office Equipment	2000.00	5.00	1.33	-706.30	3241.84	539.16
Other office facilities	400.00	10.00	0.67	-70.63	400.00	70.04
Water pump (garage)	280.00	10.00	0.67	-49.44	280.00	49.03
Well	1200.00	10.00	0.67	-211.89	1200.00	210.11
Support Car Maintenance					640.00	640.00
Support Car Fuel					6500.00	6500.00
Wages Office Staff					11700.00	11700.00
Wages Field Staff					19500.00	19500.00
Office Material					3000.00	3000.00
Subtotal	**25430.00**			**-8825.18**	**78288.09**	**47320.07**
Subtotal per Operation Hour						**31.55**
Tractor						
Tractor New Holland TM 165	223510.00	6.67	1.00	0.00	223510.00	47527.30
Maintenance	15000.00	6.67				2250.00
Repair	72000.00	6.67			46304.88	9846.30
Subtotal					**269814.88**	**59623.60**
Subtotal per Operation Hour						**39.75**
Chopper						
Chopper Ahwi FM 600	127000.00	4.63	1.44	-37584.19	208723.73	36391.21
Maintenance	45000.00	4.63				9729.00
Repair	42000.00	4.63	1.44		43147.50	9174.91
Subtotal						**55295.12**
Subtotal per Operation Hour						**36.86**
Total						***162238.79***
Total per Operation hour						***108.16***

Table 1 shows the investment cost per operation hour based on the assumption that a private firm would engage in providing mechanical mulching to farmers in the study region. According to Michelotti, actual chopping time is only 86.48% of tractor operation time, which is considered in the calculation.

Using chopping time and fuel consumption information from three districts the average mulching cost per hour and hectare can be obtained as shown in table 2.

Table 2: Average mulching cost

Item	Igarapé-Açu	Concordia	Mãe do Rio
Total area mulched in ha	*10.49*	*14.65*	*7.49*
Operation hours in h/ha	*5.70*	*6.02*	*7.56*
Support in R$/h	31.55	31.55	31.55
Tractor in R$/h	39.75	39.75	39.75
Chopper in R$/h	36.86	36.86	36.86
Driver in R$/h	10.00	10.00	10.00
Diesel in R$/h	30.40	26.31	39.01
Total cost in R$/ha	**846.90**	**870.36**	**1188.58**
Total cost in R$/h	**148.56**	**144.47**	**157.17**
Average R$/ha*	***935.81***		
Average R$/h*	***148.70***		

*Average weighted by total area mulched

The main reasons for differences in mulching time is the size of the field (share of turn-over time is higher on small plots), the amount of biomass, and the existence of massive root stumps on fields that have not been under agricultural use for a long time Block (2004). Since fallows can have different ages and biomass contents in the bio-economic model, biomass together with field size, and a location dummy were regressed on mulching time:

Table 3: Regression Results

	Coefficients	Standard Error	t Stat	*R square adj*	*N*
Intercept	8.0603	1.1269	7.1529	*0.4866*	*25*
Field size ha	-3.5711	0.8021	-4.4520*		
Biomass in t	0.0225	0.0315	0.7134		
D Concordia	1.6158	0.8337	1.9381		

All coefficients except the one for biomass are at least significant at the 10% level. The coefficient for field size suggests that huge amounts of time could be saved by using the machine on larger areas. Yet, in a smallholder environment it is unlikely that fields will be much larger than the average (0.88 ha) of the sample. The relatively high coefficient of the dummy variable suggests that conditions at the district level can be quite different, e.g. areas that were more recently cleared from primary forests dispose of more woody trunks.

Despite the low significance of the coefficient for biomass, the estimation result was evaluated at the mean of field size and for the levels of fallow age/biomass in order to determine the costs of mulching in the bio-economic model (table 4).

Table 4: Mulching costs depending on fallow age and biomass

Fallow Age	Biomass/ha	Cost/ha
1	4.48	807.52
2	8.89	825.09
3	13.23	842.37
4	17.49	859.36
5	21.68	876.05
6	25.79	892.45
7	29.84	908.56
8	33.81	924.38
9	37.70	939.90
10	41.52	955.14
11	45.27	970.08
12	48.95	984.72

Options to reduce mulching costs

The most relevant options to reduce mulching costs can be divided into reductions of investment costs and reductions of mulching time. Embrapa is currently testing an alternative chopping device that costs roughly half of the AHWI FM600. Since a powerful tractor is necessary for effective mulching it is rather unlikely that the tractor costs can be reduced in the near future.

It is possible to reduce mulching time by selecting larger fields (if possible), younger fallows, and at the same time avoiding areas with large trunks. Another option that remains to be tested is to apply one instead of two treatments per field. The latter is primarily done to reduce the size of mulch particles. The potential effects of reducing chopper investment costs and the amount of treatments are summarized in table 5:

Table 5: Options for cost reduction

Measure	**Mulching cost R$/ha**
Reduced Chopper Costs (50%)	859.72
Only one treatment per field	626.99
Combined	576.01

Appendix 7

Coefficients, maximum, and minimum values of the Monte Carlo Simulation result

	Unit	Cassava s&b + mulching	Cassava mechanized	Beans s&b	Beans mechanized	Black pepper traditional y6	Black pepper intensive y6
				expected value functions			
Coefficients	a	1.39E+04	5.51E+03	2.78E+02	2.34E+02	6.09E+02	8.05E+02
	b	8.12E+02	1.34E+03	1.20E+02	9.99E+01	3.03E+01	6.52E+01
	c	1.60E+01	2.21E+01	4.48E+00	2.64E+00	1.07E-01	2.51E-01
	d	9.69E-02	1.17E-01	5.27E-02	2.31E-02	4.78E-05	2.59E-04
Coefficient of determination	R	9.67E-01	9.98E-01	9.89E-01	1.00E+00	1.00E+00	9.98E-01
				variance functions			
Coefficients	a	2.99E+07	4.14E+07	6.50E+04	7.48E+05	1.22E+06	3.18E+06
	b	1.76E+02	2.53E+03	1.55E+03	1.98E+01	6.11E+01	2.26E+02
	c	-2.72E-01	-2.30E-01	-6.02E-01	-1.80E-01	-3.98E-02	-4.73E-02
	d	1.52E+07	3.35E+07	8.20E+03	-5.47E+03	8.28E+04	1.87E+05
Coefficient of determination	R	1.00E+00	9.97E-01	1.00E+00	1.00E+00	1.00E+00	1.00E+00
				maximum expected yield			
Fertilizer	kg P/ha	39.85	43.69	21.51	34.53		
Fertilizer	kg N/ha					157.68	179.87
Expected value of yield	kg/ha	26959.95	31892.67	1303.42	1483.70	2901.04	5915.86
Standard deviation of yield	kg/ha	6704.77	8414.32	270.07	854.20	1084.88	1797.53
				minimum variance			
Fertilizer	kg P/ha	0.00	0.00	0.00	0.00		
Fertilizer	kg N/ha					0.00	0.00
Expected value of yield	kg/ha	13850.72	5507.02	278.36	233.99	609.10	804.71
Standard deviation of yield	kg/ha	3916.34	5791.80	90.77	174.66	320.16	447.84

Appendix 8

Sensitivity analysis of calibration parameters

	α	β	R^2	θ
Damage function weight factor (α) 0.16-0.26				
Average Annual Consumption in R$	4435.99609	384.0796	0.16	0.019
Average Annual Cash Expenses in R$	7954.81857	2899.5904*	0.95	0.074
Value of Production from Annual Crops in R$	4402.12517	-8921.0976*	0.89	-0.805
Value of Production from Perennial Cash Crops in R$	6407.27463	10670.6910*	0.95	0.271
Hired Labor in Man Days/Year	20.3285542	-19.5926	0.31	-0.300
Sold off labor in Man Days/Year	0.0544339	283.6048*	0.90	1.029
Average Area under Annuals in ha	5.56657217	-13.9028*	0.98	-1.178
Average Area under High Input Perennials in ha	0.81293954	1.4105*	0.96	0.279
Average Area under Low Input Perennials in ha	0.02468427	0.0001*	0.56	0.001
Average Area under productive fallow in ha	6.73826229	11.2062*	0.97	0.270
Average Age of productive Fallow in Years	1.49478875	9.8130*	0.93	0.610
Average Area under Pasture in ha	0.98719615	0.1006*	0.77	0.022
Total Cropland * pastures	7.39139213	-12.3916*	0.98	-0.574
Shadow Value of Fallow in R$/ha	185.599497	-325.2409*	0.71	-0.645
Shadow Value of Land in R$/ha	65.0067816	-133.3330*	0.61	-0.930
Shadow Value of Labor Peak Month in R$	295.733398	-381.3259*	0.92	-0.391
Shadow Value of Labor outside Peak Month in R$	92.59728	-96.2664*	0.78	-0.296
Mean of Total absolute deviation from revenue in R$	1209.00339	3264.297*	0.96	0.376
degraded fallow	1.01676865	1.0392*	0.97	0.185
average carbon	148.315861	333.4009*	0.92	0.339
average carbon loss	-8.47861817	17.2822*	0.94	-0.762
MOTAD risk aversion parameter (ψ) 0-2				
Average Annual Consumption in R$	7408.81957	-3035.3257*	0.99	-0.896
Average Annual Cash Expenses in R$	14380.1663	-4694.7578*	0.90	-0.691
Value of Production from Annual Crops in R$	561.105152	1536.5572*	0.94	0.706
Value of Production from Perennial Cash Crops in R$	19817.1823	-9831.5958*	0.96	-1.548
Hired Labor in Man Days/Year	153.780335	-98.7379*	0.81	-17.084
Sold off labor in Man Days/Year	-34.9059662	123.0661*	0.91	1.773
Average Area under Annuals in ha	0.48374367	1.6877*	0.91	0.725
Average Area under High Input Perennials in ha	2.68807214	-1.3897*	0.96	-1.714
Average Area under Low Input Perennials in ha	-0.18713006	0.3923*	0.61	18.340
Average Area under productive fallow in ha	7.52070867	1.2225*	0.66	0.159
Average Age of productive Fallow in Years	4.76919056	-0.8126*	0.53	-0.274
Average Area under Pasture in ha	0.73698131	0.1925*	0.56	0.228
Total Cropland * pastures	3.72166705	0.8828*	0.88	0.220
Shadow Value of Fallow in R$/ha	18.0193176	93.5294*	0.93	0.878
Shadow Value of Land in R$/ha	30.2502034	4.2059	0.02	0.148
Shadow Value of Labor Peak Month in R$	317.281502	-114.3333*	0.95	-0.747
Shadow Value of Labor outside Peak Month in R$	129.515304	-42.8995*	0.69	-0.754
Mean of Total absolute deviation from revenue in R$	5452.9859	-2992.113*	0.84	-2.167
Degraded fallow	3.28869857	-1.6471*	0.82	-1.758
Average carbon	216.508179	5.3719	0.03	0.029
Average carbon loss	-5.87851215	0.9517*	0.27	-0.232

* significant at the 95% confidence level

Appendix 9

Sensitivity analysis of the baseline

Price wedge between sold off and bough in products (+ 0 to 50% increase)

	α	β	R^2	θ
Annual consumption in R$	8507.05	-4069.19*	0.95	-1.22
Annual cash expenses in R$	3342.67	4341.06*	1.00	0.60
Value of production from annual crops in R$	2469.16	124.70	0.18	0.05
Value of production from perennial cash crops in R$	7303.40	231.91	0.16	0.04
Hired labor in man days/year	6.61	-0.04	0.01	-0.01
Sold off labor in man days/year	61.75	18.46*	0.90	0.26
Area under annuals in ha	2.60	0.14	0.36	0.06
Area under high input perennials in ha	0.93	0.03	0.18	0.04
Area under low input perennials in ha	0.01	0.01	0.31	0.50
Area under productive fallow in ha	9.46	-0.18	0.23	-0.02
Age of productive fallow in years	3.65	-0.13	0.14	-0.04
Area under degraded fallow in ha	1.12	0.00	0.00	0.00
Area under pasture in ha	1.01	0.01	0.15	0.01
Total cropland in ha	4.55	0.19	0.35	0.04
Shadow value of initial fallow in R$/ha	117.49	3.33	0.02	0.03
Shadow value of land in R$/ha	27.18	0.83	0.00	0.04
Shadow value of labor peak month in R$	169.89	6.70	0.20	0.04
Shadow value of labor outside peak month in R$	67.80	0.18	0.01	0.00
Total carbon in t	221.50	-4.23	0.08	-0.02
Annual carbon loss in t	-4.74	-0.31*	0.88	0.07
Npv of non-essential consumption in R$	73981.04	-36766.40*	0.97	-1.33
Npv expenditure in R$	30010.63	34607.97*	1.00	0.57

* Significant at the 95% confidence level

Discount factor (0.05 to 0.15)

