# Alternatives to Slash-and-Burn in Brazil

## *Summary Report and Synthesis of Phase II*

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November 2002
Nairobi, Kenya

**About ASB**

This report is one of a series detailing results from the Alternatives to Slash-and-Burn (ASB) Programme, a global consortium founded in 1994 as a system-wide programme of the Consultative Group on International Agricultural Research (CGIAR). ASB is convened by the Nairobi-based World Agroforestry Centre (ICRAF) and is governed by a global steering group of 12 representatives from participating national and international institutions. At its inception, ASB was financially supported by the Global Environment Facility (GEF), with sponsorship from the United Nations Development Programme (UNDP). Additional funding for ASB global work is provided by the Governments of Australia, through the Australian Center for International Agricultural Research (ACIAR), Brazil, through the Empresa Brasileira de Pesquisa Agropecuária (Embrapa), Denmark, through the Danish International Development Agency (DANIDA), the Netherlands, New Zealand, Norway and the USA, through the United States Agency for International Development (USAID). The Governments of Japan and Switzerland, the Inter-American Development Bank (IDB) and the Center for Natural Resources Policy Analysis at the University of California at Davis provided additional support for ASB work in Brazil.

**Acknowledgements**

The authors and editors are grateful to all donors and partners for their support to ASB's work in Brazil and to the many people whose ideas and work contributed to this report. They would like to thank Green Ink Ltd UK for copy-editing and laying out the report.

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# Contents

# List of tables and figures

## Tables



## Figures

# Visão geral e resumo no formato exigido pelo PNUD

## I. O PROBLEMA DE DESENVOLVIMENTO E PROBLEMAS IMEDIATOS ENFOCADOS

A conversão da floresta primária na Amazônia ameaça a biodiversidade e libera estoques de carbono na atmosfera mas permite contribuições possíveis ao desenvolvimento econômico e à redução de pobreza. Parte significativa do desmatamento em florestas tropicais resultante da agricultura de derruba-e-queima está relacionada com pequenos produtores que vivem nas áreas de floresta. No entanto, as condições necessárias para maior produtividade de sistemas de uso da terra alternativos, que aumentem o bem-estar dos produtores rurais e reduzam o desmatamento, não são bem conhecidos. Este trabalho se esforçou em determinar as conseqüências ambientais dos vários sistemas de uso da terra, se tais conseqüências poderiam ser mitigadas com mudanças tecnológicas, políticas e institucionais apropriadas e, se não, quais as trocas e compensações existentes entre estes objetivos sociais.

O programa de pesquisa da Fase II foi estruturado para melhor entender como o governo do Brasil, instituições de pesquisa nacionais e internacionais e agências de fomento à pesquisa poderiam conciliar objetivos ambientais globais com o desenvolvimento econômico e a redução da pobreza. O ponto fundamental da Fase II do Programa ASB no Brasil se resume à seguinte questão: *A intensificação simultânea do uso de áreas de floresta e das áreas já desmatadas reduz o desmatamento e a pobreza?*

## II. PRODUTOS DA PESQUISA

Duas das três principais metas da Fase II foram *a medida dos efeitos de práticas alternativas de uso da terra na mudança climática (seqüestro de carbono e fluxo de gases-estufa) e na biodiversidade (acima e abaixo do solo).* Os resultados destes estudos para o Brasil se encontram resumidos neste documento. Detalhes completos para todos os locais e as novas metodologias desenvolvidas pelo Programa ASB para obter os dados necessários se encontram em publicações a parte.

Este relatório aborda, ainda, a terceira principal meta da Fase II: *conciliar benefícios ambientais globais com alternativas sustentáveis à agricultura de derruba-e-queima no Brasil*. Pelo fato de o desenvolvimento de tais alternativas ter impacto significativo no Brasil (ou em quaisquer dos seis países atualmente envolvidos no Programa ASB), o alcance da pesquisa teve que ir além da mudança climática e da biodiversidade. Isto envolveu a determinação das trocas e complementaridades entre os impactos—desde aquele de nível local, em nível de bacia hidrográfica, até o impacto nacional, bem como no fenômeno ambiental global—e não poderia ser alcançado plenamente sem a determinação da sustentabilidade e adotabilidade dos sistemas alternativos. Assim, este relatório também aborda as inovações metodológicas e os resultados de dois outros grupos de trabalho de nível global: sustentabilidade agronômica dos sistemas alternativos e aspectos políticos e socioeconômicos que influem na adotabilidade destes sistemas pelos pequenos produtores. O trabalho destes dois últimos grupos permite a identificação das expectativas atuais para a intensificação dos sistemas uso da terra com a preservação da floresta bem como as opções políticas e tecnológicas necessárias para superar os obstáculos a esta intensificação sustentável.

Para atingir esta extensa agenda de pesquisa recursos adicionais para o trabalho no Brasil foram proporcionados pelo Banco Interamericano de Desenvolvimento, Danida, Governo da Suíça, Governo do Japão e Embrapa.

## III. OBJETIVOS ALCANÇADOS

### *1. Mudança climática*

- Os estoques de carbono foram medidos para amostras localizadas nas áreas de pesquisa selecionadas nos estados do Acre e de Rondônia. Estas medidas foram efetuadas para sistemas diversos desde floresta primária e sistemas agroflorestais até culturas anuais e pastagens. Houve avanços na definição de metodologia para estimativa de estoque de carbono acima e abaixo do solo.
- Estes dados foram usados para estimar estoques de carbono médios ponderados no tempo para os principais sistemas. Com esta informação foi possível gerar estimativas do seqüestro líquido de carbono associado com mudanças no uso da terra.
- Medidas preliminares sobre a emissão de gases-estufa (metano e óxido nitroso) foram feitas para os mesmos sistemas em que se determinou o estoque de carbono. Foi descoberta pronunciada sazonalidade na emissão de gases-estufa: assim, medidas adicionais serão necessárias para estimar, de modo confiável, os fluxos anuais.

### *2. Biodiversidade*

- Uma equipe de pesquisadores brasileiros foi formada para estudos de biodiversidade abaixo do solo e a metodologia foi compatível e coordenada com estudos em outros países participantes do Programa ASB.
- Indicadores para rápida determinação da biodiversidade vegetal acima do solo, desenvolvidos e validados em estudo intensivo realizado na ilha de Sumatra, Indonésia, foram testados para todos os sistemas.
- Indicadores de biodiversidade abaixo e acima do solo foram determinados para os mesmos sistemas nos quais houve determinação do estoque de carbono.

### *3. Compatibilização dos benefícios ambientais dos sistemas alternativos e sustentáveis de uso da terra*

- Indicadores de sustentabilidade agronômica (estrutura do solo, balanço de nutrientes, proteção das culturas e microrganismos do solo) foram desenvolvidos para determinar as restrições agronômicas de longo prazo para cada sistema avaliado nas áreas de estudo do Brasil.
- A preocupação dos pequenos produtores relativa aos sistemas atuais ou novos foi avaliada em termos do interesse dos mesmos, na lucratividade, uso de mão-de-obra familiar e segurança alimentar.
- Os indicadores de lucratividade, de necessidade de mão-de-obra e restrições de fluxo de caixa foram estimados para os principais sistemas estudados.
- Foi desenvolvida, com pesquisadores envolvidos no Programa ASB em outros países, uma técnica matricial para examinar simultaneamente indicadores ambientais, agronômicos, políticos, socioeconômicos e institucionais. Esta matriz completa é a ferramenta básica para a determinação integrada de opções que conciliem os benefícios ambientais com o desenvolvimento rural sustentável.

### *4. Avaliação das opções políticas e tecnológicas para a remoção de obstáculos ao desenvolvimento sustentável*

- Um modelo bioeconômico ao nível da propriedade rural e um modelo macroeconômico de equilíbrio geral foram usados para simular efeitos de mudanças de políticas específicas e de

tecnologias no comportamento do produtor rural e dos setores econômicos mais amplos na região.
- Barreiras políticas e institucionais à adoção dos sistemas alternativos foram analisadas e opções viáveis para a remoção destes obstáculos foram desevolvidas.

## IV. RESULTADOS PRINCIPAIS E LIÇÕES APRENDIDAS

### Conclusões significativas

*Seqüestro de carbono*
- Os sistemas agroflorestais, simples ou complexos, estocam mais carbono que qualquer outro sistema estudado, exceto a floresta primária.
- Os estoques de carbono no solo não se modificam significativamente se comparados aos estoques de carbono acima do solo nas florestas tropicais úmidas. Assim, o potencial para benefícios em seqüestro de carbono está na produção de biomassa acima do solo.
- O maior estoque médio de carbono ponderado pelo tempo foi encontrado nos sistemas agroflorestais multiestratificados, mas seu valor equivale a apenas 26% da quantia encontrada na floresta primária.
- A melhoria de pastagens através de manejo ou da associação com leguminosas não aumenta significativamente o estoque médio de carbono ponderado pelo tempo em relação ao nível verificado nas pastagens tradicionais.

*Biodiversidade*
- Sistemas agroflorestais multiestratificados têm a maior biodiversidade, após a floresta, seguidos por capoeira melhorada associada com espécies arbóreas.
- Cinco indicadores-chave para biodiversidade (altura média da copa, área basal, total de espécies vegetais vasculares, total de tipos vegetais funcionais (PFTs) e a razão entre a riqueza de espécies vegetais e PFT) juntos proporcionam um bom indicador preditivo do impacto da mudança do uso da terra na biodiversidade.
- Todos os grupos funcionais estudados pelo grupo de trabalho da biodiversidade abaixo do solo mostraram algum impacto associado com mudanças do uso da terra, indicando que o desmatamento realmente altera a estrutura e o desempenho do ecossistema abaixo do solo. Os efeitos destas mudanças na agricultura não são conhecidos.

*Sustentabilidade agronômica*
- Após a floresta, os sistemas de capoeira tiveram a maior sustentabilidade agronômica em termos de estrutura e proteção do solo, balanço de nutrientes e microrganismos do solo (embora alguns problemas de balanço de nutrientes estiveram presentes).

*Socioeconomia e política*
- Todos os sistemas estudados proporcionaram maiores retornos à mão-de-obra familiar que a floresta (tradicionalmente manejada com a coleta de castanha-do-pará e mínima extração madeireira); este é o principal fator que explica a decisão de os produtores rurais converterem floresta em áreas agropecuárias na região.
- O desmatamento e as decisões sobre uso da terra por pequenos produtores nas áreas de florestas tropicais são determinados principalmente em função da falta de mão-de-obra e da lucratividade relativa dessas alternativas. Estes dois últimos fatores favorecem a pecuária em detrimento de outras atividades, promovendo constante conversão da floresta em pastagem.
- A análise dos dados coletados em campo sugerem que, se não houver maiores mudanças de preços, políticas e/ou tecnologias na região, a área das pastagens continuará a se expandir, a área sob floresta continuará a declinar e a prática de agricultura itinerante desaparecerá.

- Cada sistema intensificado proposto oferece alguns benefícios em relação aos sistemas tradicionais vigentes tanto para o produtor rural quanto para o meio-ambiente, mas todos têm suas desvantagens e obstáculos à adoção.
- A rentabilidade dos sistemas de uso da terra (medida através de retorno da mão-de-obra familiar) é usualmente conflitante com os fatores ambientais como diversidade de espécies vegetais e estoque de carbono.
- Sistemas baseados em árvores proporcionam retornos mais elevados à mão-de-obra familiar que os sistemas tradicionais, mas possuem outros obstáculos à adoção como maior demanda por mão-de-obra, custos iniciais elevados e falhas institucionais.
- O manejo florestal em pequena escala pode ampliar os retornos proporcionados pela atividade de modo que seja compatível com as restrições de mão-de-obra existentes na propriedade rural. Entretanto são grandes os obstáculos de ordem técnica, social e institucional à adoção deste sistema alternativo experimental.
- Tempo extenso para gerar fluxo de caixa positivo, custos iniciais e gastos no período de manutenção elevados colocam muitos sistemas agroflorestais fora do alcance de muitos pequenos produtores.
- Melhorias de transporte e mudança nas leis trabalhistas poderiam reduzir o custo de trabalho, especialmente o custo de transação relacionado à contratação de mão-de-obra pelas propriedades rurais. No entanto, a redução dos custos de mão-de-obra pode aumentar o desmatamento.
- Praticamente todos sistemas intensificados dependem de mercados imperfeitos, incluindo os mercados para capital, insumos e produtos mais importantes.

**Lições aprendidas**

- As florestas continuarão a ser derrubadas enquanto a rentabilidade (especialmente quando medida em termos de retorno à mão-de-obra familiar) das atividades agropecuárias forem maior que a rentabilidade das atividades de extração realizadas na floresta, e se a legislação atual não se modificar.
- A intensificação sustentável da agricultura sem a continuidade do desmatamento pode ser possível na Amazônia, mas requer incentivos econômicos e políticos apropriados bem como base tecnológica e infraestrutura de mercado para sustentar esta opção de desenvolvimento.
- Esforços em desenvolver sistemas alternativos e opções políticas buscando uma preocupação ambiental global serão infrutíferos sem a consideração simultânea dos objetivos dos produtores rurais e dos formuladores de políticas nos vários níveis, e a fragilidade dos mercados de outras instituições que influenciam a adotabilidade dos sistemas alternativos pelos pequenos produtores.
- A colaboração atual, contato e presença de brasileiros e estrangeiros na equipe de pesquisa, são essenciais para abordar em profundidade a questão do desmatamento. A construção de equipes multidisciplinares para estudar as complexidades da mudança do uso da terra é factível, mas recursos suficientes (tempo e dinheiro entre outros) são necessários para que as equipes sejam efetivas.
- Métodos podem ser desenvolvidos para medir os efeitos ambientais da mudança do uso da terra, mas dados suficientes que sejam coletados e analisados sistematicamente são necessários para a validação destes métodos.

## V. RECOMENDAÇÕES

- Um conjunto mais amplo de alternativas para os pequenos produtores baseadas em árvores (tanto sistemas agroflorestais como silvopastoris) deve ser examinado levando em conta suas características ambientais, agronômicas, econômicas e a viabilidade de adoção.

- A determinação local da sustentabilidade deve ser expandida para incluir externalidades ambientais em nível mais amplo como, por exemplo, bacia hidrográfica ou região.
- Novos instrumentos de política devem ser desenvolvidos para induzir pequenos produtores a modificar seus parâmetros de desmatamento e uso da terra. Embora estas mudanças políticas possam aumentar a chance de intensificação sustentável, grandes investimentos são necessários para se alcançar este fim.
- É imprescindível pesquisa que enfatize uma visão econômica mais ampla dos problemas de desmatamento e bem-estar na Amazônia ocidental brasileira, já que as atividades econômicas em outros setores e regiões do país se ligam progressivamente à Amazônia, integrando a região no contexto nacional.
- Os métodos de pesquisa desenvolvidos e utilizados neste estudo devem ser relevantes para um conjunto mais amplo de casos onde questões de pobreza, meio-ambiente e crescimento são simultaneamente abordados. Uma combinação de ferramentas analíticas como as utilizadas neste estudo (descrição do problema, determinação de como fatores heterogêneos afetam o problema e a consideração explícita dos elementos dinâmicos do problema) é necessária para alcançar conclusões que sejam de fato subsídios para a formulação de políticas.
- Canais adicionais devem ser abertos para integrar os resultados do Programa ASB com a agenda política aumentando, assim, o impacto deste Programa na política nacional e internacional sobre o uso da terra na Amazônia.

# Overview and Summary in UNDP-mandated Format

## I. DEVELOPMENT PROBLEM AND IMMEDIATE PROBLEMS ADDRESSED

The conversion of primary forest to other land uses in the Amazon threatens biodiversity and releases carbon into the atmosphere but makes economic development and poverty reduction possible. Small-scale farmers practising slash-and-burn cultivation account for a significant proportion of tropical deforestation. However, the conditions necessary for increased productivity of alternative land use systems (LUS) to improve farmer welfare and simultaneously reduce deforestation are not well understood. This research attempted to determine the environmental consequences of different LUS, whether these consequences could be mitigated with appropriate technological, policy and institutional changes and what sorts of tradeoffs existed among the different social objectives facing policy makers.

The research programme implemented during Phase II of ASB's project in Brazil was designed to better understand how the Government of Brazil, national and international research organizations and donor agencies can balance global environmental objectives with economic development and poverty reduction. The key question can be summarized as: *can intensifying land use within forest and on cleared land simultaneously reduce deforestation and reduce poverty?*

## II. OUTPUTS PRODUCED

Two of the three main goals of Phase II were *measurement of the effects of alternative land use practices on climate change (carbon sequestration and greenhouse gas fluxes) and on biodiversity (above and below ground)*. Results of studies on these topics in Brazil are summarized here. Full details for all sites, and the new tools developed by ASB to obtain the necessary data, are reported in separate documents.

This report draws on these and other data to address the third main goal of Phase II: *linking global environmental benefits to sustainable alternatives to slash-and-burn cultivation in Brazil.* For the development of such alternatives to have a significant impact in Brazil (or in any of the six countries currently participating in ASB), the scope of the research must expand beyond climate change and biodiversity. This 'linking' goal, which involves assessments of the tradeoffs (and complementarities) among impacts—spanning the plot, household, landscape, watershed and national levels as well as global environmental phenomena—could not be achieved meaningfully without an assessment of the sustainability and adoptability of the alternative land uses. Thus, this report also draws on the methodological innovations and empirical results of two other global working groups: one on the agronomic sustainability of land use alternatives and the other on the socio-economic and policy issues that affect the adoptability of these alternatives by smallholders. The work of these two latter groups allows assessment of the prospects for intensifying LUS while protecting forests, as well as the policy and technology innovations necessary to overcome the obstacles to intensification.

To address this expanded research agenda, additional funding was sought and received from the Inter-American Development Bank, the Danish International Development Agency (DANIDA), the Government of Switzerland, the Government of Japan and Embrapa.

## III. OBJECTIVES ACHIEVED

*1. Climate Change*

- Carbon stocks were measured for sample plots in the benchmark sites of Acre and Rondônia in the western Brazilian Amazon for LUS ranging from natural forests, through agroforestry

to annual cropping and pastures. Progress was made in resolving weaknesses in the methods for estimating above- and below-ground carbon stocks.
- These data were used to estimate ‘time-averaged carbon stocks’ for major LUS. Land use change was thus translated into a net release or net sequestration of carbon.
- Attempts were made to measure greenhouse gas emissions (methane and nitrous oxide) for the same LUS as those studied for their carbon stocks. Pronounced seasonality was discovered in greenhouse gas emissions, so additional measurements will be necessary to derive reliable estimates of annual fluxes.

*2. Biodiversity*
- A team of national researchers was formed for below-ground biodiversity studies and the methodology was coordinated with studies in other ASB countries.
- Indicators for rapid assessment of above-ground plant biodiversity, originally developed and validated in an intensive study in Jambi Province of Central Sumatra, were tested for all LUS.
- Indicators of above- and below-ground biodiversity were measured in comparable LUS to those in which the carbon stocks were measured.

*3. Linking environmental benefits to sustainable land use alternatives*
- Indicators of agronomic sustainability (soil structure, nutrient balance, crop protection and soil biota) were developed to assess the long-term agronomic constraints for each of the LUS studied at the Brazilian benchmark sites.
- Smallholders’ economic concerns regarding new or current LUS were evaluated in terms of profitability, labour requirements and food security.
- Indicators of profitability, labour requirements and cash flow constraints were estimated for the most important LUS.
- A matrix for linking environmental, agronomic, policy, socio-economic and institutional indicators was developed in collaboration with scientists from other ASB sites. This is the basic tool for the integrated assessment of options for balancing global environmental benefits with poverty reduction through sustainable agricultural development.

*4. Evaluating policy and technology options for overcoming obstacles to sustainable development*
- A farm-level bio-economic model and an economy-wide model were used to simulate the probable effects of policy and technology changes on farmer behaviour and the performance of broader economic sectors in the region.
- Policy and institutional barriers to the adoption of alternative land uses were analysed and workable options for addressing these obstacles were developed.

## IV. KEY FINDINGS AND LESSONS LEARNED

### Significant conclusions

*Carbon sequestration*
- Long-rotation tree-based systems store more carbon than any other land use studied, except for natural forests.
- Topsoil carbon stocks (0-20 cm) do not change significantly relative to above-ground carbon stocks when humid tropical forest is replaced. Hence, the potential for carbon sequestration benefits from alternative land uses lies in those uses that produce the most above-ground biomass.

- The highest time-averaged carbon stocks are provided by multi-strata agroforests, which average about 40% of those of the forest.
- Improving pastures either through better herd management or through planting legumes does not significantly increase time-averaged carbon stocks above those of traditional pastures.

*Biodiversity*

- Multistrata agroforests have the highest biodiversity after forests, followed by improved fallows with tree species.
- Five key biodiversity indicators (mean canopy height, basal area, total vascular plant species, total plant functional types (PFTs) and a ratio of plant species richness to PFT richness) together provide a good predictive indicator of the impact of land use change on biodiversity.
- All functional groups studied by the below-ground biodiversity working group showed some impact of land use change, indicating that deforestation does alter below-ground ecosystem structure and performance; the effects on agriculture of these changes are not known.

*Agronomic sustainability*

- After forests, fallow systems were found to have the highest overall agronomic sustainability in terms of soil structure, nutrient balance, crop protection and soil biota (though some nutrient balance problems were present).

*Socio-economic and policy issues*

- All of the LUS studied yield higher returns to labour than do forests (traditionally used for the extraction of Brazil nuts and for minimal logging); this is the primary factor behind farmers' decisions to convert forest to other uses.
- Deforestation and land use decisions by small-scale farmers at the forest margins are driven primarily by labour scarcity and the relative profitability of land use alternatives, both of which favour livestock production at the expense of other activities. This promotes the steady conversion of forest to pasture.
- Analyses of field data suggest that, in the absence of major changes in prices, policies and technology in the region, the area in pasture will continue to increase, that in forest will continue to decline, and the swidden long-cycle fallow system will not be practised.
- Each of the intensified LUS proposed offers some benefits over the traditional system, either to the farmer or to the environment, but none comes without some tradeoffs or obstacles to adoption.
- The profitability of LUS (measured by returns to labour) is usually in conflict with environmental services such as biodiversity and carbon storage.
- Tree-based systems earn higher returns to labour than traditional land uses, but have other obstacles to adoption, such as high labour requirements, high start-up costs and institutional failures.
- Small-scale managed forestry can boost the returns to forest-based activity in ways that are compatible with household labour constraints; however, technical, social, regulatory and institutional obstacles to adoption loom large.
- High start-up costs, multi-year delays in achieving positive cash flow and substantial maintenance requirements may place many agroforestry systems out of reach for the majority of smallholders.
- Improved transport networks and modifications to labour laws could reduce labour costs, especially the transaction costs associated with hiring labour onto farms. However, reduced labour costs may increase deforestation.
- Practically all intensified systems include reliance on other markets themselves plagued by imperfections, including the capital market and markets for critical inputs and outputs.

**Lessons learned**

- Forests will continue to fall for as long as the profitability of agricultural pursuits on cleared land is greater than that of traditional forest extraction, assuming the regulatory environment remains unchanged.
- Sustainable intensification of agriculture without continued deforestation may be possible in the Amazon, but it requires real economic and policy incentives as well as the necessary technological base and marketing infrastructure to support such a development path.
- Efforts to develop land use alternatives and policy options that will meet global environmental concerns are futile without simultaneous consideration of the objectives of farmers and policy makers and of weaknesses in markets and other institutions that influence the adoptability of land use alternatives by smallholders.
- Intensive work on the ground by national and international members of the research team is essential for understanding and tackling deforestation. It is possible to build effective multidisciplinary teams for the study of complex land use issues, but sufficient resources (time, funds, etc) are required for the teams to remain effective.
- Methods can be developed for measuring the environmental effects of land use change, but the systematic collection and analysis of considerable amounts of data are needed in order to validate these methods.

## V. RECOMMENDATIONS FOR FOLLOW-UP

- A wider range of tree-based 'best bet' alternatives for smallholders (both agroforestry and silvopastoral) should be examined for their environmental, agronomic and economic characteristics and for the feasibility of their adoption.
- Assessments of sustainability at plot level should be broadened to include environmental externalities at the landscape and watershed levels.
- New policy instruments should be developed that will induce small-scale farmers to modify their deforestation and land use patterns. Although such policy changes can increase the chances of sustainable agricultural intensification, considerable capital investments will be required.
- New research must place increased emphasis on an economy-wide view of the problems of deforestation and poverty reduction in the western Brazilian Amazon, since economic activities in other sectors and regions of the Brazilian economy are increasingly linked to those in the Amazon.
- The research methods developed and deployed in this study should be relevant for a broader set of cases in which the issues of poverty, environment and economic growth are addressed simultaneously. A set of analytical tools similar to those used in this study is needed to developed balanced, reliable policy advice.
- Additional channels must be sought for integrating ASB findings with the policy agenda at national and international levels, so as to increase the impact of ASB on land use in the Amazon.

# 1. Introduction

The search for sustainable land use strategies in tropical forest margins has preoccupied environmentalists and rural developers for decades (Serrão et al, 1996; de Almeida and Uhl, 1995). In Brazil, strategies involving slash-and-burn and the conventional use of cleared land are not sustainable and are associated with negative environmental consequences, both globally and locally. The Alternatives to Slash-and-Burn (ASB) Programme, a system-wide programme of the Consultative Group on International Agricultural Research (CGIAR), seeks to identify and promote combinations of policy, institutional and technological options that can simultaneously improve local livelihoods and reduce environmental degradation in the forest margins of the humid tropics.[1] ASB research is carried out by a consortium of international and national research partners whose collaborative aim is the development of improved land use systems (LUS) and policy recommendations.

ASB began its work in three areas: the western Amazon of Brazil, the island of Sumatra in Indonesia and the Congo Basin forest of central/southern Cameroon. The consortium later expanded into the Peruvian Amazon, the northern mountains of Thailand and the island of Mindanao in the Philippines (Figure 1). Phase I (1994 to 1996) consisted of site selection and characterization of the problems contributing to unsustainable slash-and-burn agriculture (Palm et al, 1994; Avila, 1994; Swift and Bandy, 1995; Kenyatta, 1997). During Phase II (1996 to 1999), data were collected and analysed for various environmental, agronomic and socio-economic indicators associated with land use change in the tropical forest margins. This work included analysis of the tradeoffs and complementarities among the various indicators, and identification of the obstacles to positive changes in land use that can be addressed through policy action.

## 1.1 The Amazon Basin [2]

The Amazon rainforest is one of the world's last remaining forests vast and intact enough to provide globally important environmental services (Bryant et al, 1997). The largest tracts of the world's tropical moist rainforests are located in the Amazon Basin, which occupies about 7.86 million km$^2$ in nine countries, covering approximately 45% of the South American continent and extending over 50% of Brazil's national territory (IBGE, 1997; Valente, 1968). More than 60% of the Amazon forest is located in northern Brazil (IBGE, 1997), an area larger than the whole of western Europe (INPE, 2000).

Starting in the early 1960s, the Federal Government of Brazil strove to use the Amazon's abundant natural resources (forests, agricultural land and minerals) to fuel regional and national economic growth. However, it soon became apparent that low population density (about 0.9 inhabitants/km$^2$ in 1970) was a significant obstacle to this end, as the labour needed to tap and transport resources was scarce. In addition, the general absence of Brazilian citizens in the region was perceived as a threat to national security, particularly given the production and transportation of illicit drugs to neighbouring countries (Government of Brazil, 1969, 1981; Forum sobre a Amazônia, 1968; Homma, 1998; IBGE, 1997; Santana et al, 1997; Smith et al, 1995; SUDAM, 1976).

Initial attempts to develop the region ran into difficulties. First, huge distances separated the Amazon from the rest of Brazil, making the region's needed inputs more expensive and its

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1 A general framework is set out in Vosti and Reardon (1997).

2 Much of this is based on Valentim and Vosti (forthcoming).

**Figure 1. ASB sites and extrapolation domains in the western Amazon, West/Central Africa and Southeast Asia**

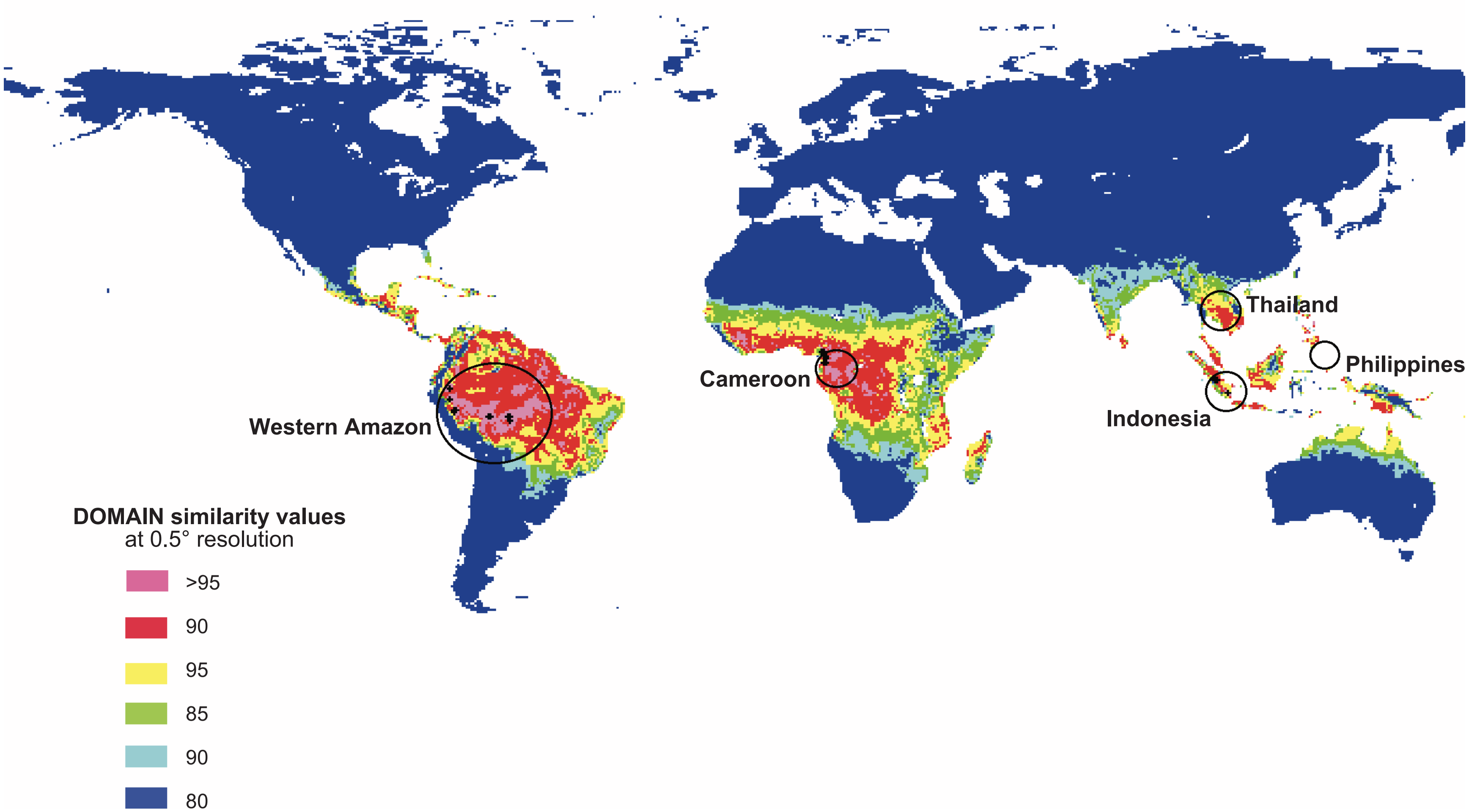


Figure created with DOMAIN software. DOMAIN similarity values based on: elevation; potential evapotranspiration; total annual precipitation; precipitation during driest month; precipitation range; minimum average monthly temperature; maximum average monthly temperature.
A full colour version of this map is available from the ASB website: http://www.asb.cgiar.org

Sources: Carpenter et al (1993); Gillison (2000) outputs less valuable. Second, the early settlers of the Amazon faced a huge mosaic of different ecosystems rather than a homogenous, forested area. This discovery had both positive and negative consequences: biophysical scientists were introduced to the world's greatest 'known' cache of biodiversity, but development planners were faced with the unforeseen need for expensive niche-specific projects and support programmes. Third, the biodiversity of the Amazon forest and the carbon stored in it were increasingly viewed as belonging to groups both larger and smaller than the Brazilian Federal Government, which held legal claim to much of this vast area. Indigenous communities became increasingly vocal in their claims to land and resources, while the international community, concerned about greenhouse gas emissions and biodiversity conservation, also began to voice its opinions on what portions of the Amazon should be used, and how (Myers, 1984).

Brazilian policy makers launched the region's development process in the early 1960s. 'Operation Amazon', established in 1966, set out a broad geopolitical and economic plan for the region (Government of Brazil, 1969; Santana et al, 1997). In support of this programme, new policy objectives and instruments were created to supply the legal and financial means, the labour force, the transportation networks and the electric power needed to establish migrant communities, agriculture and industry in the Amazon. New regional development agencies, such as the Amazon Development Agency, the Amazonian Duty-Free Authority and the Amazonian Regional Bank, were established to organize and support development activities via the provision of subsidized credit to agriculture, extensive beef cattle ranching and mining projects (Government of Brazil, 1969; 1981; Forum Sobre a Amazônia, 1968; IBGE, 1997; Faminow, 1998; Santana et al, 1997; Smith et al, 1995; SUDAM, 1976). Since the establishment of federally subsidized credit in the late 1960s, thousands of agricultural and industrial projects have been approved and implemented in the Amazon. In the western Brazilian states of Acre and Rondônia, home to ASB's benchmark sites, 33 projects were approved over the period 1965-1996 for agricultural and industrial activities, roughly 12% of the total of 392 projects implemented throughout the Amazon during that time (Santana et al, 1997).