	α	β	R^2	θ
Annual consumption in R$	4520.60	-4667.52*	0.99	-0.11
Annual cash expenses in R$	8670.40	-5093.78*	1.00	-0.06
Value of production from annual crops in R$	2696.97	-684.79*	0.90	-0.03
Value of production from perennial cash crops in R$	8715.52	-11174.32*	0.99	-0.15
Hired labor in man days/year	14.59	-78.74*	0.99	-1.17
Sold off labor in man days/year	38.65	450.87*	0.99	0.55
Area under annuals in ha	2.80	-0.35*	0.71	-0.01
Area under high input perennials in ha	1.12	-1.48*	0.99	-0.15
Area under low input perennials in ha	0.03	-0.02*	0.44	-0.07
Area under productive fallow in ha	8.89	3.47*	0.99	0.04
Age of productive fallow in years	3.15	3.22*	0.99	0.09
Area under pasture in ha	1.02	-0.07*	0.53	-0.01
Total cropland in ha	4.97	-1.92*	0.98	-0.04
Shadow value of initial fallow in R$/ha	138.80	-194.80*	0.91	-0.16
Shadow value of land in R$/ha	68.21	-356.38*	0.96	-1.05
Shadow value of labor peak month in R$	236.05	-598.09*	0.99	-0.34
Shadow value of labor outside peak month in R$	91.30	-220.22*	0.99	-0.32
Area under degraded fallow in ha	1.26	-1.32*	1.00	-0.12
Total carbon in t	197.69	182.91*	0.99	0.08

	α	β	R^2	θ
Annual carbon loss in t	-5.53	5.45*	0.83	-0.11
Npv of non-essential consumption in R$	68206.62	-322512.00*	0.96	-0.96
Npv expenditure in R$	136412.92	-635954.77*	0.96	-0.93

* significant at the 95% confidence level

Risk aversion factor (0 to 2)

	α	β	R^2	θ
Average annual consumption in R$	7408.82	-3035.33	0.99*	-0.90
Average annual cash expenses in R$	14380.17	-4694.76	0.90*	-0.69
Value of production from annual crops in R$	561.11	1536.56	0.94*	0.71
Value of production from perennial cash crops in R$	19817.18	-9831.60	0.96*	-1.55
Hired labor in man days/year	153.78	-98.74	0.81*	-17.08
Sold off labor in man days/year	-34.91	123.07	0.91*	1.77
Average area under annuals in ha	0.48	1.69	0.91*	0.72
Average area under high input perennials in ha	2.69	-1.39	0.96*	-1.71
Average area under low input perennials in ha	-0.19	0.39	0.61*	18.34
Average area under productive fallow in ha	7.52	1.22	0.66*	0.16
Average age of productive fallow in years	4.77	-0.81	0.53*	-0.27
Area under degraded fallow in ha	3.29	-1.65	0.82*	-1.76
Average area under pasture in ha	0.74	0.19	0.56*	0.23
Total cropland in ha	3.72	0.88	0.88*	0.22
Shadow value of fallow in R$/ha	18.02	93.53	0.93*	0.88
Shadow value of land in R$/ha	30.25	4.21	0.02	0.15
Shadow value of labor peak month in R$	317.28	-114.33	0.95*	-0.75
Shadow value of labor outside peak month in R$	129.52	-42.90	0.69*	-0.75
Total carbon in t	216.51	5.37	0.03	0.03
Annual carbon loss in t	-5.88	0.95	0.27*	-0.23
Npv of non-essential consumption in R$	-17476.21	52516.51	0.98*	-0.62
Npv expenditure in R$	-34660.41	114460.13	0.90*	-0.61

* Significant at the 95% confidence level

Cassava flour price (0.4 to 1.2 R$/kg)

	α	β	R^2	θ
Annual consumption in R$	3595.22	711.54*	0.72	0.14
Annual cash expenses in R$	8850.34	-868.50*	0.94	-0.08
Value of production from annual crops in R$	-854.82	4461.03*	0.99	1.35
Value of production from perennial cash crops in R$	10823.09	-4063.77*	0.98	-0.43
Hired labor in man days/year	-0.49	10.90*	0.69	1.29
Sold off labor in man days/year	123.74	-37.04*	0.42	-0.36
Area under annuals in ha	0.44	2.73*	0.96	0.79
Area under high input perennials in ha	1.40	-0.55*	0.97	-0.45
Area under low input perennials in ha	0.03	0.00*	0.61	-0.11
Area under productive fallow in ha	10.25	-1.11*	0.84	-0.10
Age of productive fallow in years	5.02	-1.72*	0.89	-0.40
Area under pasture in ha	1.03	-0.03*	0.95	-0.02
Area under degraded fallow in ha	1.51	-0.53*	0.92	-0.38
Total cropland in ha	2.90	2.14*	0.93	0.36
Shadow value of initial fallow in R$/ha	-122.12	324.30*	0.97	2.20
Shadow value of land in R$/ha	10.58	30.96*	0.59	0.83
Shadow value of labor peak month in R$	218.10	-62.77*	0.80	-0.28
Shadow value of labor outside peak month in R$	54.46	18.83*	0.96	0.22

	α	β	R^2	θ
Total carbon in t	271.24	-62.68*	0.89	-0.23
Annual carbon loss in t	-2.38	-2.95*	0.86	0.47
Npv of non-essential consumption in R$	25167.68	11464.55*	0.93	0.27
Npv expenditure in R$	72835.84	-5586.57*	0.92	-0.07

* significant at the 95% confidence level

Pepper price (2.42 to 7.26 R$/kg)

	α	β	R^2	θ
Annual consumption in R$	-4439.12	1824.33*	0.98	2.17
Annual cash expenses in R$	3839.50	910.46*	0.97	0.54
Value of production from annual crops in R$	4422.23	-382.91*	0.97	-0.70
Value of production from perennial cash crops in R$	-8124.59	3320.56*	0.98	2.10
Hired labor in man days/year	-54.32	15.84*	0.74	11.38
Sold off labor in man days/year	386.46	-55.30*	0.92	-3.29
Area under annuals in ha	4.47	-0.36*	0.96	-0.63
Area under high input perennials in ha	-0.59	0.31*	0.99	1.56
Area under low input perennials in ha	0.05	-0.01*	0.69	-0.97
Area under productive fallow in ha	10.74	-0.29*	0.96	-0.15
Age of productive fallow in years	2.91	0.16*	0.66	0.22
Area under pasture in ha	1.05	-0.01*	0.57	-0.05
Area under degraded fallow in ha	-0.26	0.28*	0.99	1.22
Total cropland in ha	4.98	-0.06*	0.48	-0.06
Shadow value of initial fallow in R$/ha	219.20	-19.21*	0.92	-0.79
Shadow value of land in R$/ha	23.61	1.22*	0.41	0.19
Shadow value of labor peak month in R$	-4.62	37.51*	0.96	1.02
Shadow value of labor outside peak month in R$	47.23	5.01*	0.85	0.35
Total carbon in t	220.52	0.81	0.03	0.02
Annual carbon loss in t	-4.39	-0.04	0.04	0.04
Npv of non-essential consumption in R$	-30082.85	13702.93*	0.98	1.97
Npv expenditure in R$	35660.30	6967.52*	0.98	0.49

* significant at the 95% confidence level

Bean price (0.45 to 1.36 R$/kg)

	α	β	R^2	θ
Annual consumption in R$	3746.13	377.52*	0.87	0.08
Annual cash expenses in R$	7975.49	217.19*	0.86	0.02
Value of production from annual crops in R$	1618.91	1154.63*	0.99	0.40
Value of production from perennial cash crops in R$	7782.09	-190.30	0.29	-0.02
Hired labor in man days/year	4.17	3.22*	0.74	0.43
Sold off labor in man days/year	118.71	-39.78*	0.98	-0.44
Area under annuals in ha	2.31	0.50*	0.93	0.16
Area under high input perennials in ha	0.99	-0.02	0.25	-0.02
Area under low input perennials in ha	0.02	0.00*	0.57	0.09
Area under productive fallow in ha	9.65	-0.45*	0.96	-0.04
Age of productive fallow in years	4.30	-0.92*	1.00	-0.24
Area under pasture in ha	1.01	0.00*	0.44	0.00
Area under degraded fallow in ha	1.14	-0.03	0.30	-0.02
Total cropland in ha	4.34	0.48*	0.95	0.09
Shadow value of initial fallow in R$/ha	137.73	-21.47*	0.73	-0.17
Shadow value of land in R$/ha	29.39	1.61	0.04	0.05
Shadow value of labor peak month in R$	210.93	-38.75*	0.95	-0.20
Shadow value of labor outside peak month in R$	57.28	13.95*	0.87	0.19

	α	β	R^2	θ
Total carbon in t	254.98	-43.51*	1.00	-0.18
Annual carbon loss in t	-3.61	-1.45*	0.86	0.26
Npv of non-essential consumption in R$	31681.26	2364.38*	0.91	0.06
Npv expenditure in R$	67076.13	1507.75*	0.87	0.02

* significant at the 95% confidence level

Wages (4.5 to 13.5 R$/day average level)

	α	β	R^2	θ
Annual consumption in R$	5765.79	-171.33*	0.85	-0.34
Annual cash expenses in R$	10664.39	-258.80*	0.91	-0.26
Value of production from annual crops in R$	3149.06	-59.36*	0.97	-0.20
Value of production from perennial cash crops in R$	12393.19	-503.42*	0.94	-0.51
Hired labor in man days/year	108.79	-9.52*	0.67	-2.44
Sold off labor in man days/year	-62.39	16.84*	0.99	3.22
Area under annuals in ha	3.26	-0.06*	0.99	-0.18
Area under high input perennials in ha	1.61	-0.07*	0.94	-0.53
Area under low input perennials in ha	0.03	0.00	0.01	-0.01
Area under productive fallow in ha	7.46	0.19*	0.96	0.20
Age of productive fallow in years	2.19	0.14*	0.97	0.40
Area under degraded fallow in ha	1.66	-0.06*	0.95	-0.40
Area under pasture in ha	1.02	0.00*	0.78	-0.01
Total cropland in ha	5.92	-0.12*	0.97	-0.22
Shadow value of initial fallow in R$/ha	151.04	-3.29*	0.75	-0.24
Shadow value of land in R$/ha	42.19	-1.05	0.34	-0.33
Shadow value of labor peak month in R$	149.67	2.17*	0.43	0.12
Shadow value of labor outside peak month in R$	40.40	3.26*	0.98	0.48
Total carbon in t	142.46	8.09*	0.98	0.37
Annual carbon loss in t	-8.28	0.36*	0.97	-0.56
Npv of non-essential consumption in R$	42389.39	-849.01*	0.79	-0.21
Npv expenditure in R$	86934.27	-1908.36*	0.91	-0.23

* significant at the 95% confidence level

Fertilizer price (0.55 to 1.65 R$/kg NPK)

	α	β	R^2	θ
Annual consumption in R$	7555.82	-3253.57*	0.98	-0.88
Annual cash expenses in R$	8522.66	-508.45	0.32	-0.07
Value of production from annual crops in R$	2428.14	225.54*	0.45	0.09
Value of production from perennial cash crops in R$	12308.52	-4622.55*	0.90	-0.67
Hired labor in man days/year	38.57	-26.04*	0.88	-4.25
Sold off labor in man days/year	-69.27	152.00*	0.89	2.05
Area under annuals in ha	2.37	0.39*	0.76	0.16
Area under high input perennials in ha	1.60	-0.62*	0.89	-0.70
Area under low input perennials in ha	0.02	0.00*	0.92	0.19
Area under productive fallow in ha	8.31	0.93*	0.90	0.11
Age of productive fallow in years	2.85	0.57*	0.94	0.18
Area under degraded fallow in ha	1.71	-0.59*	0.87	-0.58
Area under pasture in ha	1.00	0.01*	0.66	0.01
Total cropland + pastures	4.99	-0.22*	0.94	-0.05
Shadow value of initial fallow in R$/ha	31.43	85.23*	0.97	0.79
Shadow value of land in R$/ha	36.31	-4.61	0.30	-0.20
Shadow value of labor peak month in R$	266.09	-87.40*	0.98	-0.54
Shadow value of labor outside peak month in R$	94.85	-22.97*	0.99	-0.37

	α	β	R^2	θ
Total carbon in t	173.89	39.58*	0.98	0.20
Annual carbon loss in t	-6.66	1.71*	0.94	-0.37
Npv of non-essential consumption in R$	58597.50	-22844.05*	1.00	-0.75
Npv expenditure in R$	70066.20	-2658.02	0.27	-0.04

* significant at the 95% confidence level

Passion fruit price (0.78 to 2.35 R$/kg)