To support these projects, large hydro-electric dams, such as the Tucurui Dam in Pará, were built. In addition, several new roads were planned and partially constructed to provide access to the region. The trans-Amazon highway, for example, was to comprise about 5000 km of all-weather road, but has yet to be finished. Nevertheless, some major roads were completed, such as the BR-364[3] linking Acre and Rondônia to southern and southeastern Brazil (Santana et al, 1997; SUDAM, 1976).

In the early 1970s, world economic and oil crises—combined with changes in agricultural technology and consequent changes in farm structure—generated large increases in unemployment, landlessness and consequent social conflicts in southern and southeastern Brazil. The federal government began moving unemployed and/or landless people to the Amazon region and establishing them in settlement projects in order to reduce social pressures in the south and increase the labour available for development in the north (Government of Brazil, 1981; Bunker, 1985; SUDAM, 1976).

The process of assisted migration and colonization was rapid and intense. Millions of hectares of forested land were handed over to incomers with little knowledge of the potential of these areas to support agriculture. The new small-scale farms, ranging in size from 60 to 100 ha, came to be known as 'dumb rectangles', since few soil, water or watershed conditions were

[3] The all-weather BR-364 allows goods, services and people to reach these remote states in the western Brazilian Amazon from major markets in the south, around São Paulo. Initially it linked the south to Porto Velho, Rondônia's state capital and a major port on the Rio Madeira, in 1968. This created access for streams of migrants throughout the 1970s for intensive colonization that accelerated in the early 1980s, after the road was paved. The section linking Porto Velho to Rio Branco, the capital of Acre, was finished in 1992.

taken into consideration during their demarcation (Wolstein et al, 1998; Walker and Homma, 1996; Valentim, 1989). Policy makers hoped that research undertaken alongside development, and at times supported by the financiers of development activities, would provide the necessary guidance to ensure wise stewardship of the Amazon. Instead, the inadequacies of the existing knowledge base became increasingly apparent and research throughout the 1970s and 1980s proved unequal to the task of closing the gap.

Roughly 7600 $km^2$ of tropical rainforest in Brazil were cut down and burned between 1995 and 1997. These forests were of commercial value and the land they stood on *is* of agricultural value, both to the small-scale farmers who cleared it to meet their livelihood and food security needs and to the regional economy, which benefits from increased aggregate production for consumption and trade. However, these forests also provided important environmental services with global benefits, most notably in the form of the carbon and other greenhouse gases they sequestered and the biodiversity they contained, which have non-economic values placed on them by society. Between the private individual and the global social benefits fall the local benefits provided to individuals and communities living in or near forests: clear air, clean water and beautiful, tree-covered landscapes. In the absence of mechanisms for reflecting social values in private decision-making, the uses of forest land implied by private and social values are likely to be at odds with one another. For as long as this is so, the tradeoffs among the differing objectives of different actual or potential user groups—such as environmental protection, agricultural sustainability, economic growth and poverty alleviation—will need to be better understood, and perhaps also changed, by those who would try to balance these objectives.

## 1.2 Characterization of ASB benchmark sites

Within the Brazilian Amazon, ASB chose to focus its research on two colonization projects in the western states of Acre and Rondônia (Figure 2). The projects were considered representative of a region where deforestation was ongoing and at risk of accelerating, with the primary driving force being agriculture (including livestock production). The region was deemed to have soils, vegetative cover and climatic conditions representative of larger areas of the Amazon (Avila, 1994).

The western states of Acre and Rondônia provided an opportunity to examine agriculture's role in frontier development as this process unfolds. Compared to the eastern Amazon, this is a less established frontier, more recently connected to the rest of Brazil. The two states also formed a contrast with one another in terms of their settlement history, including the extent of existing forest use before colonization, the magnitude of migration, the policies adopted towards agriculture and the degree and timing of links to the broader Brazilian economy. A further factor governing the choice was that this part of the western Amazon seemed to be on the brink of large-scale economic changes, as the port and road facilities recently finished or nearing completion linked it to the rest of the country and to external markets.

Sites within the two states were chosen to examine the contribution to trends in land use of one type of land user in one type of area—small-scale farmers in government-sponsored colonization projects—but in different policy and market settings.[4] Between 1970 and 1999,

[4] The research focuses on smallholders because past and current migration policies, which have poverty alleviation as one of their objectives, have made this group a presence in the Brazilian Amazon and an important force in both deforestation and economic growth, and because this focus allows the analysis of direct links between poverty and the environment. Farmers with holdings under 100 ha number some 750 000 in the region as a whole and, according to the most recent agricultural census, contribute some

**Figure 2. Brazil, the Brazilian Amazon and Acre and Rondônia states**


settlement projects in Rondônia numbered 96, spanning close to 5 million ha, with close to 50 000 families settled. Acre, in contrast, had 53 settlement projects by 1999, covering nearly 1.3 million ha or 9% of the state, with over 16 000 families settled (Government of the State of Acre, 2000). Over time, the natural forest area of projects in both states has tended to shrink, and with it the initial lot size distributed to farmers (Ferreira, 1996; S. Oliveira, personal communication).

The Theobroma colonization project, in Rondônia, was chosen principally because its poor soils are representative of large areas of the Amazon; it is characterized by ongoing deforestation (which has increased to over 50% of the land area); and it contains a broad range of LUS, from secondary forests to perennials, pastures and annual crops, which it was considered important to measure biophysically (Witcover and Vosti, 1996; Avila, 1994). Theobroma is located some 350 km south of Porto Velho along the BR-364 and spans approximately 300 000 ha, much of which was spontaneously settled well before the project's official opening in 1979, when approximately 3000 additional families were settled on 100-ha parcels (Fujisaka et al, 1996; Browder, 1994).

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36% to the agricultural GDP of northern Brazil (IBGE, 1997). In 1997 there were about 48 000 small-scale farming households in Acre and Rondônia. Some 56% of registered farmland in Rondônia belonged to farmers with operational holdings of less than 100 ha, while the proportion in Acre was about 30%.

In Acre, Pedro Peixoto offered a contrast as a younger colonization project with less advanced deforestation and different land use activities (more extraction from forests and fewer perennials). Pedro Peixoto lies some 500 km west of Porto Velho along the BR-364, with its centre about 60 km east of the Acre state capital, Rio Branco. Opened in 1972, it covers approximately 317 600 ha and is officially home to 4225 families (Government of the State of Acre, 2000).

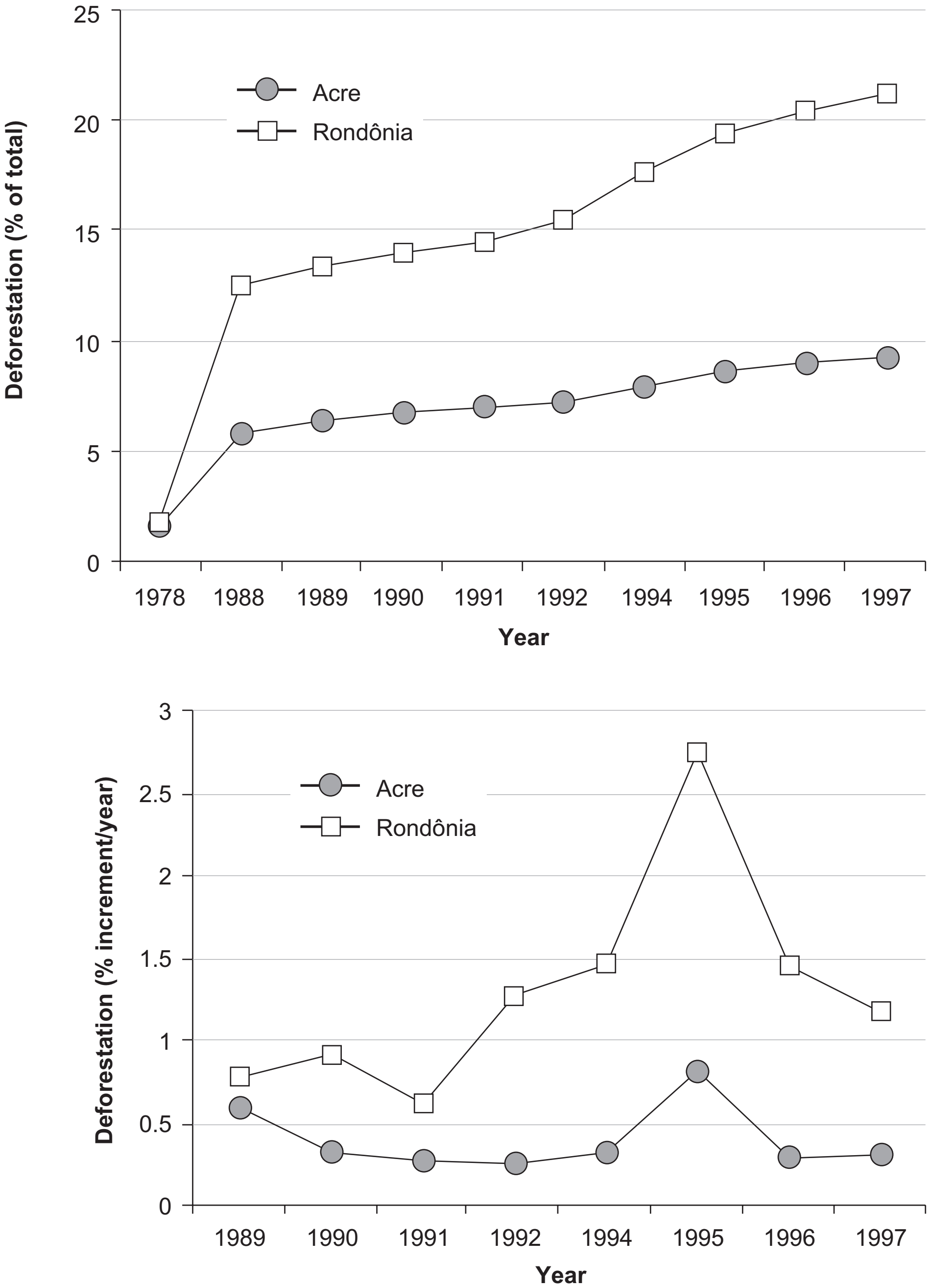
The main differences between the two projects can be summarized as follows: the level of deforestation, which is much more pronounced in Theobroma than in Pedro Peixoto (Figure 3); land use, with perennial tree crops more evident in Theobroma; soil degradation, which is more advanced in Theobroma; time since initial settlement, which is shorter for Pedro Peixoto; population pressure, which is higher in Theobroma; and variations in market access and the policy environment (Avila, 1994). Market access is easier in Theobroma, which is close to the main BR-364 road linking the major river port of Porto Velho with the rest of Brazil and the outside world. Pedro Peixoto, in contrast, straddles the final stretch of the BR-364, and while this road provides easy access to Rio Branco, this city is the 'end of the road'. As regards the policy environment, Rondônia has tended to adopt a 'wild west' approach to development, with policies in place to promote the rapid conversion of forest to agriculture, whereas in Acre agricultural development has been slower and more cautious, with policies exerting a restraining influence. By and large, Rondônia began the colonization process before Acre and so was less subject to the international and other pressures to conserve forest, at least during the early phases of the process. Acre, having started later, came under more and closer scrutiny.

Although Rondônia generally has higher fertility soils and flatter topography than Acre, the Theobroma project was selected for its relatively poor soils so as to enhance the capacity to control for this potentially important factor across different policy settings. Since both projects contained areas with settlements of different ages, researchers were also able to capture the impact of 'time since opening' (Witcover and Vosti, 1996; see also Figure 16, Section 6).

The humid tropical area of the southwestern Amazon rainforest, where the benchmark sites are located, has temperatures averaging 22-26°C, while mean rainfall is about 2000 mm annually, with a heavy rainy season from October until February, more sporadic rains until May, and a marked dry season from about June until September (Fujisaka et al, 1996). The soil quality varies widely and is patchy, but the predominant soil types—Oxisols in Acre, and Oxisols, Alfisols and Ultisols in Rondônia (Fujisaka et al, 1996)—are of relatively low natural fertility, with high levels of acidity, low phosphorus contents, low levels of cation exchange and high levels of aluminum toxicity (Sanchez, 1976; Palm et al, 1994). The distinct dry season permits agriculture following a slash-and-burn process, which stands in contrast to the slash-and-mulch system found in more humid Amazonian areas (Pichón, 1997). A typical agricultural year starts in May, with the beginning of the dry season, and finishes in April, at the end of the rainy season. Forest felling occurs during the dry season, from May to August. The cleared vegetation is allowed to dry, then burned in August or September, before the onset of the rains, when the area is planted to annuals, perennials or pasture grasses.

Although both Rondônia and Acre states are subject to contrasting pressures for agricultural expansion due to differences in their policy and market environments, they have both seen a similar pattern of change in land use, with the area of private forest falling and that of pasture rising over the two-and-a-half decades since colonization began in earnest. Just as the absolute area in forests on farms in Rondônia grew fivefold from 1970 to 1995, as more farms were allocated and settled, so the proportion of each farm in natural forest dropped, from about 66% to nearly 57% over the same period, and planted pastures grew from 2% to 29% of farm area (IBGE, 1997). Acre showed a similar though less dramatic pattern, starting with a higher proportion of each farm in natural forest. Its farmland went from close to 95% forested and less than 1% in planted pastures in 1970 to 73% forested and nearly 18% in planted pastures in 1995 (IBGE, 1997).

**Figure 3. Deforestation at benchmark sites in Acre and Rondônia states, 1978 to 1997**




Source: INPE (2000)

The communities at the benchmark sites in the two project areas were surveyed in 1993/94 and 1995/96, using a sample of approximately 150 households. In 1993/94, primary forest covered the majority of the farm area (62%), while pasture dominated the open areas, accounting for 20% of total land. The most prevalent food crops were (and remain) rice, maize, beans and cassava, which together accounted for 7% of land area. Cultivated perennial tree crops accounted for 4% of total land area and included coffee, banana and cocoa. By 1996, pasture had reached 28% of farm area, at the expense of virtually all other types of vegetation, including forest (Witcover et al, 1996).

Among the Brazilian Amazon states, Rondônia has a relatively high population density, due in part to higher than average in-migration to the state's colonization projects during the 1970s and 1980s.[5] Population density, which was 0.5 people per $km^2$ in 1970, rose to 5.2 people per $km^2$ by 1996 (IBGE, 1997). In-migration was accompanied by a substantial increase in the area deforested—approximately a quarter of the state's forests have been converted in the past 20 years, with annual deforestation rates reaching 2.8% of the total area of the state in 1995 (Fearnside, 1991; INPE, 2000; Lisboa et al, 1991). A substantial number of intra- and extra-regional infrastructural links were also established during that time.

In contrast, Acre has a lower population density, having experienced much less in-migration during the 1970s than did Rondônia (only 13 000 people, compared with 207 000 to Rondônia, according to Ozorio de Almeida and Campari, 1995). Between 1970 and 1997 population density rose from 1.4 to 3.2 people per $km^2$ (IBGE, 1997). The deforestation rate in the state is lower, with 9.3% deforested over the past 20 years and a peak rate in 1995 of 0.8% of total state land (INPE, 2000) (see Figure 3). Acre has fewer infrastructural connections with other areas, as the stretch of the BR-364 between Porto Velho and Acre was only paved in the early 1990s. The tradition of using forests for extractive purposes (principally Brazil nut collection and rubber tapping) is also far stronger than in Rondônia: 11% of Acre's land is in extractive reserves, compared with 1% in Rondônia (Avila, 1994).

Economic growth has been substantial throughout the Amazon since the 1960s. By 1995, Rondônia became the third-largest cocoa and fifth-largest coffee-producing state in Brazil. With 70% of its deforested area (3.9 million ha) planted to pastures, it also had roughly 4 million head of cattle by that year (IBGE, 1997). Gross regional product per capita in Rondônia rose from US$ 2025 in 1970 to US$ 6448 in 1996, close to the Brazilian national average for that year (IBGE, 1997; Faminow and Vosti, 1998; UNDP, 1999). In Acre, farmers have converted roughly 80% of their cleared land (1.2 million ha) to pastures and now manage about 1 million head of cattle (Embrapa, 1999a). Gross regional product per capita in Acre rose from US$ 1302 in 1970 to US$ 5741 in 1996 (IBGE, 1997; UNDP, 1999).

The development policies implemented over the past three decades have brought substantial social benefits to the western Brazilian Amazon (Table 1). Poverty has been reduced, matriculation rates have risen, incomes have increased and nutritional status has improved. Total primary and secondary school matriculation in Acre and Rondônia more than doubled in 26 years, rising from 36% and 32% respectively in 1970 to 74% and 71% in 1996. Over the same period, life expectancy at birth in both states rose from 53 years to over 67 years, and illiteracy rates among adults decreased from 53% to 30% in Acre and from 35% to 14% in Rondônia. The UNDP human development indices for Acre and Rondônia rose from 0.38 and 0.47 respectively in 1970 to 0.75 and 0.82 in 1996.[6]

However, along with these social and economic improvements have come serious environmental repercussions. In addition to the losses of biodiversity and carbon stocks associated with deforestation, soil degradation has occurred widely throughout the Amazon. The main reason is that far too little was known about the degree of heterogeneity in Amazonian soils and the ability of the different soil types to support different agricultural activities. Poorly guided planning led to the settling of thousands of farmers on land that could not support prolonged agricultural activity without substantial inputs of nutrients. It is estimated that, by 1997, as much as half of the 55 million ha converted to agriculture were already degraded (INPE, 2000). The states of Rondônia and Acre have an estimated 1.5 million and 450 000 ha of degraded pastures and 540 000 and 140 000 ha in secondary fallow respectively (Embrapa, 1999a; INPE, 2000).

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5 This section is excerpted from Valentim and Vosti (forthcoming).

6 These indices are still below the value for Brazil as a whole, which was 0.83 (IBGE, 1997; UNDP, 1999).

**Table 1. Changes in human welfare indicators for Acre, Rondônia and Brazil, 1970 to 1996**

| Socio-economic indicator | Year | Acre | Rondônia | Brazil |
|---|---|---|---|---|
| Grammar school matriculation (% of school-aged registered) | 1970 | 36.1 | 31.7 | 49.2 |
| | 1980 | 48.5 | 50.7 | 61.2 |
| | 1991 | 59.0 | 63.0 | 67.8 |
| | 1995 | 74.1 | 69.8 | 75.7 |
| | 1996 | 74.1 | 70.7 | 76.8 |
| Literacy rates (%) | 1970 | 47.3 | 64.7 | 67.0 |
| | 1980 | 55.2 | 68.5 | 74.7 |
| | 1991 | 65.7 | 80.4 | 80.6 |
| | 1995 | 70.2 | 84.3 | 84.4 |
| | 1996 | 70.2 | 85.8 | 85.3 |
| GDP per capita (US$) | 1970 | 1 302 | 2 025 | 2 315 |
| | 1980 | 2 343 | 3 426 | 4 882 |
| | 1991 | 3 767 | 4 185 | 5 023 |
| | 1995 | 5 499 | 5 562 | 5 986 |
| | 1996 | 5 741 | 6 448 | 6 491 |
| UNDP Human Development Index (HDI) | 1970 | 0.376 | 0.474 | 0.494 |
| | 1980 | 0.506 | 0.611 | 0.734 |
| | 1991 | 0.662 | 0.725 | 0.787 |
| | 1995 | 0.752 | 0.782 | 0.814 |
| | 1996 | 0.754 | 0.820 | 0.830 |

Sources: IBGE (1997); UNDP (1999)

## 1.3 Problem identification

During the initial stages of colonization, new colonists have a lot of forest at their disposal—but little else. They lack financial capital, human resources and technologies as individuals, and they lack the wealth of skills and institutions typically found at community level in areas where agriculture is traditional. Virtually all farmers seek to diversify their assets as quickly as possible, and they do so in ways that meet household food and livelihood needs first. The opportunities for meeting these needs from standing forest are limited: forest qualities of value to the international community—namely carbon stocks and biodiversity—do not have functioning markets from which farmers can profit; the legal sale of timber is effectively impossible for farmers (hindered by bureaucratic obstacles in the forest reserve area of the farm and blocked by policy measures on the farm's remaining portion[7]); and other forest products cannot be reliably converted into income because markets for them are non-existent or weak and profits are too low.

In contrast, meeting food and livelihood needs by converting forest into agricultural land appears more promising. With agriculture, there are more options for the direct consumption of production, while the sale of surpluses can generate the necessary income to purchase other needed goods. This is the basic reason why smallholders fell forests, burn the dried vegetation and convert the land to the production of annual and perennial crops and livestock.

[7] Farmers face a complex administrative procedure intended to establish that the timber they wish to sell comes from an area outside the 50% reserve.

The answer to the ‘why do small-scale farmers deforest’ question lies in the comparison they make, often intuitively, between the gains from extractive activities based on their forested area with the gains from agricultural activities based on their cleared area. This comparison must, of course, take into account the costs of converting forest into cleared land. The policy and macro-economic environment may tip the balance towards or away from leaving land in forest. Farmers also experience critical costs and benefits associated with purely biophysical factors. They may clear an area because they think it will be more useful or profitable to them when converted than as forest, but in the conversion process the forest provides essential nutrients that may make an agricultural activity agronomically possible or economically profitable on soils where it might not be otherwise. When those nutrients are exhausted, the new activity may no longer be possible. This is the basis of traditional shifting cultivation systems.

Soils in the western Brazilian Amazon are poor, labour is scarce, and the potential for intensive extraction from forests is limited by the low natural occurrence of commercially valuable products and the high storage and transportation costs.[8] As a frontier area, the western Brazilian Amazon is characterized by a general absence of strong government, lack of effective policy instruments, and incomplete knowledge regarding the natural resource base and its possible uses.

Deforestation and land-use decisions by small-scale farmers in the forest margins are driven primarily by the relative profitability of alternative cropping, livestock and extractive activities, and by labour scarcity. At present these factors combine to favour livestock production at the expense of other activities and hence the steady conversion of forest to pasture. Seasonal swings in rainfall, and consequently in the labour requirements of different production activities, condition both profitability and labour scarcity. Some potentially profitable alternatives are not adopted due to labour shortages during the establishment phase and/or at key points in the production or maintenance cycles.

The combination of abundant land and scare labour undermines attempts to make forest-based activities attractive, since it favours extensive production and hence accelerated deforestation. Early optimism about agricultural intensification—the solving of agronomic difficulties on land cleared at the forest margins—as a way of protecting forests has eroded as studies have shown that it sometimes has the opposite effect (Angelsen and Kaimowitz, 2001; Lee et al, 2001). From an economic standpoint, *farmers will continue to deforest land for as long as the expected gains from keeping it as standing forest fall short of those from alternative agricultural activities,* taking into account the cost of clearing, which involves labour, tools, some bureaucratic costs and some risk of being fined if you exceed the permitted limits. Under Brazilian law, farmers are required to keep a certain proportion of their lots under forest. This

[8] Farms are relatively large compared to those at the other ASB sites, with operational holdings within the sample of small-scale farmers averaging about 83 ha. The soils at these sites are quite varied, but farmers tilling them generally face one or more of the following impediments to agriculture and its intensification: low soil fertility, waterlogging, rocky soils or steep topography. Based on the soil analyses done to date, only an estimated 5% of sample farms are virtually free of these impediments, while some 20% do not experience them to a serious degree. The colonization projects themselves are large and travel time to get to a paved road from the farm gate is substantial. Sample farmers in Pedro Peixoto and Theobroma spent on average 1.7 hours and 2.7 hours respectively to reach a paved road during the dry season. In the wet season, this time increased by 2 hours in Pedro Peixoto and by 1 hour in Theobroma, indicating the higher susceptibility of the Pedro Peixoto road system to seasonal damage from rains and the greater isolation from markets of some of this state’s farmers. Farming households tend to be relatively small (an average of five members) and relatively old (the average age of household heads was close to 50 and only half of household members were in their prime working years). Close to 30% of household heads covered by the survey could not read and write. Higher literacy levels will be needed if farmers are to take in the necessary technical and market information to make the leap into successful market integration—and to negotiate the bureaucratic obstacles in their way (Vosti et al, 2002).

proportion was 50% until 2000, when it was changed to 80%. The difficulties of implementing this law—essentially, insufficient resources for monitoring and enforcement—will be compounded by this new requirement which, if it is enforced, will make farm households even poorer than they are now, since it will remove a valuable asset from their portfolio.

In the search for sustainable alternative LUS at the Brazilian benchmark sites, several key questions emerge:

- How much do small-scale farmers and the agricultural sector benefit from deforestation, and what are the environmental effects?
- Are farmers' post-deforestation land uses sustainable and do they safeguard remaining areas of forest? That is, do they continue to bring in profits over time, enabling farmers to leave some forest intact on their farm? If not, can they be made to do so via intensification?
- What policies in lieu of or in addition to outright prohibitions might be effective in slowing deforestation by smallholders and in making subsequent land use more sustainable, without sacrificing income?

## 1.4 Analytical criteria[9]

As discussed above, most smallholder farmers at the Brazilian benchmark sites practise slash-and-burn to convert forest to pasture or other agricultural uses because this is the most profitable option for them. For this reason, ASB goes beyond assessing the negative environmental consequences of this option—specifically, the release of stored carbon and other greenhouse gases and the loss of biodiversity—to assess also the needs and objectives of farmers. During Phase II, ASB developed and tested a research framework that quantifies the biophysical and socio-economic parameters associated with the exploitation of natural forests and alternative forms of land use. This framework is briefly described here to provide a basis for understanding the research results for the Brazilian case.[10]

### Global environmental concerns

Land uses implemented after deforestation differ significantly in their ability to substitute for the global environmental services of forests, which represent the optimum in terms of carbon storage and the conservation of biodiversity. ASB scientists quantified three indicators of the global environmental consequences of converting forest to other land uses. Two of these are linked to global climate change: carbon stocks and net absorption of the greenhouse gases carbon dioxide, methane and nitrous oxide. The third indicator is biodiversity, the conservation of which is a major international concern, especially in moist tropical forests. Both above-ground vegetation biodiversity and below-ground faunal diversity are measured. The techniques and protocols used are described in greater detail in the global working group reports (Palm et al, 2000; Gillison, 2000; Bignell et al, forthcoming).

### Agronomic sustainability

Agronomic sustainability refers to long-term production capacity at the plot level. Although researchers and farmers may differ in their assessment of what 'sustainable' means, all agree

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[9] This section is based on Tomich et al (1998a).

[10] Cross-site synthesis is the ultimate goal. See the forthcoming ASA special publication (eds, Sanchez et al), as well as ASB's global reports on biodiversity (Gillison, 2000), climate change (Palm et al, 2000) and socio-economic indicators (Vosti et al, 2000).

that maintaining agronomic sustainability is important for both traditional and alternative LUS. Soil scientists and agronomists collaborating in ASB research identified three basic components of agronomic sustainability—soil structure, nutrient balances and crop protection—and developed indicators for each.

### Smallholders' socio-economic concerns

A minimum set of three quantifiable socio-economic criteria was judged necessary to assess land use alternatives from the smallholders' perspective (Vosti et al, 2000; 2001a; Tomich et al, 1998a):

- *Production incentives*. Is the land use profitable for smallholders? Does it pay smallholders better to invest in it or in some alternative?
- *Labour constraints*. Can households supply the necessary labour for a given land use, either themselves or by hiring workers?
- *Household food security*. Is the option so risky (either in terms of variance in food yields or as a source of income to exchange for food) that adoption would jeopardize food security for the household?

During Phase II, methods for measuring these criteria were developed and used.

### Institutional barriers to adoption

Given the growing importance to ASB of policy and institutional issues, quantitative measures of the concerns of smallholders and policy makers need to be supplemented by (usually qualitative) assessments of a site or country's institutional endowments as they affect land, labour, capital and commodity markets as well as the availability of relevant technological information and materials. These factors affect the feasibility of adoption of technological innovations by smallholders. For example, formal and informal land and tree tenure institutions, often operating at the community level, appear to be key determinants of the incentives (and disincentives) to invest in productive assets and to manage resources sustainably or otherwise. ASB scientists developed a set of 12 indicators to assess the market and other institutional issues affecting land use decisions (Vosti et al, 2000; Diaw, personal communication).

## 1.5 The ASB matrix

Field-based measurements of the differing economic, agronomic and global environmental consequences of the various LUS that replace natural forest provide a starting point for quantifying some of the major tradeoffs (or complementarities) involved in land use change and for identifying the 'best bet' alternatives that may provide an attractive balance among competing objectives. Tomich et al (1998a) define a best bet as 'a way to manage tropical rainforests or a forest-derived land use that, when supported by necessary technological and institutional innovation and policy reform, somehow takes into consideration the local private and global public goods and services that tropical rainforests supply.' This implies that a best bet must make a significant contribution to all the criteria discussed above.

The difficulty of identifying a 'best bet' for a specific site depends on the nature of the tradeoffs among the four broad classes of criteria identified above. As already explained, these criteria reflect the diverse and often conflicting interests of various international, national and local groups. In assessing best bets, there are many indicators that could be considered for each criterion. If these indicators reveal tradeoffs across objectives, either a multidimensional decision-scheme or some system of weighting competing objectives will be needed to identify a best bet. Economic valuation provides a suitable weighting scheme for some indicators, but is problematic for others (e.g. biodiversity). The difficulty is compounded by the differing perceptions of the criteria across interest groups and the problem of selecting a few key indicators for each criterion. The upshot is that no single indicator is likely to capture the complex factors affecting the choice of a best bet.

ASB researchers solved these problems by developing the ASB matrix (Tomich et al, 1998a). This provides a framework for organizing the information needed to assess the tradeoffs and complementarities across indicators. The general version of this framework, the'ASB meta matrix', is shown in Figure 4. The columns of the matrix are the general classes of criteria discussed above, while the rows list seven 'meta' land uses defined for the purpose of allowing comparisons across ASB study sites and regions. (The ASB matrix for Brazil appears in Section 5 of this report.)

**Figure 4. The ASB meta matrix: a tool for evaluating and comparing LUS in the humid tropics**

| Meta land uses | Global environmental concerns | Agronomic sustainability | Smallholders' socio-economic concerns | Institutional issues |
|---|---|---|---|---|
| Natural forest | | | | |
| Forest extraction | | | | |
| Complex, multistrata agroforestry systems | | | | |
| Simple tree-crop systems | | | | |
| Crop/fallow systems | | | | |
| Continuous annual cropping systems | | | | |
| Grasslands/pasture | | | | |

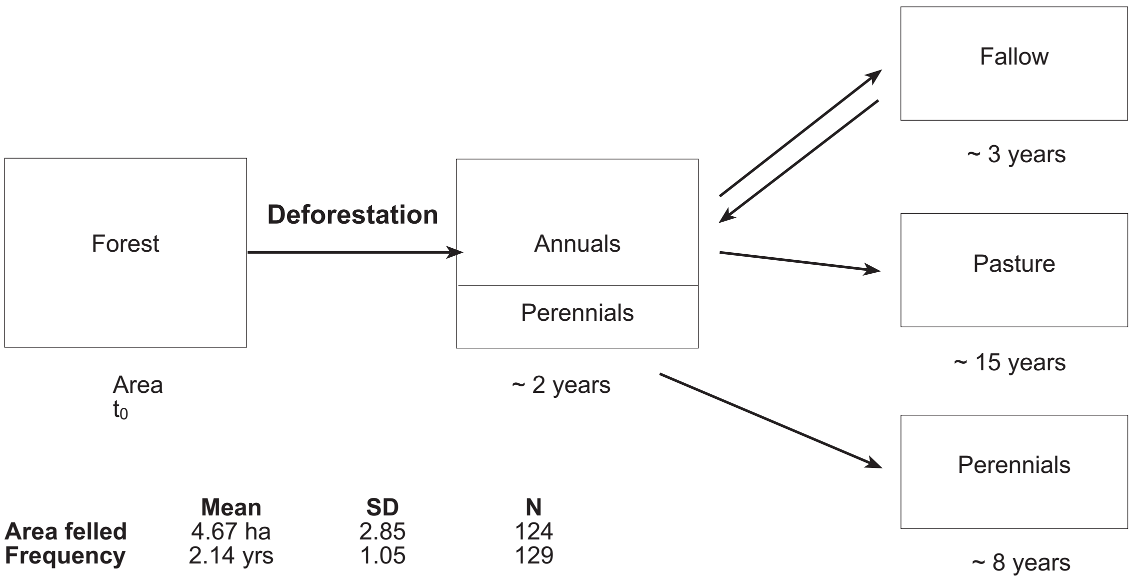
Because deforestation is one of the two primary concerns of ASB research, natural forests provide the logical reference point as regards the contribution of a given LUS to global environmental services. Grasslands and pastures are included as reference points at the opposite end of the ecological continuum since, as will be shown, this LUS is least able to provide the environmental services provided by natural forests. Between these two extremes, a representative range of five generic rainfed LUS were selected for cross-site and/or cross-regional comparisons: extraction of forest products; complex multistrata agroforestry systems; simple tree-crop systems (including, but not limited to, monoculture); annual crop/fallow systems (which include the textbook version of 'shifting cultivation'); and continuous annual systems (which may be monocultures or mixed crops). This range covers the whole spectrum of land uses, in both traditional and modernized (more intensive) forms, found both in Brazil and at the other ASB sites in Indonesia, Cameroon, Thailand, the Philippines and Peru.