	α	β	R^2	θ
Annual consumption in R$	72.59	2753.17*	0.85	1.06
Annual cash expenses in R$	5673.82	1541.69*	0.90	0.30
Value of production from annual crops in R$	3908.85	-799.61*	0.85	-0.48
Value of production from perennial cash crops in R$	-473.99	5296.78*	0.87	1.09
Hired labor in man days/year	-16.26	16.76*	0.76	3.90
Sold off labor in man days/year	162.36	-50.55*	0.95	-0.98
Area under annuals in ha	4.07	-0.81*	0.86	-0.46
Area under high input perennials in ha	0.03	0.57*	0.92	0.91
Area under low input perennials in ha	0.73	-0.35*	0.72	-19.89
Area under productive fallow in ha	9.83	-0.40*	0.69	-0.07
Age of productive fallow in years	3.00	0.33*	0.57	0.15
Area under degraded fallow in ha	-0.14	0.76*	0.87	1.05
Area under pasture in ha	1.02	-0.01*	0.61	-0.01
Total cropland in ha	5.85	-0.60*	0.91	-0.20
Shadow value of initial fallow in R$/ha	182.18	-36.15*	0.89	-0.48
Shadow value of land in R$/ha	31.27	-0.68	0.02	-0.03
Shadow value of labor peak month in R$	34.28	85.81*	0.95	0.76
Shadow value of labor outside peak month in R$	64.57	4.21*	0.50	0.10
Total carbon in t	218.14	-0.16	0.00	0.00
Annual carbon loss in t	-4.56	-0.14	0.11	0.04
Npv of non-essential consumption in R$	5381.65	19585.42*	0.85	0.91
Npv expenditure in R$	48826.23	12043.95*	0.91	0.28

* significant at the 95% confidence level

Product price of extensive perennials (*Murici*) (0.2 to 0.6 R$/kg)

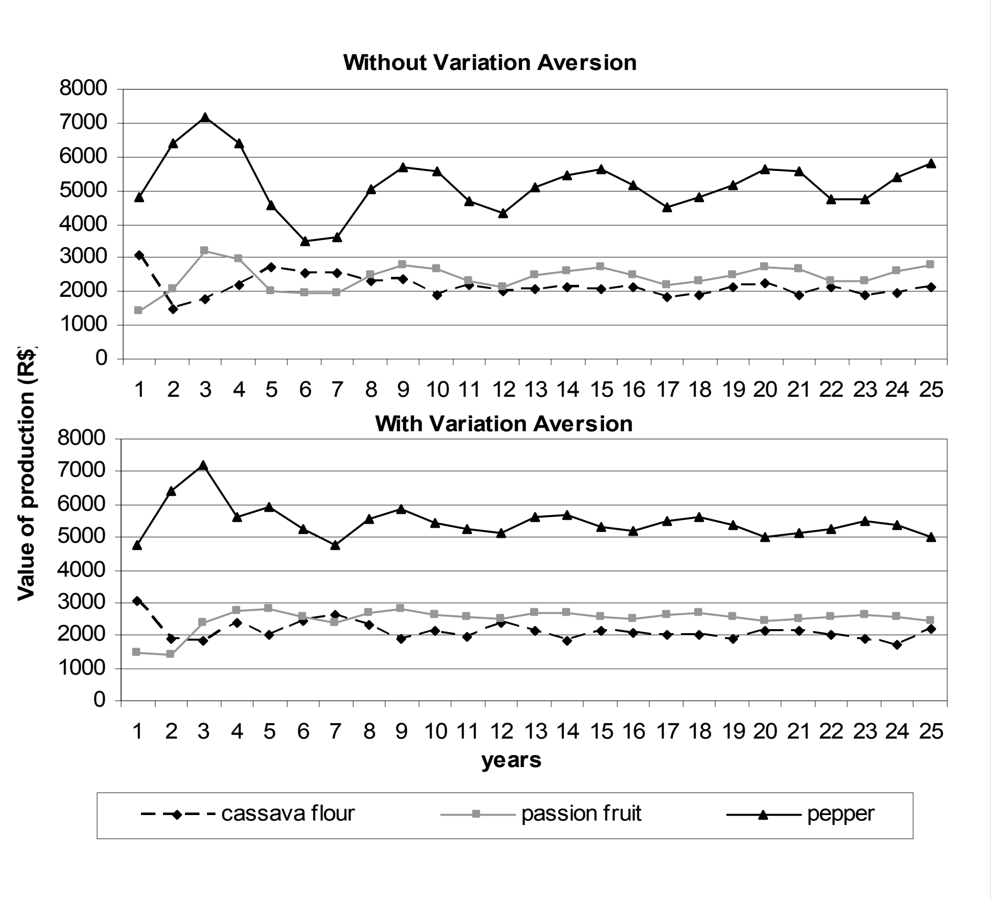
	α	β	R^2	θ
Annual consumption in R$	4479.41	-1346.59*	0.70	-0.13
Annual cash expenses in R$	8469.31	-1010.75*	0.64	-0.05
Value of production from annual crops in R$	2626.84	45.48	0.06	0.01
Value of production from perennial cash crops in R$	8248.46	-2114.86*	0.64	-0.11
Hired labor in man days/year	4.42	6.75	0.36	0.40
Sold off labor in man days/year	100.10	-58.84*	0.77	-0.29
Area under annuals in ha	2.77	0.02	0.01	0.00
Area under high input perennials in ha	1.18	-0.68*	0.67	-0.28
Area under low input perennials in ha	-1.04	3.51*	0.70	50.97
Area under productive fallow in ha	9.88	-2.13*	0.73	-0.09
Age of productive fallow in years	3.55	-0.28*	0.54	-0.03
Area under pasture in ha	1.02	-0.01*	0.63	0.00
Area under degraded fallow in ha	1.26	-0.44*	0.61	-0.16
Total cropland in ha	3.92	2.84*	0.71	0.24

	α	β	R^2	θ
Shadow value of initial fallow in R$/ha	102.44	54.64*	0.67	0.19
Shadow value of land in R$/ha	28.14	5.44	0.11	0.07
Shadow value of labor peak month in R$	201.88	-84.18*	0.69	-0.19
Shadow value of labor outside peak month in R$	61.91	21.48*	0.72	0.13
Total carbon in t	216.57	-3.37	0.07	-0.01
Annual carbon loss in t	-5.51	1.53	0.36	-0.12
Npv of non-essential consumption in R$	36652.03	-9730.29*	0.74	-0.12
Npv expenditure in R$	70198.71	-6048.48*	0.64	-0.04

*significant at the 95% confidence level

Appendix 10

Aversion to deterministic income variation



Appendix 11

Selected results from sensitivity analyses of technology scenarios

Cassava flour price (R$/kg 0.4 to 1.2)

	α	β	R^2	θ
Annual consumption in R$	1076.37	5973.28*	0.79	0.97
Annual cash expenses in R$	6906.27	3737.84*	0.75	0.33
Value of production from annual crops in R$	-5763.77	17686.58*	1.00	1.65
Value of production from perennial cash crops in R$	11112.63	-6438.57*	0.59	-1.25
Hired labor in man days/year	-117.24	255.01*	0.96	2.92
Sold off labor in man days/year	60.23	-57.92*	0.56	-11.20
Area under annuals in ha	0.61	4.55*	0.86	0.75
Area under high input perennials in ha	1.09	-0.63*	0.59	-1.26
Area under low input perennials in ha	n.a.	n.a.	n.a.	n.a.
Area under productive fallow in ha	11.55	-5.55*	0.96	-0.64
Age of productive fallow in years	5.63	-3.29*	0.83	-1.03
Degraded fallow in ha	-0.09	3.34*	0.92	1.12
Area under pasture in ha	1.71	-1.36*	0.93	-1.82
Total cropland in ha	3.43	2.53*	0.72	0.35
Shadow value of initial fallow in R$/ha	-204.22	343.06*	0.69	35.66
Shadow value of land in R$/ha	-31.09	89.22*	0.74	3.41
Shadow value of labor peak month in R$	206.94	16.08	0.27	0.06
Shadow value of labor outside peak month in R$	33.03	136.07*	0.90	0.70
Area under mulch in ha	-2.41	5.36*	0.84	2.26
Area under mechanization in ha	-0.75	2.20*	0.95	1.74
Carbon	304.77	-139.69*	0.89	-0.62
Carbon loss	-1.99	-4.86*	0.85	0.63
Npv cons	7031.28	51558.56*	0.86	0.98
Npv exp	51805.56	40654.29*	0.81	0.42

* significant at the 95% confidence level

Pepper price (R$/kg 2.42 to 7.26)

	α	β	R^2	θ
Annual consumption in R$	-414.06	1266.00*	0.74	1.25
Annual cash expenses in R$	6633.36	598.26*	0.68	0.32
Value of production from annual crops in R$	11005.07	-630.34*	0.55	-0.36
Value of production from perennial cash crops in R$	-6310.07	2526.78*	0.69	2.98
Hired labor in man days/year	-11.55	18.58*	0.89	1.29
Sold off labor in man days/year	13.12	-1.65*	0.68	-1.93
Area under annuals in ha	5.95	-0.27*	0.48	-0.27
Area under high input perennials in ha	-0.25	0.16*	0.64	1.93
Area under low input perennials in ha	n.a.	n.a.	n.a.	n.a.
Area under productive fallow in ha	5.87	0.28*	0.66	0.19
Age of productive fallow in years	2.17	0.10*	0.58	0.18
Degraded fallow in ha	2.89	-0.14*	0.63	-0.28
Area under pasture in ha	0.86	-0.05*	0.78	-0.40
Total cropland in ha	6.55	-0.16*	0.51	-0.13
Shadow value of initial fallow in R$/ha	48.68	-9.63*	0.86	-6.25
Shadow value of land in R$/ha	31.13	-2.20*	0.71	-0.49
Shadow value of labor peak month in R$	198.43	3.59*	0.43	0.08
Shadow value of labor outside peak month in R$	130.58	5.33*	0.98	0.17

	α	β	R^2	θ
Area under mulch in ha	1.61	0.08	0.22	0.21
Area under mechanization in ha	1.60	-0.16*	0.63	-0.75
Carbon	161.15	4.99*	0.72	0.13
Carbon loss	-6.96	0.21*	0.62	-0.17
Npv cons	-3254.47	10326.52*	0.83	1.19
Npv exp	57163.56	4724.51*	0.73	0.29

* significant at the 95% confidence level

Mulching cost reduction under full technology access (90%-70%)

	α	β	R^2	θ
Average annual consumption in R$	4927.96	-279.74*	0.83	-0.01
Average annual cash expenses in R$	9208.33	-1388.34*	0.90	-0.02
Value of production from annual crops in R$	8643.08	-1275.48*	0.90	-0.01
Value of production from perennial cash crops in R$	4151.75	-486.14*	0.86	-0.01
Hired labor in man days/year	72.50	-21.19*	0.88	-0.03
Sold off labor in man days/year	2.79	9.98*	0.89	0.24
Average area under annuals in ha	4.89	-1.20*	0.79	-0.02
Average area under high input perennials in ha	0.41	-0.05*	0.85	-0.01
Average area under low input perennials in ha	n.a.	n.a.	n.a.	n.a.
Average area under productive fallow in ha	6.90	0.94*	0.94	0.01
Degraded fallow in ha	2.42	0.34*	0.38	0.01
Average age of productive fallow in years	2.53	1.00*	0.74	0.04
Average area under pasture in ha	0.60	0.00	0.01	0.00
Total cropland in ha	5.90	-1.26*	0.80	-0.02
Shadow value of initial fallow in R$/ha	-20.55	371.64*	0.96	4.83
Shadow value of land in R$/ha	13.23	153.04*	0.77	0.69
Shadow value of labor peak month in R$	204.21	139.90*	0.74	0.07
Shadow value of labor outside peak month in R$	159.60	-49.44*	0.89	-0.03
Average area under mulch in ha	2.03	-7.39*	0.76	-0.39
Average area under mechanization in ha	1.03	0.24*	0.52	0.02
Average carbon	179.75	13.69*	0.82	0.01
Average carbon loss	-6.23	1.04*	0.79	-0.02
Npv cons	42092.17	-1271.59*	0.69	0.00
Npv exp	77937.21	-7590.08*	0.83	-0.01

* significant at the 95% confidence level

Appendix 12

Estimation of the central distribution moments for truncated distributions (following Schlieper 1997, pp. 187)

To estimate mean and variance of a truncated distribution (as in the case of the insured mulching activity) it is necessary to transform the continuous cumulative distribution function of profits (Π) into discrete values. This allows calculating the individual probability of occurrence $p(\Pi_i)$ for each discrete event according to:

$$p(\Pi_i) = \frac{f(\Pi_i)}{\sum_{i=1}^{n} f(\Pi_i)} \qquad (1)$$

Where $f(\Pi_i)$ is the change of the cumulative distribution function with respect to Π.

The probability of occurrence of the minimum profit (Π_g) in the presence of the insurance is given by:

$$p(\Pi_g) = \sum_{i=1}^{g} p(\Pi_i) \qquad (2)$$

Which can be used to determine the expected value of the profits (E(Π)) using:

$$E(\Pi) = \sum_{i=g}^{n} \Pi_i * p(\Pi_i) \qquad (3)$$

And the variance V(Π) using:

$$V(\Pi) = \sum_{i=g}^{n} (\Pi_i - E(\Pi))^2 * p(\Pi_i) \qquad (4)$$

Appendix 13

Documentation of the structure of the bio-economic model

The different objective function specifications have been discussed in chapter 3. This appendix, hence, documents the remaining model equations and constraints. The model was implemented using the General Algebraic Modeling System (GAMS).

Table 1: Indices

Indices	Description	Elements
a	Livestock type	a1= milking cows a2= beef cattle
h	Trips to market	h1= using bike h2= using bus
in	Tools/instruments	i1= horse, i2= (manual) processing plant), i3(mech.) processing plant, i4= bike
m	Months	m1= October m2= November … m12= September
p	Seasons	p1= slash-and-burn (SB) + harvest; p2= planting(wet season) + maintenance; p3= planting(dry season) + maintenance + harvest
pr	Products	pr1 = rice; pr2 = corn; pr3 = beans;pr4 = manioc; pr5 = passion fruit; pr6 = black pepper;pr7 = farinha (processed manioc); pr8 = beef ; pr9=agroforestry products= pr10=charcoal
r	Crops/rotations	r1= beans (dry), r2= manioc (wet), r3= manioc + corn (wet), r4= manioc + beans (dry), r5= passion fruit, r6= black pepper, r7= agroforestry
r	Pasture types	r1= pasture traditional r2= improved pasture
s	Labor demand/supply steps	Labor demand/supply steps (s1 to s4)were determined using transport and transaction costs (e.g. including alimentation etc.)
t=T	Planning horizon	t1 to t15 (in agricultural years)= T denotes the final year of the planning horizon
ty	Time series years	Time series 1995 to 2002 weighted average of municipality level producer prices
v	Cropping technologies	V1= SB low weeding intensity, v2= SB high weeding intensity, v3= Mulch low weeding intensity, v4= Mulch high weeding intensity, v5= Ploughing low weeding intensity, v6= Ploughing high weeding intensity
v	Land preparation technologies	v1= SB, v2= Mulch, v3 Plough
v	Pasture technologies	v1= low maintenance no fertilization, v2= high maintenance + fertilization
v	Processing technologies	v1= manual processing, v2=mechanized processing
y	Vintage	y1 to y20 (in years)= to track the ages of animals= rotations= and fallow
x	Extractive products	x1= charcoal

Table 2: Variables

Variables	Description	Units
A_{ayvpt}	Livestock	head season^{-1}
BEC_{yvpt}	Culled male cattle	units
BEQ_{inpt}	Bought equipment/instruments	units
BE_{yvpt}	Male cattle	units
CAL_{vt}	Calves	units
CB_{yvpt}	Bought cows	units
CF_{yvt}	Cleared fallow (v_1 to v_3)	ha year^{-1}
COC_{yvpt}	Culled cows	units
CO_{yvpt}	Cows	units
CPA_{yvt}	Cut pasture	ha year^{-1}
CRE_t	Rehabilitated fallow	ha year^{-1}
CR_{ryvt}	Cut/de-established crops/rotations	ha year^{-1}
D_{pt}	Consumption	R$ season^{-1}
EQ_{inpt}	Available equipment/instruments	units
E_t	Total indebtedness	R$ year^{-1}
F_{yt}	Fallow (y1 to y20)	ha year^{-1}
H_{hprmt}	Trips to market	trip month^{-1}
I	Initial condition (e.g. Cash, land use in y = 0)	various units
JB_{prmt}	Food grain purchases	kg month^{-1}
J_{prmt}	Stocks of food grains	kg month^{-1}
JS_{prmt}	Food grain sales	kg month^{-1}
KB_t	Borrowed cash	R$ year^{-1}
K_{pt}	Cash balances	R$ season^{-1}
LH_{mst}	Labor hired in (adult males only; md = mandays)	md month^{-1}
LS_{mst}	Household labor sold off farm (adult males only)	md month^{-1}
LT_{mt}	Labor transferred among activities (adult males only)	md month^{-1}

Variables	Description	Units
ND_{pt}	Nutrient deficiencies in cleared areas	kg year^{-1}
NF_{t}	New fallow	ha year^{-1}
NOM_{t}	Stocks of nutrients in mulched areas	kg year^{-1}
NO_{t}	Stocks of nutrients in burned areas	kg year^{-1}
NPA_{vt}	New pasture	ha year^{-1}
NRE_{t}	New degraded fallow	ha year^{-1}
NR_{rvt}	Newly planted/established crops/rotations	ha year^{-1}
PA_{yvt}	Pasture v1 (y1 to y8) v2 (y1 to y14) v3 (y1 to y20)	ha year^{-1}
PC_{mvt}	Processing quantity per month	kg month^{-1}
P_{prmt}	Production (summed over each rotation)	kg month^{-1}
RE_{yt}	Degraded fallow (y1 to y5)	ha year^{-1}
R_{ryvt}	Land in crops/rotations	ha year^{-1}
SD_{pt}	Switch crops/rotations to degradation (p1 to p2)	ha year^{-1}
SP_{t}	Switch to pasture	ha year^{-1}
S_{pt}	Savings	R$ season^{-1}
SR_{pt}	Switch to mechanization	ha year^{-1}
TGM_{pt}	Total Gross Margin	R$ season $^{-1}$
X_{xmt}	extractive activities: x1 (charcoal)	kg month^{-1}

Table 3: Technical coefficients

Coefficients	Descriptions	Units
ca_{ayvp}	Variable production costs for livestok	R$ season^{-1}
cc_{ryxvpt}	Variable production costs for crops/rotations	R$ season^{-1}
co_{prm}	Grain storage losses by crop	% month $^{-1}$
cvr_{yv}	Calving rate	% year^{-1}
dm_{p}	Days per month in season p	days
dp	Depreciation rate	% year^{-1}
dtr_{yv}	Livestock mortality rate	% year^{-1}
e	Interest rate on loan	percent year^{-1}
eqt_{*in}	Utilization time requirement of equipment in for activity *	days
h_{hprmt}	Transport costs	R$ season^{-1}
j_{prm}	Household food grain requirements	kg month $^{-1}$
$jr_{rpry1vm}$	Seed requirements (for v1 technologies only)	kg month $^{-1}$
k	Loan repayment rate	R$ year^{-1}
la_{ayvp}	Labor of any type needed for herd management	md month $^{-1}$
lfm_{m}	Adult males in the family (md = mandays)	md month $^{-1}$
lfo_{m}	Other family members (expressed in adult equivalents)	md month $^{-1}$
lf_{ym}	Adult male labor needed to clear one hectare of fallow of age y	md month $^{-1}$
lh_{m}	Male labor required for marketing	md trip^{-1}
lnd_{t}	Available land	ha year $^{-1}$
lrm_{ryvm}	Monthly adult male labor needed for crop production by rotation age and technology	md month $^{-1}$
lro_{ryvm}	Monthly labor of any type needed for crop production by rotation age and technology	md month $^{-1}$
lu_{y}	Livestock units	units
lxo_{m}	Labor of any type needed to extract charcoal (per ha. Of forest)	md month $^{-1}$
nd_{ry1v}	Nutrient demand by rotation	kg year $^{-1}$
nf_{y}	Nutrients released by slashing/burning the forest	kg year $^{-1}$
nr_{rprvp}	Nutrient deficiency response by rotation	kg year $^{-1}$
pcc_{ryv}	Pasture carrying capacity	units ha $^{-1}$
$pint_{in}$	Prices for tools/instruments	R$/kg
prext	Charcoal price	R$/kg
$priceb_{pr}$	Purchasing crop prices	R$/kg
$price_{pr}$	Selling crop prices	R$/kg
$prliv_{ayvp}$	Livestock price	R$/kg
$procf_{mvt}$	Female labor for processing	md trip^{-1}
$procm_{mvt}$	Male labor for processing	md trip^{-1}
$wage_{sm}$	Monthly wage	R$ month^{-1}
yld_{rpryv}	Monthly yields by rotation	kg year $^{-1}$

Cash Constraint and Balance

Cash in hand in any season *p* must equal minimum household expenses and expenditures for agricultural inputs (equipment + depreciation, fertilizer + pesticides, hired labor). If credit is taken (KB) loan repayment enters the RHS [(k + e)*E_t]; all loans have to be repaid until T.

$$\begin{aligned} K_{pt} \geq & +(k+e)E_t + eE_{p=3T} + \sum_a \sum_y \sum_v ca_{ayvp} A_{ayvpt} + \\ & \sum_r \sum_y \sum_x \sum_v \sum_{p \in m} cc_{ryxvpt} (R_{ryvt} + CF_{yv=2,3t} + X_{xmt} + PA_{yvt}) \\ & + \sum_{prp \in m} priceb_{pr} JB_{prmt} + \sum_s wage_{sm} LH_{mst} + \sum_h \sum_{pr} \sum_{p \in m} h_{hprmt} H_{hprmt} \\ & + \sum_{inp} p\,int_{in} BEQ_{inpt} \end{aligned} \tag{1a}$$

$$K_{pt} = I + K_{p-1(=3)t(-1)} + KB_{t<15} + S_{pt} \tag{1b}$$

$$E_t = KB_{t-1} + I + KB_{t<15} \tag{1c}$$

Labor Constraint

Slash-and-burn-, marketing-, and a part of processing time are restricted to man labor. Man labor can be transferred to the family labor constraint (5). External man labor can be hired at stepwise increasing costs and quantities (s).

$$\begin{aligned} lfm_m + \sum_s LH_{mst} - LT_{mt} \geq & \sum_r \sum_y \sum_v lrm_{ryvm} R_{ryvt} \\ & + \sum_y \sum_{v=1,3} lf_{myv} CF_{yv=pt} + \sum_{pr} \sum_h lh_{hm} H_{hprmt} + \sum_v procm_{mvt} PC_{mvt} \end{aligned} \tag{2}$$

All activities, but marketing and slash-and-burn can be done by all family members. Labor can be sold at a stepwise decreasing wage rate and increasing quantities.

$$\begin{aligned} lfo_m + LT_m - \sum_s LS_{mst} \geq & \sum_r \sum_y \sum_v lro_{ryvm} R_{ryvt} \\ & + \sum_a \sum_y \sum_v la_{yvm} A_{ayvp=mt} + lxo_{x=1m} X_{x=1m} + procf_{mvt} PC_{mvt} \end{aligned} \tag{3}$$

Stocks

Food grains and seeds can be stored and a subject to a volumetric upper bound. Depending on the product type, parts of the stock spoils over time.

$$\begin{aligned} J_{prmt} = & J_{prm-1(=12)t(-1)} + I + co_{prm} J_{prmt} + P_{prmt} + JB_{prmt} \\ & - j_{prm} - \sum_{r<5} \sum_{v<5} jr_{rprvm} R_{ry=1vt} - JS_{prmt} \end{aligned} \tag{4}$$

Nutrients

A leontief technology is assumed for each crop type, i.e. constant returns to scale. However, yields at harvest (5a) decline depending on a nutrient deficit at the planting date (5b,c). Each crop in the slash-and-burn system has an individual nutrient deficiency response (nr) that was estimated using the yield decline observed in field trials (Kato 1998). The minimum nutrient requirement per crop (nd) was obtained from the same study. Equation (5d) determines the nutrient inflow that depends on the age of fallow vegetation cut and burned before planting (nf).

$$\begin{aligned} P_{prmt} = {} & \sum_r \sum_y \sum_v yld_{r<8pryv} \; R_{ryvt} - \sum_r \sum_y \sum_v nr_{r=1pr=3v<5p<3} \; ND_{r=1v<5p<3t} \\ & - \sum_r \sum_y \sum_v nr_{r>1<4pr=4v<5p<3} \; ND_{r>1v<5p<3t-1} \end{aligned} \tag{5a}$$

$$\begin{aligned} \sum_r \sum_v ND_{rvpt} + NO_{pt} \geq {} & \sum_r \sum_v nd_{r=2,3v=1,2} R_{r=2,3yv=1,2t} \quad \forall p = 1 \\ & + \sum_r \sum_v nd_{r=1,4v=1,2} R_{r=1,4yv=1,2t} \quad \forall p = 2 \end{aligned} \tag{5b}$$

$$\begin{aligned} \sum_r \sum_v ND_{rvpt} + NOM_{pt} \geq {} & \sum_r \sum_v nd_{r=2,3v=3,4} R_{r=2,3yv=3,4t} \quad \forall p = 1 \\ & + \sum_r \sum_v nd_{r=1,4v=3,4} R_{r=1,4yv=3,4t} \quad \forall p = 2 \end{aligned} \tag{5c}$$

$$NO_t = NO_{t-1} + \sum_y \sum_{v=1} nf_{yv} \; CF_{yvt} + I \tag{5d}$$

$$NOM_t = NOM_{t-1} + \sum_y \sum_{v=2} nf_{yv} \; CF_{yvt} + I \tag{5e}$$

Land constraint

$$\ln d_t = \sum_y \sum_v (R_{ryvt} + PA_{yvt} + F_{yt} + RE_{yt}) \tag{6}$$

Fallow and fallow rehabilitation balance

Depending on rotation type and technology, land goes into productive or rehabilitating (unproductive) fallow.