## 1.6 Prevailing and alternative land use systems

Agriculture in the forest margins of western Brazil generally begins on completely or partly forested lots, which are cleared by slashing and burning the vegetation (Fujisaka et al, 1996). May, the onset of the dry season, marks the start of the agricultural year. Labour demand (especially for adult males) peaks early in the season, during the forest-felling months of May, June, July and August. In August or September, just before the start of the rains, farmers burn the areas they have cleared and, 1or 2 months later, plant them to annual or perennial crops or pasture grasses. The rains intensify from December to March, then taper off in April. After the first-season harvest, in February and March, a second crop (beans) may be planted, for harvesting in June.

Figure 5 indicates the main pathways of land use on small-scale farms at the benchmark sites. On average, farmers clear about 4.7 ha of forest, every other year. For the first 2 years or so, cleared land is used to grow annual crops, after which it is either put into pasture (for about 12 years) or perennial tree crops (mainly coffee, for about 8 years), or allowed to revert to fallow, where it will remain for about 3 years before making one or more ‘loops’ through annual crops on its way to its final use, as pasture.

**Figure 5. Land use trajectories observed at the benchmark sites**[1]




Number of years noted below each land use box indicates time continuously in a given land use (not time elapsed from $t_0$).

Source: ASB field data

Summary descriptions of these land uses—as they fit within the ASB meta matrix—are given in Table 2, which lists all the major LUS studied in Brazil by the various ASB working groups. The results are presented in the subsequent sections of this report. Although the actual subset of LUS studied by each group differed, each subset represented a range of land uses along a continuum consistent with the ASB meta matrix, thereby enabling cross-group analysis and comparison.

**Table 2. ASB meta LUS and their representative systems at the benchmark sites in Brazil**

| Meta LUS | Representative LUS |
|---|---|
| Forest | 'Disturbed forest' = primary forest with some extraction (i.e. Brazil nut) and selective logging[1] |
| Managed forest | Small-scale selective logging using low-impact techniques, with some on-farm processing |
| Multistrata agroforestry systems | Cupuaçu, Brazil nut, peach palm (and sometimes mahogany) |
| Simple, intensive treecrop systems | Coffee mixed with rubber and/or *bandarra* |
| | Coffee monoculture |
| Annual crop/long fallow | No longer in existence[2] |
| Annual crop/short fallow | 2-year annual production followed by 2- to 5-year fallow |
| Improved fallow (Intensive crop/short fallow) | Legume-based crop or tree fallows of 2-5 years |
| Traditional pasture/grasslands | Grass-based pastures, no internal fencing, minimal pasture and herd management |
| Improved pasture | Legume-based pastures with internal fencing and substantial pasture and herd management |

[1] No pristine forest is present at the Brazilian benchmark sites. The forests referred to here—with minimal extraction of forest products plus selective logging—are used as the point of departure for analysis of the various LUS found at the benchmark sites. In most cases, this minimal extraction/logging is undertaken illegally on the 50% (at the time of study) of farmers' land which, under Brazilian law, is to remain untouched.

[2] Traditional shifting cultivation is no longer practised by farmers at the Brazilian benchmark sites. For this report, traditional long fallows were reconstructed using data from short fallows, modified and extended over 20 years.

Of the LUS under study at the Brazilian benchmark sites, two are widely practised by farmers:

- *Traditional pasture*. After growing annual crops for 2 or 3 years, farmers plant the pasture grass *Brachiaria brizantha*, which is then grazed by cattle. Pastures are burned to control weeds and insects, sometimes annually, but there is little or no other management.
- *Traditional (short) annual crop/fallow.* This system involves annual food crops, usually grown for 2 years, followed by 3 or more years of natural bush fallow. Usually this is again followed by a rotation of annual crops, after which the plot is usually dedicated to pasture.

The remaining systems under study are proposed alternatives to the prevailing traditional uses at the Brazilian benchmark sites. These systems, which are still being tested in pilot projects, are as follows:

- *Managed forest.* Embrapa-Acre has developed a model for the 'rational use'—for sustainable timber harvesting—of the privately held forested land that colonists are required under Brazilian law to retain as such. The basic rationale for this work is that farmers will be more likely to protect forest if they can earn money from it. The Embrapa forest management plan is designed to sustain the forest at the same time as providing small-scale farmers with a steady income. Low-impact timber harvesting, which creates a mosaic of clearings of different ages, allows adequate forest regeneration and regrowth, while felling cycles are shorter and extraction methods have lower capital costs than those designed for large-scale operations. This LUS is proposed as an alternative to the current situation, in which farmers extract timber illegally and sell it at low prices, with the result that, in many places, agriculture and pastures occupy a far higher percentage of farm area than is allowed by law. The system is being tested in a pilot project in Pedro Peixoto, by Embrapa-Acre scientists and local farmers (d'Oliveira et al, 1998).

- *Multistrata agroforestry*. This was chosen as an alternative LUS on cleared land because it offers possibilities for higher income generation as well as more sustainable and environmentally friendly farming. ASB scientists hypothesized that these systems would provide a higher level of global environmental benefits and would, at the same time, reduce the need to clear new areas for cultivation. However, very few mutistrata agroforestry systems are currently in use in the western Amazon, so on-farm research was needed to find out why and to develop, test and, if possible, support the adoption of such systems. This research is being conducted under an Acre-based project on Mixed Species Reforestation for Economic Production, known as the RECA project. Some 349 families participate in the project, which covers an area of 1050 ha. In consultation with Embrapa and other technical advisors, the families have developed a system in which cupuaçu (*Theobroma grandiflorum*), pupunha (*Bactris gasipaes*) and Brazil nut (*Bertholletia excelsa*) trees are intercropped.
- *Simple, intensive tree-crop systems.* Two LUS of this kind are being investigated. The first, which has several variants, is an agroforestry system with coffee. This is being tested in Rondônia, where the declining productivity of coffee trees, together with coffee bean quality problems, has promoted the intercropping of coffee with *Hevea brasiliensis* (rubber) and/or *Schizolobium amazonicum* ('bandarra') trees. These alternative species are used both to fill gaps in existing plantations and in new plantings. *Schizolobium* is used primarily as a shade tree, but is also valued because the timber fetches a good price. These species have not been widely planted with coffee in the past, since they take a long time to mature and, in the case of rubber, also suffer from disease problems. Combining them with coffee will shorten the time to positive cash flow and may help resolve the disease problems.[11] The other system being studied is coffee monoculture. This is a fairly intensive LUS (1000 plants per ha) that is common among smallholders in Rondônia (less so in Acre). It is practised on small plots, generally under 7 ha. Plants take about 7 years to reach full maturity, but begin producing in about year 3 and last about 12 years.
- *Improved fallow*. The aim of research on this LUS is to 'intensify' food production and so reduce the need to clear new areas of forest. In an experiment in Rondônia, *Inga edulis* or *Cassia siamea* is planted with the legume *Pueraria phaseoloides* to enrich the fallow phase of the annual crop/fallow system. The system is tested for biomass production and soil improvement (erosion, in particular, is prevented when *Pueraria* is used as a cover crop), as well as methods of preventing the invasion of weed species. In separate but similar trials in Acre, *Pueraria* only was planted in the first year, in degraded or abandoned areas. After a fallow period of 2 to 3 years, the area is used for food crop production.
- *Improved pasture*. In this system, *P. phaseoloides* is planted with a recommended pasture species, *Brachiaria brizantha*, as a means of increasing the carrying capacity and productive

[11] The occurrence of serious leaf blight in rubber, caused by the fungus *Microcyclus ulei* and its association with anthracnose (*Colletotrichum gloeosporioides)*, has had a major negative impact on rubber production. In addition, plantation rubber in the Amazon requires on average 10 years before it becomes economically productive. The long time to positive cash flow makes rubber unattractive for small-scale farmers. Mixing rubber with coffee, however, provides a potentially attractive alternative as the coffee starts yielding while the rubber is still immature.

life of pastures. The secondary benefits of this system are reduced pressure from pests, diseases and weeds, better soil cover, nitrogen fixation, increased soil organic matter and nutrient cycling, higher forage yields and better quality forage during the dry season, and less reliance on burning to renovate pastures (and hence reduced carbon emissions and smoke pollution). The development of this alternative is vital, given the large area occupied by pasture (e.g. 75% of the deforested area in Acre, according to INPE estimates) and the strong economic incentives for farmers to engage in cattle production. Establishment costs are, however, much higher than those for traditional pastures (Vosti et al, 2001a).

# 2. Global environmental concerns

This section describes ASB's efforts to quantify the effects of land use change at the forest margins on two globally important environmental services: carbon sequestration and biodiversity conservation. The aim was to arrive at simple, reliable indicators suitable for comparisons using the ASB matrix. Specific methods are described in more detail in each of the global working group reports, cited below.

## 2.1 Carbon sequestration[12]

**Background**

The goal of research on this topic was to quantify the changes in carbon stocks associated with land clearing and the establishment of different LUS. The net carbon dioxide ($CO_2$) flux from the tropics, which contributes to climate change, is largely a result of the conversion of forested land to other LUS (Woomer et al, 2000). When vegetation is removed through slash-and-burn, carbon is released to the atmosphere as $CO_2$. The net amount released depends on how quickly forest is converted, the biomass of the cleared vegetation, what happens to the carbon in the vegetation, the regrowth and biomass of new vegetation, and the time for which the subsequent LUS remain in place. Much of the uncertainty over the values of the $CO_2$ flux from the tropics is a result of inadequate estimates for these parameters (Houghton, 1997). In particular, there is little information on the carbon sequestration potential of many of the LUS that replace forest in the humid tropics (Houghton et al, 1993).

ASB scientists in the consortium's climate change working group established standardized methods for measuring carbon stocks in forests, in the traditional LUS established following slash-and-burn clearing and in the alternative LUS identified as possible options for farmers at the different sites (Woomer and Palm, 1994; 1998). The data gathered by these methods were used to calculate both the immediate and the longer term losses of carbon associated with forest conversion and to identify the alternatives that sequester the most carbon.

As discussed in detail in the working group's report (Palm et al, 2000), comparing the carbon sequestration potential of different LUS requires knowledge about the average C stored in each system over the period for which it remains in place, known as its 'rotation time'. In other words, it is not necessarily the maximum C stock of the system that is important but rather the average C stock of the system over time (LUS $C_{ta}$).

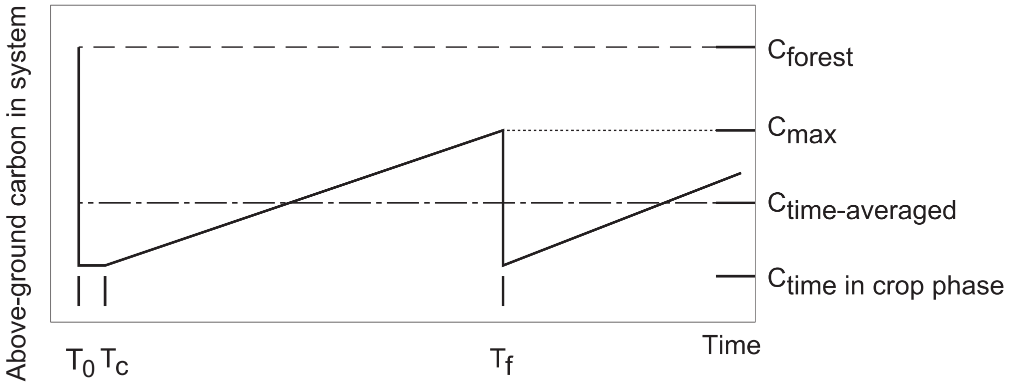
A natural forest has a fairly constant C stock, whereas clearing the forest and establishing a tree plantation, for example, results in an initial large loss followed by a gradual re-accumulation of C. ASB data indicate that a typical tree plantation may eventually reach 50 to 80% of the C stock of the forest, but the time it takes to do so will vary according to the tree species, the management regime, the soils and the climate. The time-averaged C stock depends on the carbon accumulation rates, the maximum C stored in the system, the time it takes to reach maximum C, and the rotation time of the system (Figures 6a, 6b).[13]

[12] This section is excerpted from Palm et al (2000).

[13] The calculations in Figures 6a and 6b are essentially the same; the latter links carbon re-accumulation to the tree plantation establishment and production cycle.

**Figure 6. Above-ground C losses and re-accumulation in (a) traditional swidden agriculture and (b) a tree plantation compared with stocks in a natural forest**

(a)



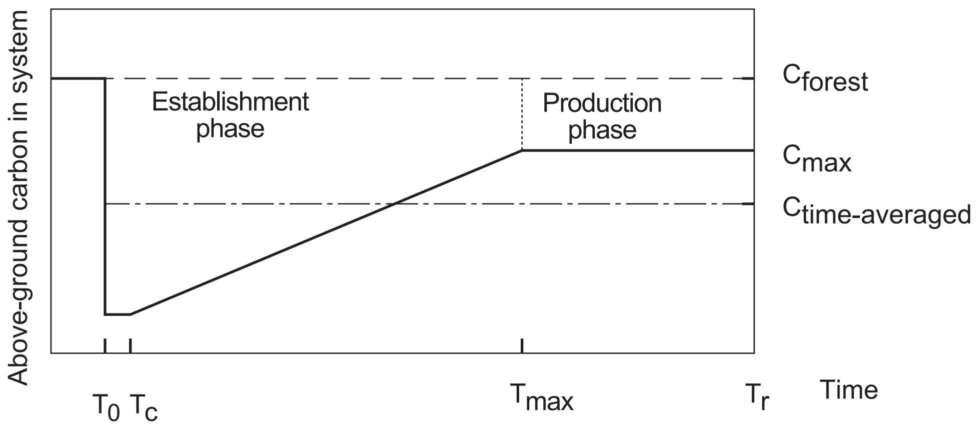

C accumulation rate = $I_c = (C_{max} - C_c)/(T_f - T_c)$, or if $T_c$ and $C_c$ are small,

then $I_c = C_{max}/T_f$

Time-averaged C = $(I_c * T_f)/2$, assuming $T_c$ and $C_c$ are small.

$C_{max}$ = carbon in fallow at time of clearing
$C_c$ = carbon in crop (assumed to be negligible)
$C_{ta}$ = time-averaged carbon
$T_f$ = time (years) in fallow phase
$T_c$ = time (years) in crop phase (assumed short compared to $T_f$).

(b)




Maximum C in system = $C_{max} = I_c * T_{max}$

Time-averaged C in system = LUS $C_{ta}$

= weighted mean ($C_{ta}$ establishment and production phases)

$C_{ta}$ establishment phase = $C_{estab} = (I_c * T_{max})/2$

$C_{ta}$ production phase = $C_{prod} = C_{max}$

= $[(C_{estab} * T_{max}) + (C_{prod} * T_r - T_{max})]/*T_r$

## Results

*Above-ground carbon*

At ASB sites across the humid tropics, the carbon stocks of selectively logged forests—from which most slash-and-burn clearing occurs—is only about 50% that of true primary forest. In Brazil, the average carbon stock (the above-ground vegetation plus litter) of the four selectively logged forests studied by the group[14] was approximately 150 tonnes of carbon per hectare (t C $ha^{-1}$), ranging from 130 to 175 t C $ha^{-1}$. The average value, 150 t C $ha^{-1}$, was compared with the maximum C stored ($C_{max}$) and to time-averaged C (LUS $C_{ta}$) (Table 3, Figure 7) of all the LUS evaluated. Traditional pastures—the end result of most forest conversion—result in only 2% of the above-ground C of forest. The average rotation time of a pasture is 8 to 10 years before re-establishment, but the rotation time does not have much effect on C storage in pastures because of the constant offtake of biomass through grazing. Notably, improving pastures, either through managing livestock better or through planting legumes, does not significantly increase their carbon storage or time-averaged C stocks. Indeed, poorly managed pastures may sequester more carbon than well managed ones.

Lands planted to simple tree-crop systems, such as monocultured coffee, attain a maximum C stock of as little as 15 t C $ha^{-1}$, only 10% of forest C stock. In contrast, multistrata agroforestry systems, which may have rotation times of up to 20 years, may reach a maximum of 90 t C $ha^{-1}$ or 54% of forest C stock. However, the time-averaged C stocks for these LUS are only 7% and 40% respectively of those of the forest. For land put into an annual crop/fallow rotation, the maximum C stock of a natural fallow of 5 years is approximately 20 t C $ha^{-1}$, compared with 34 t C $ha^{-1}$ for an improved tree fallow, which is about 23% that of the forest. However, the time-averaged C stock of the 5-year natural fallow is only 6.86 t C $ha^{-1}$ or 5% of that of the forest. The value increases to only 11.5 t C $ha^{-1}$ for improved tree fallows. The slight increase in C storage and time-averaged C achieved by the improved fallow is due to its high C accumulation rate of 6.86 t C $ha^{-1}$ $y^{-1}$, compared with 3.91 t C $ha^{-1}$ $y^{-1}$ for the natural fallow.[15] The C accumulation rates of the multistrata agroforestry systems were high and similar to those of the improved fallow. At the Brazilian benchmark sites as in the rest of the humid tropics, *tree-based systems offer greater potential for carbon sequestration than do grass-based systems.*

*Below-ground carbon*

The preceding comparison includes only the above-ground carbon stocks, because the data on the carbon contents of the samples of roots and soils examined by the group were extremely variable. The root data, in particular, were not useful for comparing LUS. Apparently the excavation method used did not adequately sample large roots, so the values for roots in forests and other tree-based systems were underestimated. These data are not included in the report and will not be discussed. The soil data were also variable, partly because of textural differences in the soils of the chronosequence sampled at each site, despite attempts to sample similar soils. Differences in soil C measured in two different LUS could therefore be the result of soil textural differences, rather than any effect of land use. To account for the variability caused by

[14] Pristine, primary forest was measured only at ASB benchmark sites in Indonesia. In Brazil, baseline 'primary' forest measurements were taken in 'disturbed' natural forest from which most large, valuable trees had already been removed and which now supported less invasive forms of exploitation, notably the extraction of Brazil nuts. These selectively logged or disturbed forests are the closest approximation to primary forests encountered at the Brazilian benchmark sites. In this section, and throughout the remainder of the report, the term 'forests'—used as a baseline for the comparisons of different LUS—refers to these disturbed forests.

[15] The regrowth rates of the natural fallows are within the range, but at the upper end, of other studies in Brazil (Fearnside and Guimaraes, 1996).

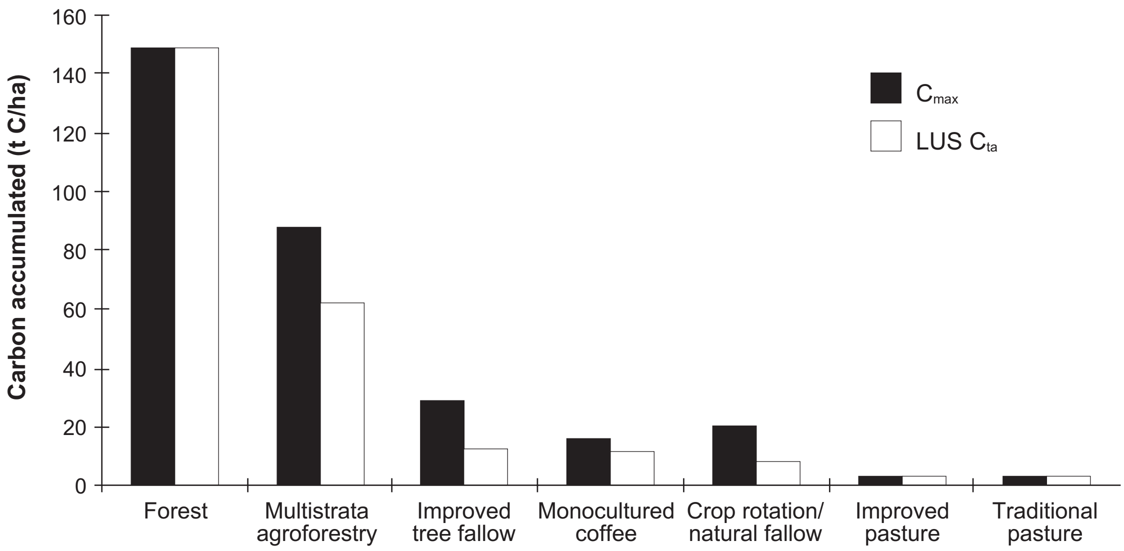
**Table 3. Carbon stocks in LUS sampled at benchmark sites**

| Meta LUS | Representative LUS | Average (t C ha$^{-1}$) C stock (SD) | Age (SD) | C accumulation rate ($1_c$) (t C ha$^{-1}$ y$^{-1}$) (SD) | Age at maximum C ($T_{max}$) | Maximum C stored* t C ha$^{-1}$ ($C_{max}$) | Time-averaged C of LUS** (LUS $C_{ta}$) (t C ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| **Forests** | Disturbed forests | 148 (19) | 100 | NA | NA | 148 (129-149) | 148 (129-149) |
| **Tree plantations** | Coffee/bandarra and coffee/rubber | 70.5 (24.3) | 10 | 7.26 (1.63) | 12 | 87.1 (67.6-106.7) | 61.2 (47.5-74.7) |
| | Coffee monoculture | 15.0 (2.66) | 8 (2.31) | 2.14 (0.38) | 7 | 15.0 | 11.0 (8.73-12.5) |
| **Annual crop/ fallows** | Short fallow | 15.4 (9.43) | 4 | 3.91 (1.66) | 5 | 19.6 (1.2-28.4) | 6.86 (4.27-9.61) |
| | Improved fallow | 13.7 (2.51) | 2 | 6.86 (1.26) | 5 | 34.3 (28.0-40.6) | 11.5 (9.50-13.4) |
| **Pastures and grasslands** | Traditional pastures | 5.70 (3.43) | 11 | - | - | - | 2.85 |
| | Improved pastures | 6.04 (1.91) | 11 | - | - | - | 3.06 |

* The range is given in parentheses and is determined by multiplying the age at maximum C by +/- 1 standard deviation of the C accumulation rate.
** The range was obtained as above, for details see Appendix 3a of Palm et al (2000).

Source: Palm et al (2000)

**Figure 7. Above-ground carbon accumulated in LUS sampled at benchmark sites**




differences in soil texture within a site, the soil C data were normalized using the equation developed by van Noordwijk et al (1997) for estimating soil C equilibrium values. The equation calculates what the equilibrium soil C would be in a natural, undisturbed system:

$$\text{Calculated forest soil C} = C_{ref} = \exp\{1.333 + 0.00994*\%clay + 0.00699*\%silt\ 0.156*pH_{KCl}\}$$

The calculated reference values for each site sampled were then compared with the actual C measured ($C_{act}$), to give a relative C value: ($C_{rel}$) = $C_{act}$/ $C_{ref}$. The $C_{rel}$ values obtained for the forest sites were not always correctly predicted by the equation, so the $C_{rel}$ of each LUS was divided by the $C_{rel}$ of the forest within each site, to serve as an estimate of the percentage change in soil C from a particular land use transition. Table 4 presents the relative C values of the different LUS, compared with those of the forest. Interpretation is difficult because soil C losses depend on the length of time the land has been in a particular use, the soil type and any topsoil erosion.

*Changes in carbon stocks and land use*

Once compiled, data on maximum, minimum and time-averaged C stocks of the different LUS can be used to determine past, current and future scenarios of the carbon flux associated with changes in land use over larger areas. Maps of the vegetative cover, based on remote sensing,

**Table 4. Corrected soil carbon values for different LUS compared with forest**[1]

| LUS | C actual | C reference | C relative | $C_{rel}$ land use/ $C_{rel}$ forest |
|---|---|---|---|---|
| Forest | 1.78 | 3.35 | 0.53 | 1.0 |
| Agroforestry | 1.52 | 3.51 | 0.43 | 0.81 |
| Fallows | 0.96 | 2.80 | 0.35 | 0.65 |
| Pasture | 1.12 | 2.84 | 0.41 | 0.77 |
| Crop | 1.70 | 3.58 | 0.48 | 0.89 |

[1] Corrected according to the equation of van Noordwijk et al (1997).

are available for each of the benchmark sites. In most cases, at least two maps are available, made at different points in time, so it was possible to use changes in cover over time as the basis for calculating the likely changes in carbon stocks associated with different LUS. For example, this work showed that, in the state of Rondônia as a whole, the conversion of 93 000 ha of forest to pasture over a 20-year period, representing a loss of 170 C $ha^{-1}$, resulted in the net release of 14 million tonnes of C to the atmosphere (Fujisaka et al, 1998).

## 2.2 Greenhouse gas emissions[16]

A second goal of the ASB climate change work during Phase II was to sample and compare trace gas fluxes from the various traditional and alternative LUS at the benchmark sites and to identify the soil-related, land-management and other factors influencing these fluxes. In addition to $CO_2$, deforestation and subsequent land uses emit methane and nitrous oxide, two other greenhouse gases. Methane is the second most important greenhouse gas in terms of amounts and effects in the atmosphere. Most well drained upland soils serve as a net sink of methane through the consumption of methane by methanotrophic micro-organisms in the soil. However, there is increasing evidence that the size of this sink diminishes when land is converted from forest to other uses. For example, conversion to pastures in the humid tropics can result in a net emission of methane from the soil through the process of methanogenesis (Steudler et al, 1996; Keller et al, 1997).

Tropical forest soils are also reputed to be a major source of nitrous oxide (Keller et al, 1997). Nitrous oxide emissions can result from the processes of nitrification and denitrification (Firestone and Davidson, 1989) and are affected by the conversion of land from forest to other uses, the application of N fertilizer, soil compaction and waterlogging. Early data indicated a large flux of nitrous oxide from areas converted to pastures (Luizao et al, 1989). More recent information, however, suggests that this flux is temporary and that emissions may eventually be less than those from nearby undisturbed forest (Keller and Reiners, 1993; Erickson and Keller, 1997). Nitrogen fertilizer application seems to be the most important management factor affecting emissions (Davidson et al, 1996; Erickson and Keller, 1997).

Unfortunately, it was difficult to collect reliable data on these fluxes. The data from Brazil were obtained during an extremely wet period in which the soils were essentially saturated at all sites, affecting the results. There appeared to be a net methane emission from pastures and agroforests and a net loss of uptake potential compared with forest soils. Nitrous oxide emissions were higher from crops and pastures than from other land uses, though none of the differences appeared significant. However, these results should be interpreted with caution.

After these initial problematic measurements, the working group redesigned its protocol to ensure intensive monthly sampling throughout the rainy and dry seasons. The results of this new work, conducted in Peru and Indonesia, will be made available in forthcoming papers. Preliminary results are included in the report of the climate change working group (Palm et al, 2000).

## 2.3 Above-ground biodiversity[17]

### Background

Humid tropical forests are home to the greatest terrestrial abundance and diversity of species on Earth. Deforestation poses a significant threat to biodiversity and to the ecosystem services

[16] This section is excerpted from Palm et al (2000).
[17] This section is based on Gillison (2000) and Gillison (forthcoming).

biodiversity provides, both in the forests themselves and in other habitats throughout the humid tropics. Biodiversity continues to be threatened globally because it is undervalued and because there are insufficient market and other mechanisms available to provide private financial incentives for its maintenance. Improvements in agricultural productivity usually come at the expense of the indigenous biodiversity of a given area. The reasons for this undervaluing and lack of maintenance are inherent in biological complexity and the consequent difficulty of developing and implementing efficient methods for assessing and valuing biodiversity. There are few published data that demonstrate links between biodiversity and profitability.

ASB sought to develop generic biodiversity assessment methods that could be used to compare vegetation patterns in different LUS and across different regions, where environment and plant adaptation may be similar but species composition may differ. This required careful sampling design and measurement of features other than species richness. The scientists in the biodiversity working group developed a series of ecoregional biophysical baselines for use in identifying and evaluating some of the key predictive relationships among plant and animal species, functional types and the physical environment. By extrapolating these relationships over space and time, it should be possible to forecast the impact of land use change on biodiversity and thus to provide a basis for deciding how the management of an LUS might be adapted to improve biodiversity or at least limit its loss. Digital Elevation Models (DEMs) were developed for each benchmark site, the 'representativeness' of which in relation to the humid tropics was mapped using DOMAIN software (see Figure 1 in Section 1). These data will serve as the basis for future extrapolation and prediction of the impacts of land use change on above-ground plant biodiversity.

In Brazil, 21 plots (each 40 m x 5 m) were sampled along a gradsect (Table 5).[18] Using the rapid survey proforma employed at all sites (Gillison, 1988; Gillison and Carpenter, 1997), a minimum set of key biophysical parameters was measured. Recorded data included:

- *Site physical features:* latitude, longitude, percentage slope, aspect, elevation, parent rock type, soil type, soil depth, terrain unit and litter depth.
- *Vegetation structure:* mean canopy height, crown cover percentage, cover-abundance estimates of woody plants (up to 1.5 m tall) and of broyphytes, furcation index (Gillison, 1988) to describe tree architecture, and basal area.
- *Plant species:* all vascular plants, which are higher plants excluding mosses and liverworts. These plants remain the major currency unit by which biodiversity is assessed, despite a growing number of challenges to this position.
- *Plant functional types (PFTs) or modi:* these are combinations of adaptive morphological or functional attributes (e.g. leaf size class, leaf inclination class, leaf form and type, and distribution of chlorophyll tissue) coupled with a modified Raunkiaerean life form (a classification of plants according to their ability to survive the most unfavourable season) and the type of above-ground rooting system (Gillison and Carpenter, 1997). PFTs are derived according to specific rules from a minimum set of 35 functional attributes. For example, an individual plant with **mi**crophyll-sized, **ve**rtically inclined, **do**rsiventral leaves supported by a **ph**anerophyte life form would be of a PFT expressed as **MI-VE-DO-PH**. Although PFTs tend to be indicative of species, they are in fact independent, in that more than one species can occur in a PFT and more than one PFT in a species. PFTs allow the recording of genetically determined, adaptive responses of individual plants that can reveal intra-specific as well as inter-specific responses to the environment in a way not usually

[18] The distribution of plants and animals is determined mainly by environmental gradients. When a gradsect is used for sampling, sites are located according to a hierarchical nesting of assumed physical environmental determinants. These include climate, elevation, parent rock type, soil, vegetation type and land use.

**Table 5. Above-ground plant biodiversity data for LUS in Brazil**

| Plot No | Mean Ht | Basal-A | PFTs | Species | Spp:PFTs | V-index | Land use |
|---|---|---|---|---|---|---|---|
| BRA017 | 26 | 22.3 | 44 | 80 | 1.82 | 10.0 | Managed forest |
| BRA012 | 22 | 18 | 40 | 79 | 1.98 | 9.23 | Disturbed forest |
| BRA019 | 12 | 11.7 | 42 | 82 | 1.95 | 8.13 | Secondary forest (fallow) |
| BRA018 | 12 | 16 | 32 | 63 | 1.97 | 7.47 | Secondary forest (fallow) |
| BRA013 | 12 | 13.3 | 36 | 50 | 1.39 | 5.82 | Agroforestry (cupuaçu + pupunha + nuts) |
| BRA014 | 12 | 11.3 | 36 | 47 | 1.31 | 5.38 | Agroforestry (cupuaçu + pupunha + nuts) |
| BRA005 | 22 | 7.3 | 21 | 27 | 1.29 | 4.17 | Agroforestry (bandarra + coffee) |
| BRA006 | 21 | 7.3 | 21 | 27 | 1.29 | 4.06 | Agroforestry (bandarra + coffee) |
| BRA007 | 2.2 | 0.5 | 29 | 34 | 1.17 | 3.40 | Capoéira/cassava plantation |
| BRA008 | 5 | 8.7 | 24 | 32 | 1.33 | 3.40 | Improved fallow (*Ingá edulis*) |
| BRA001 | 8 | 8.7 | 12 | 15 | 1.25 | 2.74 | Agroforestry (rubber tapping + coffee + cupuaçu) |
| BRA009 | 4.5 | 7 | 17 | 21 | 1.24 | 2.63 | Improved fallow (*Cassia siamea*) |
| BRA002 | 8 | 8 | 14 | 15 | 1.07 | 2.52 | Agroforestry (rubber tapping + coffee + cupuaçu) |
| BRA010 | 8 | 5 | 15 | 17 | 1.13 | 2.30 | Agroforestry (rubber tapping + coffee) |
| BRA011 | 8 | 3.3 | 15 | 16 | 1.07 | 2.08 | Agroforestry (rubber tapping + coffee) |
| BRA015 | 0.4 | 0.01 | 20 | 26 | 1.30 | 1.93 | New subsistence garden with *Bactris* |
| BRA016 | 0.4 | 0.33 | 20 | 22 | 1.10 | 1.76 | New subsistence garden with *Bactris* |
| BRA020 | 0.2 | 0.01 | 12 | 18 | 1.50 | 0.76 | Former pasture |
| BRA021 | 0.2 | 0.01 | 10 | 14 | 1.40 | 0.54 | Former pasture |
| BRA003 | 0.8 | 0.03 | 8 | 10 | 1.25 | 0.43 | Traditional pasture (*Brachiária*) |
| BRA004 | 0.8 | 0.03 | 7 | 11 | 1.57 | 0.10 | Traditional pasture (*Brachiária*) |

indicated by the name or description of a species. Because they are generic, they have a singular advantage for the purposes of ASB's research in that they can be used to record and compare data sets derived from geographically remote regions where adaptive responses and environments may be similar but where species may differ (Gillison, 2000).

**Results**

The species richness recorded at each site can be found in column 5 of Table 5, which lists land uses (rows) in order of most to least rich in terms of plant biodiversity. Multi-strata agroforests are the highest in species richness after forests, followed by the improved fallows with tree species.