$$F_{yt} = F_{y-1t-1} + NF_1 + REC_t - CF_{yvt} + I \qquad \forall y \leq 20 \tag{7a}$$

$$NF_t = \sum_r \sum_y \sum_v CR_{r\leq 5yv\leq 4t} - SP_t - \sum_p SR_{pt} \tag{7b}$$

$$\begin{aligned} RE_{yt} = {} & RE_{y-1t-1} - CRE_t + NRE_t + I + \sum_p SD_{pt} * 0.5 \\ & + \sum_{vy} CPA_{yvt} + \sum_{ry'v} CR_{r>5y'vt} \qquad \forall y \leq 5 \end{aligned} \tag{7c}$$

$$NRE_t = (\sum_r \sum_y \sum_v CR_{r=2,3yv\geq 5} - SD_{p=1t}) + (\sum_r \sum_y \sum_v CR_{r=4yv\geq 5} - SD_{p=2t}) \quad (7d)$$

Crop balance and rotational constraints

The amount of cut forest cannot be greater than the amount of planted rotations.

$$R_{ryvt} = R_{ry-1vt-1} + NR_{rvt} - CR_{ryvt} + I \qquad \forall y \neq y_{max} \text{of } \ r \quad (8a)$$

$$\sum_{r=2,3} \sum_{v>2<5} R_{ry=1vt} = \sum_y CF_{yv=2p=1t} \quad (8b)$$

$$\sum_{r=1,4} \sum_{v>2<5} R_{ry=1vt} = \sum_y CF_{yv=2p=2t} \quad (8c)$$

$$\sum_{r=1,4} \sum_{v<3} R_{ry=1vt} = \sum_y CF_{yv=1p=2t} \quad (8d)$$

$$\sum_{r=2,3} \sum_{v<3} R_{ry=1vt} = \sum_y CF_{yv=1p=1t} \quad (8e)$$

$$\sum_{r=1,4} \sum_{v>4} R_{ry=1vt} = \sum_{v'y} CF_{yv'=3p=2t} + SD_{p=2t} * 0.5 + SR_{p=2t} \quad (8f)$$

$$\sum_{r=2,3} \sum_{v>4} R_{ry=1vt} = \sum_{v'y} CF_{yv'=3p=1t} + SD_{p=1t} * 0.5 + SR_{p=1t} \quad (8g)$$

Equipment balance

$$\begin{aligned} EQ_{int} dm_p \geq & \sum_{m \in p} \sum_v \sum_{in} eqt_{*in=2,3} PC_{mvt} + \sum_{m \in p} \sum_v eqt_{*in=1} PC_{mvt} \\ & + \sum_h \sum_{pr} \sum_{m \in p} eqt_{*in=4} H_{hprmt} \end{aligned} \quad (9a)$$

$$EQ_{int} = I + (1 - dp) EQ_{int-1} + \sum_p BEQ_{inpt} \quad (9b)$$

Pasture balance and constraints

$$PA_{ryvt} = I + PA_{ryvt-1} + NPA_{rvt} - CPA_{ryvt} \quad (10a)$$

$$\sum_r \sum_y PA_{ryvt} pcc_{ryv} = \sum_y lu_y (CO_{pt} + BE_{pt} + COC_{pt} + BEC_{pt}) \quad (10b)$$

Cattle balances

$$CO_{yvpt} = I + CO_{yvp-1(=3)t(-1)} (1 - dtr_{yv}) + 0.5 CAL_{vt} + CB_{yvpt} - COC_{yvpt} \quad (11a)$$

$$BE_{yvpt} = I + BE_{yvp-1(=3)t(-1)} (1 - drt_{yv}) + 0.5 CAL_{vt} - BEC_{yvpt} \quad (11b)$$

$$CAL_{vt} = \sum_y CO_{yvp=3t-1} cvr_v \quad (11c)$$

Total Gross Margin/Savings Balance

$$\begin{aligned}\mathrm{TGM}_{pt} = {} & \sum_{prp\in m}(\mathrm{price}_{pr}\mathrm{JS}_{prm} - \mathrm{sac}_{pr}\mathrm{JS}_{prm}) + \sum_{ayvp}\mathrm{prliv}_{ayvp}(\mathrm{CO}_{yvpt} + \mathrm{BE}_{yvpt}) + \sum_{yvp}\mathrm{milkp}\ \ \mathrm{CO}_{yvpt} \\ & + \sum_{yv}\mathrm{pext}\ \ \mathrm{CF}_{yvt} + \sum_{sp\in m}\mathrm{wage}_{s}\mathrm{LS}_{mst} - (k+e)\mathrm{E}_{t} - e\mathrm{E}_{p=3T} - \sum_{a}\sum_{y}\sum_{v}\mathrm{ca}_{ayvp}\mathrm{A}_{ayvpt} - \\ & \sum_{r}\sum_{y}\sum_{x}\sum_{v}\sum_{p\in m}\mathrm{cc}_{ryxvpt}(\mathrm{R}_{ryvt} + \mathrm{CF}_{yv=2,3t} + \mathrm{X}_{xmt} + \mathrm{PA}_{yvt}) - \sum_{inp}\mathrm{pint}_{in}\mathrm{BEQ}_{inpt} \\ & - \sum_{prp\in m}\mathrm{priceb}_{pr}\mathrm{JB}_{prmt} - \sum_{s}\mathrm{wage}_{sm}\mathrm{LH}_{mst} - \sum_{h}\sum_{pr}\sum_{p\in m}\mathrm{h}_{hprmt}\mathrm{H}_{hprmt}\end{aligned} \tag{12a}$$

$$\mathrm{TGM}_{pt} = \mathrm{D}_{pt} + \mathrm{S}_{pt} \tag{12b}$$

Executive Summary

Introduction and Objectives

Apart from representing the world's largest carbon and bio-diversity pools, tropical rain forests provide a living for rural dwellers and a growing urban population. Together with large-scale commercial agriculture, cattle ranching, logging and mining industry, approximately half a million smallholder families have been responsible and continue to contribute to the high deforestation rates in the Brazilian Amazon region. Converting forests for agriculture and other purposes provides economic benefits at the local and national scale, but it also entails global cost in the form of bio-diversity and carbon losses. Consequently, and in view of the low resilience of tropical ecosystems, policy research in tropical agriculture has increasingly been focusing on land use and land cover change and its potential impact on the economic and environmental sustainability of current development paths. A great deal of this research had its regional focus on the 'hot spots' of deforestation in the western Amazon, alongside the Trans-Amazonian highway, and in the south of the federal state of Pará. Reviewing this literature with the purpose of identifying the main issues of policy relevance led to the formulation of the following five general questions that represent the main motivation for this study.

1. What kind of land use systems are likely to emerge on agricultural frontier areas twenty years from now?
2. How does economic and agricultural change affect rural livelihoods in the absence of a valuable natural resource, such as primary forests?
3. Can small-scale agriculture in the Amazon be sustainable without expansion into virgin forests?
4. If yes, what policy mix is required to create the necessary socio-economic and institutional environment to maintain and increase rural welfare and environmental sustainability in a changing economic environment?
5. If no, can policies and technological change be combined in a way to make smallholder agriculture more sustainable?

This study integrates into a branch of research efforts that focuses on one of the oldest colonization areas in the Brazilian Amazon region, the Zona Bragantina. Despite its historical, socio-economic, and ecological peculiarities the Bragantina case is understood here as a potential future scenario for some of today's agricultural frontiers. It allows looking at agricultural and economic change in a steady-state situation that is, albeit subject to land use dynamics, not influenced by dramatic demographic and ecological transformation processes.

An additional motivation of the study was the emergence of technological alternatives to the traditional land preparation technique slash-and-burn; namely mechanical plowing as well as mulching, and agro-forestry in combination with rudimentary on-farm processing. Some of these alternatives appear promising in that they could allow to reducing the social costs of slash-and-burn that accrue mainly in the form of green house gas emissions and material damages from accidental fires. Many policy makers are aware of these problems, but lack quantitative information on how to introduce new technologies such that rural welfare improves together with other development objectives, i.e. environmental sustainability and economic growth.

In order to evaluate the socio-economic and environmental costs and benefits of technological change it is necessary to analyze whether and how the technological alternatives are likely to integrate into the technology mix at the farm level and what the potential impacts on household income and the environment will be. The presence of a variety of risks, for example related to the production and commercialization of agricultural products, further increases the complexity of the situation.

The five questions listed above and the existence of concrete technological alternatives to slash-and-burn, led to the formulation of the general and specific objectives of the study:

General Objective:

Identify trade-offs and synergies involved in policy options to targeting rural poverty and environmental degradation in the presence of technology and economic change in the Zona Bragantina.

Specific Objectives:

1. Provide a socio-economic characterization of the fallow based smallholder production system.

2. Identify and evaluate actual and potential trends in land use and technology change on representative small-scale farms under alternative policy settings.
3. Identify major farm-level constraints to favorable trends in technology and land use change.
4. Provide guidance as to how existing and alternative policy instruments can address these constraints in order to achieve sustainable development goals more efficiently.

Data and Methodology

To meet these objectives, a neo-classical theoretical framework of farm-household behavior was adopted that explicitly addresses the links between poverty and the environment. Mainly locally generated secondary data on bio-physical relationships and technology parameters were combined with farm-household survey data collected from 271 randomly selected farms in three districts and 22 communities.

A descriptive analysis of secondary and primary data using standard statistical tools, such as difference of mean tests and regression analysis, provides the background for a formal quantitative analysis drawing on linear and non-linear mathematical programming techniques. One of the key assumptions of the model is that farm-households maximize the consumption of non-essential goods and minimize the risk induced variation of returns from the commercialization of agricultural products. This optimization is subject to various constraints, such as the minimum household consumption requirements, the available family labor, and the availability of land and fallow vegetation among others. A 25-year simulation horizon was chosen mainly for the following reasons: In farming systems that involve fallow-periods of more than 10 years and a substantial amount of perennial cropping activities, decision-making is inherently inter-temporal. In order to study the effects of changing key economic and policy variables on land use change and technology adoption it is, hence, necessary to account for time preferences and long-term effects that influence today's decision making. As such, the model has to be understood has a flexible tool to conduct investment analyses at the farm level that, other than conventional investment analysis, allows for resource allocation decisions to be determined endogenously.

With the purpose of identifying representative farm-household types for the modeling exercise, selected farm and community level variables were passed through a combination of principal component and cluster analysis. Four representative farm-groups emerged, which were interviewed in more detail to obtain production and technology parameters as well as indications on the land use history and consumption habits. In addition, regional budget data were used to estimate the impact of income changes on consumption behavior.

The bio-physical component of the model includes a set of crop specific yield damage functions that were estimated from experiment station and farm trial data and subsequently calibrated to the results of an econometric analysis of annual crop production. The damage functions represent the yield impact of reducing the length of the fallow period, such that this choice is endogenously determined in the model.

In addition, Monte Carlo analysis was employed to derive the response of the expected value and variance of yields to chemical fertilizer use - an important precondition for the use of mechanical land preparation technologies. This allowed analyzing the combined effect of market and production risk on the use of chemical fertilizers in the presence of risk aversion in an extended model version.

The model was validated using a statistical test of short-term robustness and a straight forward comparison of key model outcomes and long-term land use trends with the empirical evidence.

Results of the Descriptive Analysis, Baseline, and Technology Simulations

A variety of outstanding historical, socio-economic, and ecological conditioning factors positively contributed to the development of smallholder agriculture in the Bragantina. For example, due to its early colonization it was much less affected than more recent agricultural frontiers by the waves of commercial agricultural investments that hit the Amazon region in response to government incentives after 1970. Moreover, the proximity to the large urban center Belém provided a relatively safe and growing outlet market for both perishable and non-perishable agricultural products. Due to the relatively high returns to agricultural activities, e.g. intensive cash crop production and cassava processing, small-scale extensive pasture and livestock activities are less common on typical smallholdings than at the agricultural frontiers in the western Amazon. Large-scale commercial farms, however, continue to engage in cattle holding in many districts throughout the region. Finally, a combination of ecological factors, such as the deep rooting semi-deciduous vegetation cover and the absence of steep slopes, makes the Bragantina less prone to problems of soil erosion and nutrient leaching than many other parts of the Amazon region.

Today, the average size of smallholdings is lower than on more recent agricultural frontiers and the population density is comparatively high, such that the relative resource endowment is different from that of farms in the western Amazon or at the *Transamazônica*. Wealth and access to markets as well as extension service are unevenly distributed in the Bragantina and, with the exception of land and area under fallow, follow a negative gradient from west to east. As a consequence, many farm-households in the eastern Bragantina show signs of investment poverty, which is reflected in the use of more traditional production technologies.

Not all of today's agricultural frontiers will find equally favorable conditions for smallholder development, but it is likely that smallholders will continue to dominate important parts of the Amazonian landscape. In this context, the Bragantina case can provide useful indications on how these landscapes can be managed in a sustainable manner.

At a first glance, **natural resource use** seems to be in a **steady-state** in the Bragantina. However, model baseline simulations over a 25-year horizon suggest that the steady-state hypothesis only holds with respect to household income and the proportion of secondary vegetation to cropland, whereas the average age, and hence, the quality of fallow vegetation declines together with the amount of carbon bound in the system. In the long-run, this leads to a reduction of the productivity of annual cropping in the slash-and-burn system, which is compensated by a slight increase in perennial crop production. This compensation does not necessarily reduce the expected income, but it tends to increase the risk induced variation of household income, which represents a real income loss for risk averse households. The measured increase in risk induced income variation, however, is not statistically significant at least in the model baseline.