However, given that the goal of ASB is to link biodiversity with other environmental and social factors, the biodiversity working group explored the use of other variables to find better correlations and develop a predictive indicator of the impact of land use and environmental change. Mere taxonomic data mask wide variations in the range and ecological behaviour of plants. Using data from an intensive baseline study in Sumatra,[19] the working group identified five key indicators for all ASB sites, including Brazil: the mean canopy height of a plant, its basal area, total vascular plant species, total PFTs or functional modi and a ratio of plant species richness to PFT richness. Using a multi-dimensional scaling analysis, the single 'best bet' of values (or eigenvector scores) can be extracted for a specific set of sites characterized according to these variables. When standardized, these values can be used as a relative index of vegetation that, for the ASB data, corresponds closely with the observed impacts of land use on biodiversity and crop production and reflects the 'time since opening' or, in other words, since forest clearing. This set of values is termed a 'V index' (see column 7 of Table 5, and Figure 8).

While there are close correspondences with plant and animal biodiversity, the V index is more a habitat or site characterization indicator than an actual index of biodiversity. However, it does allow the cross-site and cross-region comparison of data on above-ground biodiversity with those on carbon storage, below-ground biodiversity and socio-economic factors, as will be demonstrated later in this report (Gillison, 2000).

## 2. 4 Below-ground biodiversity[20]

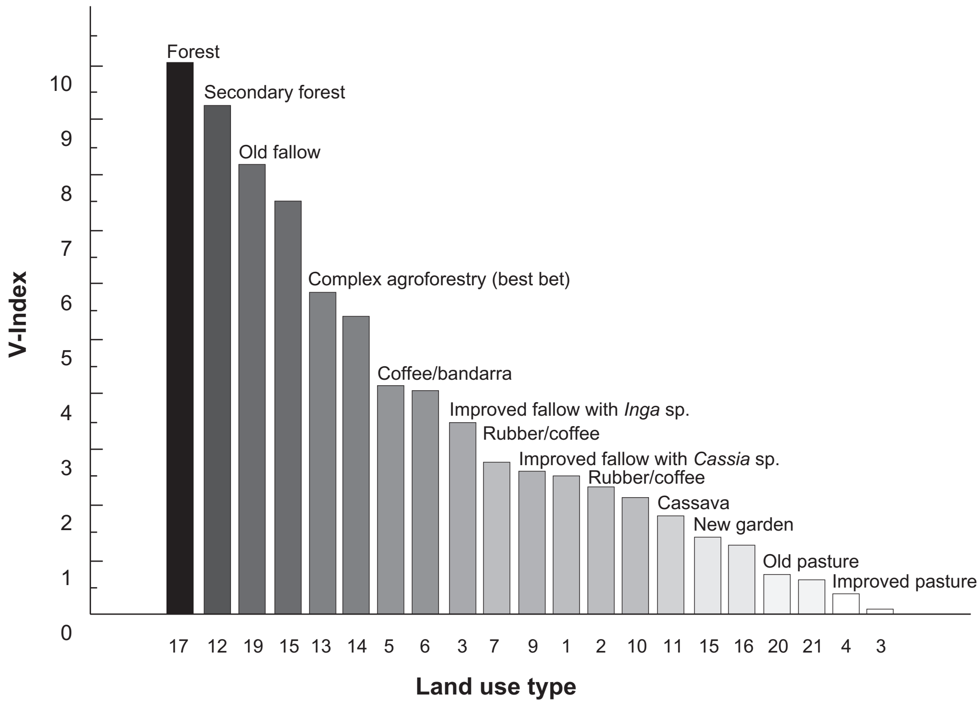
**Background**

ASB's research on the impact of land use change on the below-ground biotic community arose because of the critical role of this community in shaping an ecosystem. Soil biological processes are essential for maintaining ecosystem functions such as the decomposition of organic matter and the cycling of nutrients.

There is limited knowledge, however, of the extent to which the biota below ground, and the functions its species perform, are dependent on the biota above ground, and vice-versa. This knowledge gap makes it difficult not only to predict the effects of land-use change on ecosystem processes but also to evaluate other scenarios, such as the effects of climate change or agricultural intensification on ecosystems. There is also limited knowledge of the taxonomy of

[19] An intensive, data-rich survey covering various sites is necessary to achieve statistical confidence in the correlative relationships among the variables and the land use intensification gradient.
[20] This section is excerpted from Bignell et al (forthcoming), unless otherwise indicated.

**Figure 8. LUS at the benchmark sites ranked for plant diversity (V-index)**




many below-ground groups, which has led most scientists to use functional groups, in which fauna are categorized by their role in soil functions or processes. The biodiversity working group selected the following target functional groups for study on the basis of their diverse functional significance to soil fertility and overall ease of sampling across a range of LUS:

- *Earthworms*, which influence both soil porosity and nutrient relations through the channelling and ingestion of mineral and/or organic matter.
- *Termites and ants,* which influence (a) soil porosity and texture, through tunneling, soil ingestion and transport, and gallery construction; and (b) nutrient cycles, through transport, shredding and digestion of organic matter.
- *Other macrofauna,* such as woodlice, millipedes and certain insect larvae, and their predators (centipedes, larger arachnids and some other types of insects), which act as litter transformers and shredders of dead plant tissue.
- *Nematodes*, which (a) influence soil turnover in their roles as root grazers, fungivores, bacterivores, omnivores and predators; (b) occupy existing small pore spaces in which they are dependent on water films; and (c) usually have very high generic and species richness. Small size, high abundance and multifunctionality should make nematodes highly sensitive to disturbance.
- *Mycorrhizae*, which associate with plant roots, improving nutrient availability and reducing attacks by plant pathogens.
- *Rhizobia*, which transform $N_2$ into forms available for plant growth.
- *Overall microbial biomass,* which is an indirect measure of the total decomposition and nutrient recycling function of a soil. It is constituted by fungi, protists and bacteria (including archaea and actinomycetes).

The working research questions for the group are listed in the first column of Table 6. A series of common protocols specific to the faunal groups being measured were employed at each site. These protocols ranged from the most desirable (detailed and intensive sampling) to the more practical (less detailed and intensive, given time and resource limitations and the desire not to disturb farmers' fields).

**Table 6. Key ASB questions regarding the functional implications of below-ground biodiversity (BGBD)**

| ASB question | Affirmative evidence | Qualifying comments | Functional implications |
|---|---|---|---|
| 1. Does LUS change affect BGBD? | Macrofauna, termites, nematodes, mycorrhizae, rhizobia | Not all countries or sites | Sustainability or renewal of soil fertility may be compromised |
| 2. Does agricultural intensification reduce BGBD or affect community composition? | Macrofauna, termites (reduction and community change); nematodes (community change); cf. mycorrhizae (increase and community change) | Not all countries or sites. Trends different within macrofauna (termites vs earthworms) and between macrofauna and smaller biota[1] | Management systems and site histories may be influential |
| 3. Does agricultural diversification promote or sustain BGBD? | Macrofauna, termites | Agroforestry retains macrofaunal diversity in 3 countries, but trend is opposite for smaller biota | Canopy cover promotes large biota, but agroforestry is variable in its nature and effects |
| 4. Is extreme disturbance highly damaging to BGBD? | Macrofauna, termites | Loss of canopy reduces some macrofauna, but others are unaffected. No consistent evidence for smaller biota | Soil ecosystem engineers may be more vulnerable |
| 5. Is BGBD linked to AGBD or production? | Termites | Link to woody basal areas and plant functional modi | Termites are good indicators of niche diversity |
| | Rhizobia | Link to shoot dry weight | High soil abundance may promote plant production |
| 6. Is BGBD influenced by proximity to forest? | Macrofauna, termites | New cropfields and small cropfields are more forest-like. Intermediate disturbance favours ants and earthworms | Short-fallow rotations are damaging to soil biota |
| 7. Are there effects on abundance and biomass independent of BGBD? | Macrofauna | Earthworms promoted at intermediate disturbance without great diversity | Soil biota are robust, except at extremes of disturbance |
| | Microbial biomass | Diminishes with agricultural intensification | Indicative of lowered biological activity |

[1] 'Smaller biota' means nematodes, mycorrhizae and rhizobia.

In Brazil, the following groups were measured, using the following parameters (Moreira et al, 2000):

- *Macrofauna:* total richness, total biomass, earthworm biomass, termite density and ant density.
- *Microbial biomass:* relative to carbon and nitrogen.
- *Mycorrhizae:* spore numbers, species numbers.
- *Nematodes:* genera and family density, population density, nematode diversity (three indices), trophic function, disturbance level and decomposition pathway.
- *Rhizobia*: numbers and population efficiencies.

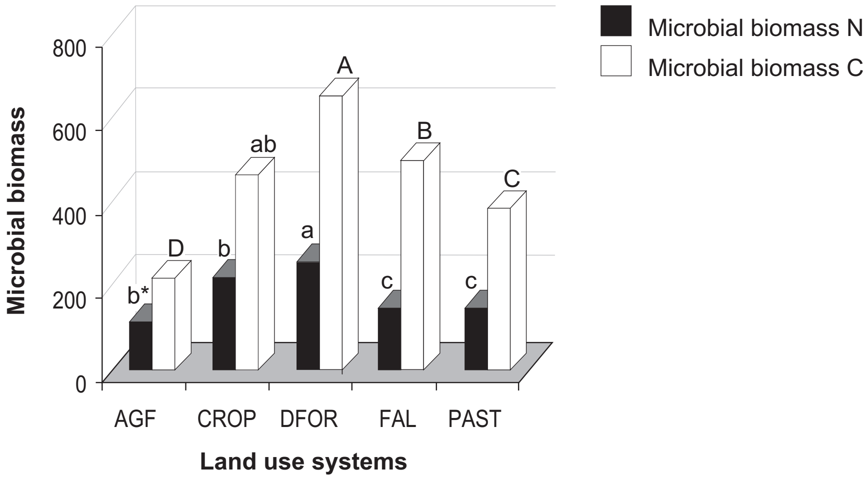
Samples were taken from the same sites used to sample carbon storage. A 25 m x 4 m transect was drawn for each research plot. Macrofauna were extracted from monoliths; microfauna from soil cores.

Full analysis of the below-ground data has been complicated by problems with taxonomic identification and the highly heterogeneous distribution patterns of soil organisms, which are rarely amenable to statistical analysis based on normal distribution. Given this heterogeneity, low confidence intervals for estimates of abundance are rarely obtained (M. Swift and D. Bignell, personal communications). A global synthesis of the evidence in answer to each research question is given in Table 6. In the case of Brazil, the following results may be considered (Moreira et al, 2000):

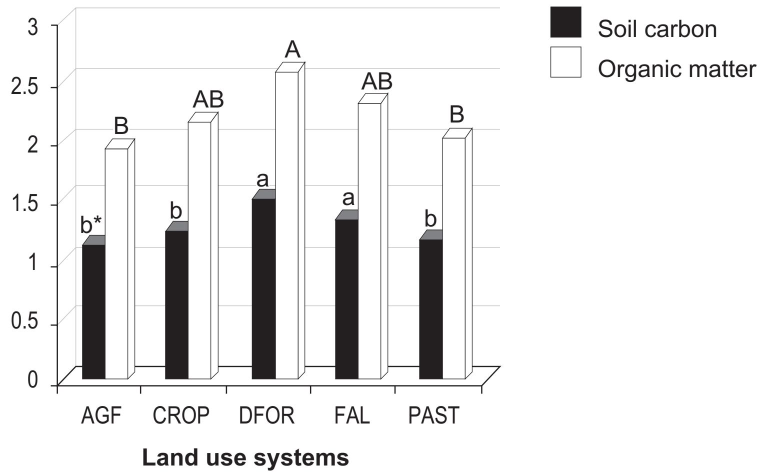
- *Microbial biomass (N and C) and total soil carbon.* These are variables that are indicative of general soil health or quality rather than biodiversity. As shown in Figure 9, forest (DFOR) had higher values for all these variables than for other land uses. It can thus be concluded that these soils are able to support lower biological activity than the forest.
- *Rhizobia.* As Figure 10 shows, there are differences in diversity at the genus (strain) level. The prevalance of *Bradyrhizobium* spp, which are slow to very slow growers, compared with other, faster growing strains, such as *Rhizobium*, *Sinorhizobium*, *Mesorhizobium* and *Allorhizobium*, is affected by land use change. This indicates a simultaneous change in ecosystem function.
- *Arbuscular mycorrhizae.* Spore numbers were highest in crops and pasture and lowest in agroforests. However, more species were found in forest and fallows and fewer in pastures and agroforests.
- *Nematodes.* Data on nematodes, unique to the Brazilian benchmarks, are presented in Table 7. Nematode abundance is lowest in agroforests and food-crop fields and highest in pasture. All three diversity indices are consistent in showing that the lowest diversity is associated with pasture and food-crop fields and the highest with fallows and agroforests. However, the reduction in generic richness (and associated diversity indices) in pasture and food-crop fields is not reflected to the same extent by the indices of trophic diversity, trophic dominance and the abundance (percentage of total) of plant-feeding and bacterial-feeding groups. This supports the conclusion that *these fauna remain functionally robust over the broad range of land uses, land covers and degrees of disturbance surveyed.* The fallow population is noticeably different in functional composition, with more bacterial feeders. The maturity index, however, clearly distinguishes food-crop fields as the most disturbed form of land use with respect to effects on soil biota. This index broadly assesses the balance between colonizers (species with high rates of reproduction and which tolerate disturbance) and persisters (species that typically have long life-cycles and low rates of reproduction). On this basis, the three tree-based systems (secondary forest, agroforest and fallow) can be seen as more stable habitats than the two non-tree systems (pasture and food-crop fields).
- *Soil macrofauna* (earthworms, ants and termites). Table 8 presents the data on these. In terms of response to land use change, the general trend is similar to that for nematodes. The diversity in agroforests is nearly as rich as in forests, so it is quite possible that the ecosystem functions remain intact. The same is substantially true for fallows, although the decline in

**Figure 9. (a) Microbial biomass (µg N/soil and µg C/g soil) and (b) soil carbon (dag/kg) and organic matter (dag/kg) in different LUS**

(a)




(b)




Notes:

1. Microbial biomass and soil carbon were measured in the first 20 cm of the soil.
2. Upper-case and lower-case letters denote separate groups within each figure; means with different letters differ by 5% (Tukey test).
3. LUS labels refer to AGF = agroforestry; CROP = annual crops; DFOR = disturbed forest; FAL = fallow; PAST = pasture

Source: Moreira et al (2000)

earthworm biomass warrants further investigation. *The decline of earthworms and termites in pastures indicates significant disruption of the biological processes that regulate soil fertility*. This is doubtless a factor at work in the long-term decline in the productivity of pastures and may also prevent the conversion of pasture to cropped fields.

Overall, the data obtained by the working group indicate that below-ground fauna are sensitive to changes in land use. The trends for macrofauna and nematodes are clearest, but more sampling is need for all classes of fauna.

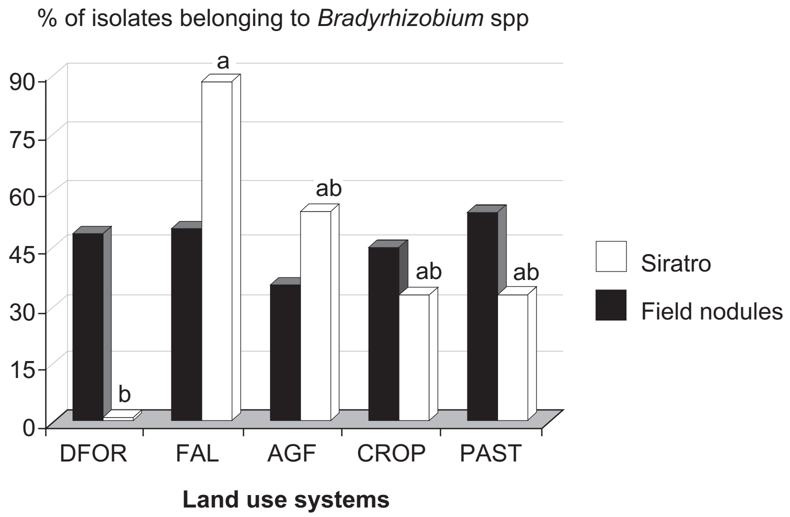
**Table 7. Nematode communities in five LUS**

| Parameter | Disturbed forest | Fallow | Agroforestry system | Pasture | Annual crop |
|---|---|---|---|---|---|
| **Abundance:** | | | | | |
| Nos. x $10^{-6}$ $m^{-3}$ | 1.7145 ab* | 1.5966 ab | 1.2985 b | 2.4012 a | 1.2258 b |
| **Diversity:** | | | | | |
| Generic richness | 7.305 ab | 8.126 a | 8.24 a | 5.819 c | 6.821 bc |
| Simpson's index | 6.6912 bc | 10.7709 a | 8.7127 ab | 5.7554 c | 6.0437 c |
| Shannon's index | 1.012 b | 1.177 a | 1.132 a | 0.9337 b | 0.9606 b |
| **Trophic function:** | | | | | |
| Trophic diversity | 2.004 d | 2.978 a | 2.847 ab | 2.171 cd | 2.559 bc |
| Trophic dominance | 0.5279 a | 0.3583 c | 0.3918 c | 0.4902 ab | 0.4182 bc |
| Plant parasites (%) | 69.65 a | 43.72 c | 53.14 b | 65.28 a | 53.72 b |
| Bacterial feeders (%) | 10.6 d | 24.22 a | 17.66 bc | 13.63 cd | 22.93 ab |
| **Decomposition pathway:** | | | | | |
| Fungivores/bacterivores | 0.9761 a | 0.2148 b | 0.7929 ab | 0.6469 ab | 0.5789 ab |
| (fungivores+bacterivores)/ plant parasites | 0.1638 d | 0.7609 a | 0.4264 bc | 0.2256 cd | 0.5420 b |
| **Soil disturbance level:** | | | | | |
| Maturity index** | 3.406 a | 3.303 ab | 3.317 ab | 3.065 bc | 2.929 c |
| Plant parasitic index | 3.178 d | 3.566 bc | 3.801 ab | 3.994 a | 3.444 cd |

* Different letters in horizontal level indicate difference for Tukey's test ($P < 0.05$).
** Lower values indicate more disturbed environments.