The **introduction of new technologies** alters the steady-state with respect to virtually all indicators of welfare and environmental sustainability. Especially mechanical land preparation technologies and the enhanced use of chemical fertilizers in annual production affect household income positively and amplify natural resource degradation. From an environmental point of view, mulching has to be preferred to plowing as it conserves below ground biomass, and thus, carbon stocks and fallow re-growth capacity. Yet, only mechanical plowing is adopted at its current service costs, whereas a cost reduction of 50% to 90% is necessary to make mechanical mulching competitive. Such a cost reduction is, hence, the precondition for a recommendation of mulching as a means to enhance the environmental sustainability of technical change.

Cash constraints appear to be less important in determining fertilizer use intensity than risk aversion. Simulations including production risk show that risk averse farm-households tend to reduce the intensity of fertilizer use in annual crop production with increasing aversion to risk. Without risk aversion, however, the model demonstrates that investments into capital intensive cash crops would be much higher than they actually are.

The **on-farm processing of agro-forestry products** appears only relevant for farms with good access to markets and information, but brings about almost exclusively positive impacts on household income and fallow conservation.

Policy Simulations and Implications for Decision-Makers

The descriptive analysis suggested that the majority of smallholders in the Bragantina will be increasingly exposed to new technologies, and hence, most policy simulations include one or more of the technological innovations discussed above. The implications for decision-makers may be divided into implications for existing policies and suggestions for additional measures.

Implications for existing policies

Technology promotion is a strategy pursued by many local and regional governments and the model suggests that environmental policy instruments may be used to balance out positive income and negative environmental effects. Most promising in this regard appears the option of levying a tax on the use of the slash-and-burn practice on farms that benefit from the improved access to mechanical land preparation. In the range of R$/ha/year 200 to 300, such a tax would provide tax revenues of more than R$300 per average farm type, which the government may reinvest into technology promotion or fallow/forest conservation payments. A tax of at least R$/ha/year 400 is necessary to induce significant changes in on-farm carbon sequestration.

The effect of **set-aside payments for the conservation of secondary forests** depends on the degree of technology access, because farms with limited access to mechanical land preparation value fallow vegetation higher than farms that can choose between alternative technology options at low transaction costs. An annual payment of at least R$/ha 100 is necessary to induce forest/fallow conservation and carbon sequestration on the model farm with limited technology access. The same farm type with full technology access begins to respond to conservation payments at an annual rate of R$/ha 50.

The option of setting **minimum conservation standards** can only be recommended if combined with improved technology access, because it reduces the expected income of risk averse farm-households.

Proambiente is an upcoming agro-environmental policy program that intends to compensate farmers for environmental services in the form of subsidized credits. Scenarios imposing the full set of Proambiente regulations on the model farm, improve environmental indicators, but lead to a strong reduction of annual household income. Hence, in the current setting of regulations it is unlikely that farmers will voluntarily enter the program. An option to make Proambiente more attractive is to establish conditions, under which the use of chemical fertilizers is eligible. Especially, labor and capital intensive cash crops, such as pepper and passion fruit depend on fertilizer application. Including them in the range of eligible activities under Proambiente would not only increase household income, but also contribute to conserving secondary forests as it ties up labor that would otherwise be allocated to fallow intensive annual cropping.

Additional Recommendations

Even without the governmental promotion of new technologies, the **trend towards the mechanization of land preparation** on smallholdings in the Bragantina and in other parts of the Amazon is likely to continue in the future. This study indicates that mechanical land preparation will not substitute for the use of fire for land preparation.

Instead it suggests that farms with access to mechanical land preparation will increase their operational scale, which causes considerable losses of below and aboveground carbon and a reduction of the total area under secondary vegetation and remaining primary forests. Independent of measures to promote technological change at the local or regional level, the results make a good case for the introduction of tax and conservation payments schemes (see example above) as a means to counteract environmental degradation. This has important implications at the regional scale, because some smallholders have been and continue to be excluded from technological change. Here again, taxing the use of slash-and-burn on farms with good technology access appears promising as it generates tax revenues that could be re-invested into technology promotion or conservation payments in economically underprivileged areas.

Policy measures aiming at reducing the **risk involved in agriculture** and commercialization can, but need not have positive effects on carbon and fallow/forest conservation. Establishing minimum prices increases the expected return to agriculture, and hence, will lead to an expansion of crop operations. The same applies to crop yield insurances as far as they are not technology specific. However, in a scenario of full technology access, a **crop yield insurance** covering fields that are prepared with mechanical mulching significantly increases the area under mulch given the assumption of risk averse investment behavior. Apart from a reduction of the average area under degraded fallows, this would alter the technology mix, such that the annual amount of fallow slashed and burned decreases. Hence, most of the benefits of a technology specific crop yield insurance are external to the farm-household and accrue in the form of reduced non-carbon greenhouse gas emissions and material damages from accidental fires.

Finally, **credit** has shown the potential to serve as a catalyst especially for investments of an indivisible character. The model suggests that taking credit is profitable for smallholders even at relatively high interest rates (up to 15%). In view of the low repayment rates experienced in the case of large amount of credits for smallholders, it is proposed to alleviate cash constraints through the provision of micro-credits. A necessary precondition is that micro-credits can be accessed at reasonably low transaction costs, which is possible, for example if credits could be provided to the farmers through the local trade unions. Other than many banks, trade unions are known, trusted, and frequently visited by many smallholders and experienced in the administration of pension payments.

References

Abromovay, R. (1992): *Paradigmas do Capitalismo Agrário em Questão*. Campinas, Hucitec-ANPOCS.

Alencar, A., Nepstad, D, McGrath, D., Moutinho, P., Pacheco, P., do Carmen, M., Diaz, V., Soares Filho, B.S. (2004): *Desmatamento na Amazônia: indo além da "Emergência Crônica"*. IPAM, Belém, Brazil.

Altieri, M.A. (1999): *The ecological role of biodiversity in agroecosystems.* Agriculture, Ecosystems and Environment. Vol. 74, 19–31.

Andersen, L.K., Granger, C.W., Reis, E.J. (2002): *The dynamics of Deforestation and Economic Growth in the Brazilian Amazon.* Cambridge University Press, Cambridge, UK.

Angelsen, A., Kaimowitz, D. (2001): *Agricultural Technologies and Tropical Deforestation.* CAB International, Wallingford, UK.

Baar, R. (1997): *Vegetationskundliche und –ökologische Untersuchungen der Buschbrache in der Feldumlagewirtschaft im östlichen AmaZonasgebiet.* Ph.D. Thesis. Heft 121. Göttinger Beiträge zur Land- und Forstwirtschaft in den Tropen und Subtropen.

Backhaus, K., Erichson, B., Plinke, W., Weiber, R.(2000): *Multivariate Analysemethoden, Eine anwendungsorientierte Einführung*. 9. Auflage. Springer-Verlag. Berlin.

Bardhan, P., Udry, C. (1999): *Development Microeconomics*. Oxford University Press, Oxford, UK.

Barbier, B., Bergeron, G. (1999): *Impact of policy intervention on land management in Honduras: results of a bio-economic model*. Agricultural Systems. vol.60, 1-16.

Barbier, B., Bergeron, G. (2001): *Natural Resource Management in the Hillsides of Honduras: Bioeconomic Modeling at the Micro-Watershed Level*. Research Report 123. IFPRI Washington D.C.

Balmann, A. (1995): *Pfadabhängigkeit in Agrarstrukturentwicklungen. Begriffe, Ursachen und Konsequenzen*. Duncker & Humblot. Berlin.

Benjamin, D. (1992): *Household Composition, Labor Markets, and Labor Demand: Testing for Separation in Agricultural Household Models*. Econometrica. vol. 60, 287-322.

Berg, E. (1998): *Der Einfluß von Unsicherheit und Risikoeinstellung auf die Intensität und Produktionsprogramm im Ackerbau*. Published in Polish. Zagadnienia ekonomiki rolnej, Zeszyt 4-5, Warzawa, S.37-57.

Berg, E. (2003): *Modeling the impacts of uncertainty and attitudes towards risk on production decisions in arable farming*. Poster Paper submitted for the 25th International Conference of IAAE Durban, South Africa.

Berger, T. (2000): *Agentenbasierte räumliche Simulationsmodelle in der Landwirtschaft. Anwendungsmöglichkeiten zur Bewertung von Diffusionsprozessen, Ressourcennutzung und Politikoptionen.* Dissertation. Agrimedia GmbH.

Bevilaqua, L.I. (2004): *Pequenos Produtores na Amazônia: Inter-Relações entre Ecossistema e Sistema Social na Utilização e Proteção da Floresta Tropical.* Final report for research stipend. NAEA/UFPA.

Binswanger, H.P., McIntire, J. (1987): *Behavioral and Material Determinants of Production Relationships in Land-abundant Tropical Agriculture.* Economic Development and Cultural Change. Vol. 36 (1), 73-99.

Block, A. (2004): *Göttinger Mähhäcksler Tritucap, und Forstmulcher – Nicht Brennende Flächenvorbereitung am Beispiel der Zona Bragantina. Nord-Ost-Amazonien, Brasilien.* Ph.D. Thesis. (forthcoming).

Bornemann, T. (2002): *The impact of cattle adoption on the labor economy of traditional Smallholders in Eastern Amazonia of Brazil.* M.Sc. Thesis University of Göttingen.

Brandes, W. (1985): *Über die Grenzen der Schreibtischökonomie*. Mohr Siebeck. Tübingen.

Brown, D. (2000): *A Review of Bio-Economic Models. Paper prepared for the Cornell African Food Security and Natural Resource Management (CAFSNRM) Program*. Cornell University.

Bünemann, E. (1998): *Einfluß von Mulch und mineralischem Dünger auf Zea mays und Vigna unguiculata in der Feldumlagewirtschaft Ostamazoniens.* Master Thesis. University of Göttingen.

Bulte. E.H., Van Soest, D. (1999): A *note on soil depth, failing markets and agricultural pricing*. Journal of Development Economics. vol. 58: 245-254.

Cacho, O.J. (2000): *The Role of Bioeconomic Models in Renewable Resource Managementt and Assessment of Solution Techniques*. Paper presented at the symposium: "Integrating Approaches for Natural Resource Management and Policy Analysis: Bioeconomic Models, Multi-Agent Systems, and Cellular Automata" at the XXIV International Conference of Agricultural Economists (IAAE), Berlin, August 2000.

Carvalho, M.L.S., Pinheiro, A.C., de Castro Neto, M. (1997): *Development of a Mathematical Programming Model to include the Effects of Crop Yield Variability on Animal Production*. In Huirne, R., Hardaker, J., Dijkhuizen A.

(editors) (1997): Risk management strategies in agriculture; State of the art and future perspectives. Mansholt Studies 7, Wageningen.

Chavas, J.-P., Kliebenstein, J., Crenshaw, T.D. (1985): *Modeling Dynamic Agricultural Production Response: The case of Swine Productio*n. American Journal of Agicultural Economics, vol. 67, no. 3, 636-646.

Chayanov (Čajanov), Aleksandr V. (1923): *Die Lehre von der bäuerlichen Wirtschaft* Reprint of Berlin, Parey, 1923. Campus-Verlag 1987. Frankfurt, Germany.

Chiang, A.C. (1992): *Elements of Dynamic Optimization*. Waveland Press, Inc. Illinois.

Conrad, J.M. and and Clark, C.W. (1987): *Natural resource economics. Notes and problems*. Cambridge. University Press, Cambridge.

Costa, F. (1989): *Amazonien - Bauern, Märkte und Kapitalakkumulation*. Saarbrücken, Fort Lauderdale: Breitenbach.

Costa, F.A. (1995): *O Investimento Camponês: considerações teóricas*. Revista de Economia Política. Vol. 15, No. 1, 83-100.

Costa F.N. editor (2000): Agricultura *familiar em transformação no nordeste paraense: o caso de Capitão Poço*. NAEA, Belém.

Cruz, E. (1953): *A Estrada de Ferro de Bragança. Visão Social, Econômica e Política*. Universidade Federal do Pará, Belém.

Dean, G.W., de Benedictis, M. (1964): *A Model of Economic Development for Peasant Farms in Southern Italy*. Journal of farm economics, vol. 46, no. 2.

Denich, M. (1989): *Untersuchungen zur Bedeutung junger Sekundärvegetation für die Nutzungssystemproduktivität im östlichen AmaZonasgebiet, Brasilien.* Göttinger Beiträge zur Land- und Forstwirtschaft in den Tropen und Subtropen. Heft 46, Göttingen.

Denich, M. (1996): *Ernährungssicherung in der Kleinbauerlandwirtschaft Ostamazoniens - Probleme und Loesungsansätze*. Goettinger Beiträge zur Land- und Forstwirtschaft in den Tropen und Subtropen, 115, 78-88.

Denich, M., Kanashiro, M., Vlek, P.L.G. (2000): *The Potential and Dynamics of Carbon Sequestration in Traditional and Modified Fallow Systems of the Eastern Amazon Region, Brazil.* In: R. Lal, J.M. Kimble and B.A. Stewart (eds.): Global Climate Change and Tropical Ecosystems. CRC Press, Boca Raton, Washington, USA, pp. 213-229.

Denich, M., Vielhauer, K., Kato, M.S. de A., Block, A., Kato, O.R., Sá, T.D. de A., Lücke, W., Vlek, P.L.G. (2004): *Mechanized land preparation in forest-based fallow systems: The experience from Eastern Amazonia.* Agroforestry Systems 2004, vol. 61, no. 1, pp. 91-106(16).

De Janvry, A., Fafchamps, M., Sadoulet, E. (1991): *Peasant Household Behavior with Missing Markets: Some Paradoxes Explained.* Economic Journal. 101:1400-17.

De Oliveira, R.F., Singh, R., Couto, W.S., Cruz, E. De S., Dutra, S. (1986): *Adubação nitrogenada na região norte*. In Santana, M.B. (editor): Simpósio sobre Adubação Nitrogenada no Brasil, Ilhéus, BA, Brasil.

De Oliveira, A. E. (1983): *Ocupação humana*. In E. Salati, H. Schubart, W. Junk, A. E. de Oliveira (editors): *Amazônia: desenvolvimento, integração, ecologia*. São Paulo: CNPq, editora brasiliense.

Da Silva, B.N.R., Carvalho, J. (1986): *Soils of the Eastern Amazon Region*. In EMPRAPA-CPATU-GTZ: Studies on the Utilization and of Soils in the Eastern Amazon Region.

De Souza Cruz, E., Couto, W.S., Oliveira, R.F., Dutra, S. (1982): *Adubação Fosfatada na Regiao Norte*. In Adubação Fosfatada no Brasil. EMBRAPA.

Dillon, J.L., Scandizzo, P. (1978): *Risk Attitudes of Subsistence Farmers in Northeast Brazil: A Sampling Approach.* American Journal of Agricultural Economics 60: 425-435.

Duarte, M.de L. R. editor (2003): *Cultivo da Pimenta do Reino na Região Norte. Sistemas de Produção 1*. Embrapa Amazônia Oriental, Belém. Available at: http://www.cpatu.embrapa.br

Egler, E.G. (1961): *A Zona Bragantina no Estado do Pará*. Revista brasileira Geografia. Vol. 23, 527-555.

Ekins, P., Simon, S., Deutsch, L., De Groot, C. F.,. (2003): *A framework for the practical application of the concepts of critical natural capital and strong sustainability*. Ecological Economics. vol. 44, issue 2-3, 165-185.

Ellis, F. (1988): *Peasant Economics*. Farm households and agrarian development. Cambridge University Press. Cambridge.

Fafchamps, M. (2003): *Rural Poverty, Risk, and Development*. Elgar Publishing.

FAO (2003): *State of the World's Forest. Rome*. Available at: http://www.fao.org/

Feder, G. J., Richard E., Zilberman D.(1985): *Adoption of Agricultural Innovations in Developing Countries: A Survey*. Economic Development and Cultural Change. vol. 33, issue 2, 255-298

Freire, R. de O., de Souza Cruz, E., da Costa, N.A. (1998): *Utilização do Sistema Integrado de Diagnose e Recomendação (DRIS) na Determinação do Estado Nutricional da Pimenta do Reino em Paragominas, PA.* Boletim de Pesquisa 191. Embrapa Amazônia Oriental.

Freire, R. de O., de Souza Cruz, E., Mourão Júnior, M. (2002): *Efeito da Adubação NPK na Produtividade, Nutrição e Sanidade da Pimenteira do Reino, em Castanhal, Pará.* Boletim de Pesquisa 10. Embrapa Amazônia Oriental.

Friedmann, H. (1980): *Household production and the national economy*. Journal of Peasant Studies, Vol 7, No.2.

Fundação IBGE (1977): *Consumo alimentar: antropometria*. Rio de Janeiro, IBGE (Estudo Nacional da Despesa Alimentar volume1)

Gilboa, I. (1989): *Expectation and Variation in Multi-Period Decisions*. Econometrica. vol. 57, no. 5, 1153-1169.

Gittinger, J. P. (1985): *Economic Analysis of Agricultural Projects*. Baltimore.

Gowdy, J., O'Hara, S. (1997): *Weak sustainability and viable technologies*. Ecological Economics. vol. 22, issue 3, 239-247.

Guimarães, L.A.C. (2000): *Estudo da Comercialização dos Principais Produtos Agrícolas e de seus Agentes Mercantis e Agricultores Familiares, em Igarapé-Açu, Estado do Pará.* Final Report to the CNPQ. Belém, PA.

Hanf, C.H. (1989): *Agricultural Sector Analysis by Linear Programming Models*. Kiel.

Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C. (1998): *Multivariate Data Analysis*. 5th edition. Upper Saddle River, NJ. Prentice Hall.

Hardaker, J.B, Huirne, R.B.M., Anderson, J.R., Lien, G. (1997a): *Coping with Risk in Agriculture.* CAB International, UK.

Hardaker, J.B., Huirne, R.M.B., Barry, P.J., King, R.P. (1997b): *Risk management strategies in agriculture: State of the art and future perspectives*. In Huirne, R., Hardaker, J., Dijkhuizen A. (editors): Risk management strategies in agriculture; State of the art and future perspectives. Mansholt Studies 7, Wageningen.

Hardaker, J.B. (2000): *Some issues in dealing with risk in agriculture*. Working Paper Series in Agricultural and Resource Economics. No. 2000-3. University of New England, Armidale, Australia. At: www.une.edu.au/febl/GSARE/AREwp00-3.PDF

Hazell, P.B.R., Norton R.D. (1986): *Mathematical Programming for Economic Analysis in Agriculture*. Macmillan Publishing Company, New York.

Hedden-Dunkhorst, B., Denich, M., Vielhauer, K., de Sousa Filho, F.R., Sá, T.D. de A., Hurtienne, T., Costa, F. de A., Mendoza-Escalante, A., Börner, J. (2003): *Forest-Based Fallow Systems as a Safety Net for Smallholders in the Eastern*

Amazon. Paper presented at International Conference on Rural Livelihoods, Forests and Biodiversity 19-23 May, Bonn, Germany.

Hengsdijk, H., Quack, W., Bakker, E.J., Ketelaars, J.J.M.H. (1996): A *land use system and technology generator for the Koutiala Region in South Mali*. DLV Report No. 5. Wageningen: AB-DLO/PSS.

Hohnwald, S. (2002): *A Grass-Capoeira Pasture fits better than a Grass-Legume Pasture in the Agrigultural System of Smallholdings in the Humid Brazilian Tropics.* Ph.D. Thesis. Cuvillier Verlag. Göttingen.

Homma, A.K.O. (without date): *O desenvolvimento da agroindústria no estado do Pará*. Embrapa Amazônia Oriental.

Homma, A.K.O. (2003): *História da Agricultura na Amazônia: da era pré-columbiana ao terceiro milênio.* Embrapa Informação Technologica, Brasília.

Hondermann, J. (1995): *Fitomassa e Estoque de Bioelementos das Diversas Fases da Vegetação Secundária, Provenientes de Diferentes Sistemas de Uso da Terra no Nordeste Paraense, Brasil*. Master Thesis. Universidade Federal do Pará.

Hölscher, D. (1994): *Wasser- und Nährstoffhaushalt eines Agrarökosystems mit Waldbrache im östlichen Amazonasgebiet.* Ph.D Thesis. University of Göttingen.

Hurtienne, T. (1988): *Ökologie, Ökonomie und Sozialsysteme Amazoniens: Versuch einer kulturökologischen Bilanz (Teil 1)*. Unpublished.

Hurtienne, T. (1998): *Vorläufige Forschungsergebnisse zur sozioökonomischen Analyse kleinbäu-erlicher Landnutzungssysteme in Ostamazonien unter Berücksichtigung des neueren tropenökologischen Forschungsstandes.* NAEA/UFPA unpublished.

IBGE (1998): *Censo Agropecuário 1995/6*. At: http://www.ibge.gov.br/.

IBGE (1995/6): *Pesquisa de Orcamentos Familiares*. At: http://www.ibge.gov.br/.

IBGE (2000): *Censo Demográfico 2000*. At: http://www.ibge.gov.br/.

IBGE (2002/3): *Pesquisa de Orçamentos Familiares*. At: http://www.ibge.gov.br/.

IBGE (1990-2002): *Produção Agrícola Municipal*. At: http://www.ibge.gov.br/.

Intriligator, M. (1971): *Mathematical Optimization and Economic Theory*. Prentice Hall, Inc.

Jordan, C. F. (1985): *Nutrient Cycling in Tropical Forest Ecosystems*. John Wiley & Sons. Chichester.

Jordan, C.F.(1989): An *Amazonian Rainforest. The Structure and Function of a Nutrient Stressed Ecosystem, and the Impact of Slash-and-Burn Agriculture*. Man and the Biosphere Series. Vol. 2. UNESCO, Paris, France.

Kato, M. de S.A. (1998): *Fire-free Land Preparation as an Alternative to Slash-and-burn Agriculture in the Bragantina Region, Eastern Amazon: Crop Performance and Phosphorous Dynamics.* Ph.D. Thesis. Cuvillier Verlag Göttingen.

Kato, M. de S.A., Kato, O.R., Denich, M., Vlek, P.L.G. (1999): *Fire-free alternatives* to slash-and-burn for *shifting cultivation in the eastern Amazon region: The role of fertilizers.* Field Crops Research. Vol. 62, 225-237.

Kato, O.R. (1998): *Fire-free Land Preparation as an Alternative to Slash-and-burn Agriculture in the Bragantina Region, Eastern Amazon: Crop Performance and Nitrogen Dynamics.* Ph.D. Thesis. Cuvillier Verlag Göttingen.

Kaiser, E. Boehlje, M. (1980): *A Multiperiod Risk Programming Model for Farm Planning*. North Central Journal of Agricultural Economics, vol. 2, no.1.

Kennedy, J.O.S. (1997): *Incorporating Aversion to Inter-Year Variation of Expected Utility in Dynamic Programming Models*. In Huirne, R., Hardaker, J., Dijkhuizen A. (editors): *Risk management strategies in agriculture; State of the art and future perspectives.* Mansholt Studies 7, Wageningen.

Kleijnen, J.P.C. (1998): Validation *of simulation, with and without real data.* Discussion Paper 22. Center for Economic Research, Tilburg University.

Köppen, W. (1936): *Das geographische System der Klimate.* In Köppen, W, Geiger, R. editors: Handbuch der Klimatologie I, Part C. Bornträger, Berlin.

Kruseman, G. (2000): *Bio-economic household modelling for agricultural intensification*. Ph.D. Dissertation. Wageningen. Wageningen University.

Kutcher, G., Scandizzo, P. (1981): *The Agricultural Economy of Northeast Brasil.* John Hopkins University Press Baltimore, Maryland.

Kwansoo, K., Bradford L., Coxhead, B.and I. (2001): *Measuring soil quality dynamics: A role for economists, and implications for economic analysis*. Agricultural Economics, vol. 25, issue 1, 13-26.

Lee, R.D., Barrett, C.B. (editors) (2001): *Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment.* CABI Publishing.

López, R. (1984): *Estimating Labour Supply and Production Decisions of Self-Employed Farm Producers.* European Economic Review. vol. 24, 61-82.

López, R. (1998): *The Tragedy of the Commons in Côte d'Ivoire Agriculture: Empirical Evidence and Implications for Evaluating Trade Policies*. The World Bank Economic Review, vol. 12, no. 1, 105-131.

Maleka, P. (1993): *An application of target MOTAD model to crop production in Zambia: Gwembe Valley as a case study*. Agricultural Economics. vol. 9, issue 1, 15-35

Margulis, S. (2004): *Causes of Deforestation of the Brazilian Amazon*. World Bank Working Paper No. 22.

Markowitz, H.M. (1959): *Portfolio Selection: Efficient Diversification of Invest*ments. New York: John Wiley and Sons, Inc.

McCarl, B.A., Spreen, T.H. (1997): *Applied Mathematical Programming Using Algebraic Systems*. Available at http://agecon.tamu.edu/faculty/mccarl/regbook.htm

Merz, O. (2002): *The relationship between length of fallow and crop yields in shifting cultivation: a rethinking*. Agroforestry Systems, vol. 55, 149-159.

Mendoza, A. (2005): *Analysis of Smallholder Agricultural Production in the Eastern Amazon: Empirical Evidence and Policy Prospects for the Bragantina Region*. Ph.D. Thesis, University of Bonn, Germany.

Michelotti, F. (2002): *Vegetação Secundária como Vegetação de Pousio na Paisagem Agrícola da Amazônia Oriental – Função e Possibilidades de Manipulação*. Final report for research stipend. NAEA, Universidade do Pará.

Michelotti, F. (2004): *Desafios para a sustentabilidade ecológica integrada a trajetórias de estabilização da agricultura familiar na região de Marabá*. In: Anais do II Encontro da ANPPAS. Indaiatuba, SP. CD-Rom.

Mintz, S.W. (1974): *A note on the definition of peasantries*. Journal of Peasant Studies. Vol.1, No.2.

Moran, E. F. (1981): *Developing the Amazon*. Bloomington: Indiana University Press.

Mudhara, M., Hildebrand, P.E. (2004): *Assessment of constraints to the adoption of improved fallows in Zimbabwe using linear programming models*. In Nair, P.K.R (editor): Valuing Agroforestry Systems: Methods and Applications. Kluwer Academic Publishers. Dordrecht.

Nepstad, D.C., de Carvalho, C.R., Davidson, E., Jipp, P.H., Levebvre, P.A., Negreiros, G.H., da, Silva, E.D., Stone, T.A., Trumbore, S.E., Vieira, S. (1994): The *role of deep roots in the hydrological and carbon cycles of Amazonian forests and pastures*. Nature 372, 666-669.

Nepstad, D., A. Moreira, and A. Alencar. 1999. *Flames in the Rainforest: Origins, Impacts and Alternatives to Amazon Fire.* Pilot Program for the Conservation of the Rainforests of Brazil, World Bank. 140 pp.

Odum, E.P. (1991): *Prinzipien der Ökologie*. Spektrum-der-Wissenschaft-Verlagsgesellschaft. Heidelberg.

OED (2000): Brazil. *Forests in the Balance:Challenges of Conservation with Development.* The World Bank. Washington D.C.. Available at: www.worldbank.org/html/oed

Pascual, U., Martínez, R. (2003): *Integrated Policy Options for Land Conservation and Rural Poverty Alleviation: A System Dynamics Approach*. Discussion Paper N. 0323, School of Economic Studies, University of Manchester.

Pearce, David W., Turner, R. Kerry (1995): *Economics of natural resources and the environment*. 10th edition. New York. Harvester Wheatsheaf.

Penteado, A. R. (1967): Problemas *de colonização e uso da terra na região Bragantina do Estado do Pará*, I+II. Ph.D. Thesis. Universidade Federal do Pará, Belém.

Poate, C.D., Daplyn, P.F., Buckwell, Carruthers, I., Hakimian, H., Kydd, J., Prescott, J. (1993): *Data for Agrarian Development (Wye Studies in Agricultural and Rural Development)*. Cambridge University Press.

Pratt, J.W. (1964): *Risk Aversion in the small and in the large*. Econometrica. vol. 32, 122-136.

Prorenda (2002): Os *Sistemas Agroflorestais nos Municípios de Ourém e Abaetetuba; Estudo da Viabilidade Econômica*. Relatório de Consultoria.

Puig, J.C. (2005): *Assessment of different land covers as atmospheric carbon sinks using field and remote sensing data, eastern Amazon, Brazil.* Ph.D. Thesis (forthcoming).

Rehm, S., Espig, G. (1991): *The Cultivated Plants of the Tropics and Subtropics*. Josef Margraf. Berlin.

Reichholf, J. H. (1990): *Der tropische Regenwald. Die Ökobiologie des artenreichsten Naturraums der Erde*. München: dtv.

Robison, L.J., Barry, P.J. (1987): *The Competitive Firm's Response to Risk.* Macmillan, New York.

Robison, L.R., Hanson, S.D. (1997): *Analyzing Firm Response to Risk Using Mean-Variance Models*. In Huirne, R., Hardaker, J., Dijkhuizen A. (editors): Risk management strategies in agriculture; State of the art and future perspectives. Mansholt Studies 7, Wageningen.

Ruben, R., Kuyvenhoven, A., Kruseman, G. (2001): *Bioeconomic Models and Ecoregional Development: Policy Instruments for Sustainable Intensification*. In Lee, R.D., Barrett, C.B. (editors): Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment. CABI Publishing.

Ruthenberg, H. (1980): *Farming Systems in the Tropics*. 3rd edition. Clarendon Press, Oxford, UK.

Ruttan, V.W. (1997): *Sustainable Growth in Agricultural Production: Poetry, policy, and Science*. In Vosti, S.A., Reardon, T. (editors): Sustainability, Growth, and Poverty Alleviation. A Policy and Agroecological Perspective. The John Hopkins University Press. Baltimore London.

Sá, T.D.de A., Vielhauer, K., Kanashiro, M., Denich, M., Vlek, P.G.L. (1998): *Towards improving natural resources use in Eastern Amazonia through a modified sequential agroforestry system*. Presented as a Poster at the II Congresso Brasileiro em Sistemas Agroflorestais, Belém, 11.1998.

Sadoulet, E., de Janvry, A. (1995): *Quantitative Development Policy Analysis.* The John Hopkins University Press, Baltimore, Maryland.

Sahn, D.E., Stifel, D. (2000): *Assets as a measure of Household Welfare in Developing Countries.* Working Paper 00-11. Center for Social Development. Washington.

Santos, R. (1980): *História econômica da Amazônia (1800-1920)*. São Paulo: T.A. Queiroz.

Sawyer, D. (1979): *Peasants and Capitalism on an Amazon Frontier*. PhD Thesis, Cambridge, Massachusetts. Harvard University Press.

Santana, A.C.de, Amin, M. (2002): *Cadeias Produtivas e Oportunidades de Negócio na Amazônia*. Universidade da Amazônia. Belém, PA.

Saxena, A.k., Jagdiah, C., Foot, N. and D. (1997): *Analyzing Deforestation and Exploring Policies for its Amelioration: A Case Study of India*. Journal of Forest Economics 3:3, Supplement

Schlieper, P. (1997): *Ertragsausfallversicherung und Intensität pflanzlicher Produktion.* Ph.D. thesis. Deutscher Universitätsverlag, Wiesbaden.

Schmitz, H. (2002): Die *Partnerschaft zwischen Bauern, Forschern, Beratern und ihren Organisationen: Reflexionen über das landwirtschaftliche Wissenssystem im Bundesstaat Pará / Brasilien*. Ph.D. Thesis. Humboldt Universität zu Berlin.

Schwarzer, H. (2000): *Impactos Socioeconômicos do Sistema de Aposentadorias Rurais no Brasil*. Evidências Empíricas de um Estudo de Caso do Pará. Discussion Paper No. 729. IPEA. Rio de Janeiro.

SEPEF I (without date): *Collection of field trial results. I Semenario Paraense de Emprego de Fertilizantes*. Available at EMBRAPA CPATU Library.

Shiferaw, B., Holden, S.T. (1998): *Resource degradation and adoption of land conservation technologies in the Ethiopian Highlands: A case study in Andit Tid, North Shewa*. Agricultural Economics, vol. 18, issue 3, 233-247.

Shone, R. (2002): *Economic Dynamics. Phase Diagrams and their Economic Application*. 2nd edition. Cambridge University Press. Cambridge.

Siegmund-Schultze, M. (2002): *Gains from Keeping Cattle on Fallow-Based Smallholdings in the Eastern Amazon.* Ph.D. Thesis. Cuvillier Verlag. Göttingen.

Singh, Inderjit (1986): *Agricultural household models: extensions, applications, and policy* .1st edition. Baltimore.Johns Hopkins University Press.

Sioli, H. (1968): *“Zur Ökologie des Amazonasgebietes”.* In Fittkau, E.J. et al. (1968): Biogeography and Ecology in South America. Den Haag.

Sioli, H. (1973): *Recent Human Activities in the Brazilian Amazon Region and Their Ecological Effects.* In B. J. Meggers, E. S. Ayensu & W. D. Duckworth (editors), Tropical Forest Ecosystems in Africa and South America: A Comparative Revue. Washington, D.C.: Smithsonian Inst. Press.

Sioli, H. (1984): *Unifying Principles of Amazonian Landscape Ecology and Their Implications.* In H. Sioli (editors), The Amazon. Limnology and Landscape Ecology of a Mighty Tropical River and Its Basin. Dordrecht, Boston, Lancaster: W. Junk.

Smith, N. (1982): *Rainforest Corridors: The Transamazon Colonization Scheme.* Berkeley: University of California Press.

Sommer, R., Denich, M., Vlek, P.L.G. (2000): *Carbon storage and root penetration in deep soils under small-farmer land-use systems in the eastern Amazon region, Brazil*. Plant and Soil. Vol. 219, 231-241.

Sommer, R. (2000): *Water and nutrient balance in deep soils under shifting cultivation with and without burning in the Eastern Amazon. Ph.D. Thesis*. Cuvillier Verlag Göttingen.

Standiford, R.B. and Howitt, R.E. (1992): *Solving empirical bioeconomic models: a rangeland management application*. American Journal of Agricultural Economics, vol.74, no.2, 421-433.

Sterman, J.D. (1991): *A Sceptic´s Guide to Computer Models*. In Barney, G.O. et al. (eds.) Managing a Nation: The Microcomputer Software Catalog. Westview Press.

Thurston, H.D., 1997. *Slash/Mulch Systems Sustainable methods for tropical agriculture*. Westview Press, Boulder, CO, 196 pp.

Toni, F., Kaimowitz, D. editors (2003): *Municípios e Gestão Florestal na Amazônia.* A.S. Editores, Natal /RN.

Tura, L.R., Costa, F.de A. editors (2000): *Campesinato e Estado na Amazônia. Impactos do FNO no Pará.* Brasília Jurídica, FASE, Brasília.

Turner, K.R. (1992): *Speculations on Weak and Strong Sustainability*. CSERGE Working Paper GEC 92-26. At: www.uea.ac.uk/env/cserge/pub/wp/gec/gec_1992_26.pdf

United Nations (2000): *United Nations Millennium Declaration.* Available at: http://www.un.org/millenniumgoals/

Vieira, L.S., dos Santos, W.H.P., Falesi, I.C. and Pedro S.O. Filho, J. (1967): *Levantamento de reconhecimento dos solos da Região Bragantina, Estado do Pará*. Pesquisa Agropecuária Brasileira, 2: 1-63.

Vieira, I.C. (1996): *Forest Succession after Shifting Cultivation in Eastern Amazonia*. Ph.D. thesis. University of Stirling. Scotland.

Vieira, I.C., de Almeida, A.S., Davidson, E.A., Stone, T.A., de Carvalho, C.J.R., Guerrero, J.B. (2002): *Classifying successional forests using Landsat spectral properties ecological characteristics in eastern Amazônia.* Remote Sensing of Environment 87, 470-481.

Vielhauer, K., Sá, T.D.d.A., Kanashiro, M., Denich, M. (1998): *Caminhos à Maior Sustentabilidade na Agricultura Familiar do Nordeste do Pará: Cultivo sem Fogo e Enriquecimento de Capoeiras*. Agricultura Sustentável. 1, 2, 24-27.

Vieth, G.R., Suppapanya, P. (1996): An *Evaluation of Selected Decision Models: A Case of Crop Choice in Northern Thailand*. Journal of Agricultural & Applied Economics. vol. 28, issue 2, 381-91

Vlek, P.L.G., Sommer, R., Vielhauer, K., A. Serrão (2000): *The carbon and nutrient balance under* slash-and-burn *agriculture and its alternatives in the Amazon*. ASA-CSSA-SSSA Meeting in Minneapolis, MN,Nov. 5-9.

Von Neumann, J., Morgenstern, O. (1947): *Theory of Games and Economic Behavior*. Princeton University Press, Princeton.

Vosti, S.A., Carpentier, C.L., Witcover, J. (2002): *Agricultural intensification by smallholders in the western Brazilian Amazon : from deforestation to sustainable land use*. RR 130. International Food Policy Research Institute.

Vosti, S.A., Reardon, T. editors (1997): *Sustainability, Growth, and Poverty Alleviation. A Policy and Agroecological Perspective*.The John Hopkins University Press. Baltimore London.

Walker, R.(2000): *Deforestation and Cattle Ranching in the Brazilian Amazon: External Capital and Household Processes.* World Development. Vol. 28, Issue 4 , 683-699.

Wander, A.E. (1998): *Die sozioökonomische Bedeutung des Maracujaanbaus für kleinbäuerliche Gemischtbetriebe im östlichen AmaZonasgebiet (Nordost Pará/Brasilien).* Master thesis. University of Göttingen.

Weischet, W. (1980): *Die ökologische Benachteiligung der Tropen*. Stuttgart: B.G. Teubner.

Wickel, B. (2004): *Water and Nutrient Dynamics of a humid tropical agricultural watershed in Eastern Amazonia.* Ph.D. Thesis. Cuvillier, Göttingen.

Wiedenbeck, M., Züll, C. (2001): *Klassifikation mit Clusteranalyse: Grundlegende Techniken hierarchischer und K-means-Verfahren*. ZUMA How-to Reihe, Nr.10. Zentrum für Umfragen, Methoden und Analysen, Mannheim.

Wiesenmüller, J. (1999): *Einfluß landwirtschaftlicher Flächenvorbereitung auf die Dynamik des Wurzelsystems und die oberirdische Regeneration der Sekundärvegetation Ostamazoniens, Pará, Brasilien*. PhD thesis, Institute of Agriculture in the Tropics, University of Goettingen, Germany.

Wolf, E.R. (1966): *Peasants*. Englewood Cliffs. New Jersey: Prentice Hall.