Source: Bignell et al (forthcoming)

**Figure 10. Frequence of *Bradyrhizobium* spp in relation to total rhizobia in different LUS**




Note:
Samples taken both from field nodules and soil, using siratro as trap host.

Source: Moreira et al (2000)

**Table 8. Soil macrofauna in five LUS**

| LUS[1] | MfD[2] (Shannon's index) | MfB ($g\ m^{-2}$) | EwB ($g\ m^{-2}$) | Tdens (ind $m^{-2}$) | Adens (ind $m^{-2}$) |
|---|---|---|---|---|---|
| **DFOR**[3] | 2.22A | 3.7 AB | 6.4 B | 370 AB | 254 AB |
| **AGF** | 1.92 AB | 4.2 AB | 5.1 B | 726 A | 653 A |
| **FAL** | 2.14 A | 8.3 A | 0.8 B | 816 A | 562 AB |
| **PAST** | 1.73 B | 3.3 B | 52.9 A | 30 B | 202 B |
| **CROP** | 1.63 C | 6.1 AB | 3.7 B | 1286 A | 198 B |

[1] DFOR = disturbed forest, AGF = agroforestry, FAL = fallow, PAST = pasture, CROP = annual crops
[2] MfD = Macrofauna density, MfB = Macrofauna biomass, EwB = Earthworm biomass, Tdens = Termite density, Adens = Ant density.
[3] Different letters across columns indicate difference for Tukey's test (P<0.05).

Source: Moreira et al (2000)

# 3. Agronomic sustainability

## 3.1 Background

Agronomic sustainability is an important link between global environmental issues and local farmers' concerns. Increases in the productivity of an LUS, or extensions to its 'life', may contribute to global environmental benefits, either directly, through the development and enhancement of, for example, complex agroforests and planted short fallows, or indirectly, through a reduction in farmers' need to clear forest for agriculture. However, for farmers, it is crucial that increases in productivity be achieved in an agronomically sustainable manner. To this end, ASB's agronomic sustainability working group developed indicators of sustainability, which the group then used to make a preliminary assessment of the long-term field-level agronomic constraints in each LUS. The indicators employed for the Phase II evaluation fall into three main categories intended to characterize (or define) agronomic sustainability: soil structure, nutrient balance and crop protection.[21] In the case of Brazil, a category for soil biota was also included because of their importance (outlined above). The methodology, described in detail in various documents of the working group, is summarized below.

No specific field measurements were made by the group itself; the indicators were based on measurements made by other working groups. Some of this information was used directly (e.g. for soil compaction assessments); some data were combined with information from the literature to create new parameters (e.g. nutrient balance calculations); and some critical assessments were based on the field experience of relevant researchers (e.g. the crop protection constraints). Many of the indicators thus derived and assessed for Brazil have to be further validated in the field. This is a priority for the national research team.

## 3.2 Soil structure

Good soil structure is critical for maintaining the long-term capacity of agricultural land to produce crops. Soil compaction (as indicated by bulk density), soil carbon and soil carbon saturation deficit (a measure of the decline in soil organic matter relative to a calculated reference) are key to maintaining soil structure. A calculation for reference carbon was developed based on an equation using soil texture and pH values (at 0-15 cm soil depth) calibrated against soils in Sumatra (van Noordwijk et al, 1997):

reference carbon (refC) = exp (1.333 + 0.00994*Clay % + 0.00699*Silt % - 0.156*pH);
orgC = organic carbon in soil as measured by soil analysis;
relative carbon (relC) = (orgC / refC);
carbon saturation deficit (defC) = 1 – relC.

The values for non-forested land uses are then compared with those for forest, which was used as the reference LUS.

Adequate soil cover is important for protecting the soil against the direct impact of raindrops and full sunlight. Longer and more frequent periods of soil exposure can lead to the deterioration of soil structure. Several indicators for this were developed:

[21] This approach has been documented in the Phase II report from Cameroon (Ericksen, 2000).

Soil exposure = ratio of the number of months of low soil cover to the length of the LUS (in months);
Note: low soil cover = dichotomous indicator: 1 = the canopy of all strata of vegetation plus any litter provide soil cover of less than 75-80% (it is assumed that all crop/plant species and litter are distributed in a regular pattern across the farmer's field and that the soil surface is adequately protected with greater than 75-80% soil cover).

An indicator was developed for assessing the frequency of removal of a protective canopy cover:

Open time = number of years since the land was last cleared, or the interval in years between clearings.

The soil cover index integrates the information on both soil exposure and open time into a single indicator:

Soil cover index = length of system cycle (in months), less soil exposure time (in months).

## 3.3 Nutrient balance

As nutrients are removed from a piece of land through the harvested product, it is important to assess whether these nutrients are adequately replenished through internal processes and/or external inputs, such as fertilizers. Internal processes that make nutrients available to plants include the mineralization of soil organic matter, releases from the soil matrix, and the biological fixation of atmospheric nitrogen. At the same time, nutrients can be lost from the system through processes such as leaching, lateral flow, soil erosion and denitrification. It is not easy to measure many of these processes rapidly. Simplified nutrient balances are, therefore, often used as a first indication of the nutrient dynamics of a system. The working group limited its calculations to the three major plant macronutrients: nitrogen (N), phosphorus (P) and potassium (K).

### Nutrient export, imports and depletion

Nutrient exports are easily determined if the quantity of harvested products, including any crop residues removed from the field, and their nutrient content are known.

Nutrient export = (nutrient content x harvest offtake) summed across all products over system cycle/length of system cycle (kg/ha/yr).

A more precise measure is:

Simple nutrient balance = nutrient import less nutrient export (kg/ha/yr).

Nutrient imports include fertilizers and N fixed through legumes. Fertilizer inputs are corrected for use efficiencies, i.e. 25% of N, 20% of P and 30% of K fertilizers are assumed to be effectively taken up by crops. Negative balances indicate greater exports than imports.

It may be desirable to calculate an NPK index that combines the three macronutrients, as a basis for investigating the tradeoffs between nutrient balance and other parameters of a system (e.g. biodiversity or profitability):

NPK index = sum of N, P and K ranks/3;

where LUS are ranked in terms of the simple nutrient balance (with the highest value receiving a 1, the second receiving a 2, the third a 3, etc). The NPK index is valid for within-country comparisons only.

**Nutrient replacement value**

Fertilizers play an important role in replacing the nutrients exported through harvested products. However, if their cost is too high relative to the value of the products, farmers will hesitate to apply them, even if they are available. The lower the ratio of the fertilizer cost to the farm-gate value of the crop, the more likely the farmers will be to consider using fertilizers and thus avoid nutrient mining (van Noordwijk et al, 1997):

> Nutrient replacement value (NRV) = sum of cost of fertilizers required to replace all exported NPK nutrients/value of all products produced by the LUS.

The fertilizer requirement is, however, corrected for nutrient recovery, i.e. only 25% of N, 20% of P and 30% of K fertilizers are assumed to be recovered by the crops. Nitrogen provided through fixation by legumes is deducted from N exports before calculating N fertilizer replacement requirements. Low NRVs indicate that the output of the LUS is high in value relative to the cost of nutrient replacement through fertilizers. Generally, NRV is calculated only for a specific crop and year. This calculation works well for monocrop systems.

**Soil biota**

As discussed in the previous section, mycorrhizae and rhizobia play important roles in agricultural productivity through their influence on nitrogen fixation and on the symbiotic relationships between soil and roots.

## 3.4 Crop protection

Attack by weeds, pests and diseases can be another important agronomic constraint to sustainable production. An attempt was made to identify potential crop protection problems, although no field observations were made. Assessments of whether or not weeds are or could become a major constraint in different LUS (in the absence of additional labour and/or technical inputs to combat them) were undertaken, based on the field experience of researchers and using the data from the above-ground biodiversity working group. A similar assessment was made for pest and disease problems, using the measurements of nematodes made by the below-ground biodiversity group.

## 3.5 Results

The results for the Brazil benchmark sites are presented in Tables 9, 10 and 11 and summarized in Table 12. The shading in Table 12 indicates those factors that pose little (grey), some (black) or severe (bold) constraints to the agronomic sustainability of different LUS.

The first point to note is that forests, obviously, face no agronomic sustainability problems. Overall, the lowest variability (between maximum and minimum recorded values) in the indicators was observed for the forest plots, and the highest for annual crop and pasture systems.

In the case of pastures, in addition to soil compaction, pests and diseases generally increase with the age and intensity of use of the pasture. Currently, spittle bug and brown plant hoppers are major pests in pastures. In the past year, many pastures containing *Brachiaria brizantha* grass have died out, posing a serious threat to sustainability (Valentim et al, 2000). However, soil carbon is higher in pastures than in some other measured systems.

**Table 9. Indicators of soil structure**

| System | Site | Bulk density | Deficit C | Soil active carbon | Soil exposure |
|---|---|---|---|---|---|
| **Forest** | Theobroma | 1.34 | 0.66 | 2.22 | 85 |
| | RECA[1] | 1.08 | 0.94 | 2.26 | ? [2] |
| | Pedro Peixoto | 1.38 | 0.54 | 0.72 | 90 |
| | **Index** | **0** | **0** | **0** | **0** |
| **Fallow** | Theobroma | 1.13 | 0.74 | 2.22 | 92 |
| | Theobroma | 1.34 | 0.57 | 1.65 | ? |
| | Pedro Peixoto | 1.12 | 0.82 | 0.58 | 95 |
| | **Index** | **0** | **-0.5** | **0** | **0** |
| **Agroforest** | Ji-Paraná | 1.02 | 0.56 | 1.33 | 45 |
| | Ji-Paraná | 1.18 | 0.63 | 0.96 | 35 |
| | RECA | 1.11 | 0.61 | 0.53 | 40 |
| | **Index** | **0** | **0** | **-0.5** | **-0.5** |
| **Pasture** | Ji-Paraná | 1.21 | 0.48 | 0.77 | 95 |
| | Theobroma | 1.30 | 0.58 | 2.23 | ? |
| | Pedro Peixoto | 1.53 | 0.64 | 0.88 | 95 |
| | **Index** | **-1** | **0** | **0** | **0** |
| **Annual crops** | Theobroma | 1.24 | 0.69 | 1.87 | 15 |
| | Theobroma | 1.31 | 0.64 | 1.52 | ? |
| | Pedro Peixoto | 1.17 | 0.72 | 0.57 | ? |
| | **Index** | **-0.5** | **-0.5** | **-0.5** | **-1.0** |

[1] RECA is a cooperative located in western Rondônia that specialized in a specific agroforestry system.
[2] Here as in subsequent tables '?' indicates no conclusions could be drawn given available evidence and/or experience.

Source: Working group document

The sustainability concerns for the agroforestry systems are related to nutrient balance, as many nutrients are exported in the harvested products without being returned. The simple nutrient balance shows significant negative values for N, P and K. The scored indicators also suggest problems related to the disturbance of mycorrhizae. Taking into account all criteria, the forest systems were rated as most sustainable, followed by fallow systems, although these did have some nutrient balance problems. Cropping systems were rated as problematic with respect to all but one of the criteria (mycorrhizae). This is a critical finding, since annual cropping systems are widespread at the Brazilian benchmark sites.

**Table 10. Indicators of soil biological health**

| System | Site | Mycorrhizae | | Nitrogen-fixing bacteria *Vigna* | Other | Various |
|---|---|---|---|---|---|---|
| **Forest** | Theobroma | 184 spores | 8 species | 0 | -0.5 | 0 |
| | RECA | 130 spores | 6 species | -1 | -0.5 | -0.5 |
| | Pedro Peixoto | 100 spores | 7 species | 0 | -0.5 | -0.5 |
| | **Index** | | **0** | | | **-0.5** |
| **Fallow** | Theobroma | 120 spores | 7 species | 0 | -0.5 | 0 |
| | Theobroma | 180 spores | 8 species | 0 | -0.5 | -0.5 |
| | Pedro Peixoto | 80 spores | 5 species | 0 | -1 | -0.5 |
| | **Index** | | **0** | | | **-0.5** |
| **Agroforest** | Ji-Paraná | 40 spores | 7 species | -1 | -1 | -0.5 |
| | Ji-Paraná | 110 spores | 4 species | 0 | -0.5 | -0.5 |
| | RECA | 40 spores | 4 species | 0 | -0.5 | 0 |
| | **Index** | | **-0.5** | | | **-1** |
| **Pasture** | Ji-Paraná | 91 spores | 5 species | 0 | -0.5 | -0.5 |
| | Theobroma | 427 spores | 4 species | 0 | -0.5 | 0 |
| | Pedro Peixoto | 121 spores | 5 species | 0 | 0 | 0 |
| | **Index** | | **-0.5** | | | **0** |
| **Annual crops** | Theobroma | 150 spores | 6 species | 0 | -0.5 | -0.5 |
| | Theobroma | 60 spores | 5 species | -1 | -0.5 | 0 |
| | Pedro Peixoto | 360 spores | 8 species | -1 | -0.5 | -0.5 |
| | **Index** | | **0** | | | **-1** |

Source: Working group document

**Table 11. Indicators of crop protection constraints**

| LUS | Site | Disease problem | Weed problem |
|---|---|---|---|
| **Forest** | Theobroma | | 0.17 |
| | RECA | | 0.10 |
| | Pedro Peixoto | | ? |
| | **Index** | **0** | **0** |
| **Fallow** | Theobroma | | 0.73 |
| | Theobroma | | ? |
| | Pedro Peixoto | | 0.30 |
| | **Index** | **0** | **0** |
| **Agroforest** | Ji-Paraná | | 0.64 |
| | Ji-Paraná | | 0.77 |
| | RECA | | 0.50 |
| | **Index** | **0** | **-0.5** |
| **Pasture** | Ji-Paraná | | 0.98 |
| | Theobroma | | ? |
| | Pedro Peixoto | | 0.95 |
| | **Index** | **-0.5** | **-1.0** |
| **Annual crop** | Theobroma | | 0.85 |
| | Theobroma | | ? |
| | Pedro Peixoto | | ? |
| | **Index** | **-0.5** | **-1.0** |

Source: Working group document

**Table 12. Agronomic sustainability indicators**[1]

| | Forest | Fallow | Agroforest | Pasture | Annual crops |
|---|---|---|---|---|---|
| **Soil structure** | | | | | |
| Bulk density | 1.08-1.38 | 1.12-1.34 | 1.02-1.18 | **1.21-1.53** | 1.17-1.31 |
| C deficit | 0.54-0.94 | 0.57-0.82 | 0.56-0.63 | 0.48-0.64 | 0.69-0.72 |
| C-active soil | 0.72-2.26 | 0.58-2.22 | 0.53-1.33 | 0.77-2.23 | 0.57-1.87 |
| Soil exposure | 85-90 | 92-95 | 35-45 | 95 | **15** |
| **Nutrient balance** | | | | | |
| NNE – N | - 0.76 | - 4.1/+ 12.4 | **- 60/- 24.5** | - 4.91 | **- 24.99** |
| NNE – P | - 0.01 | **- 2.9/- 6.8** | **- 23/- 2.5** | - 1.15 | **- 2.71** |
| NNE – K | - 0.18 | **- 4.9/10.5** | **- 31.5/- 12** | - 1.53 | **- 11.43** |
| **Soil biota** | | | | | |
| Mycorrhizae | 8-6 | 8-5 | 7-4 | 5-4 | 8-5 |
| Rhizhobia | - 0.5 | - 0.5 | **1** | 0 | **1** |
| **Crop protection** | | | | | |
| Weed problem | 0.17-0.10 | 0.30-0.73 | 0.50-0.77 | **0.95-0.98** | **0.85** |
| Nematodes | 0 | 0 | 0 | - 0.5 | - 0.5 |

[1] Colours: Grey means no problems; black = moderate problems; bold = severe problems.
Units: bulk density (g/cm$^3$); NNE (kg/ha/yr); mycorrhizae (number of species); rhizhobia (index); weed problem (data provided under above-ground biodiversity) and nematodes (index).

Source: Mendes et al (1999)

# 4. Adoption potential of alternative land use systems

In this chapter we use the ASB matrix to evaluate alternative LUS from the perspective of farmers deciding whether or not to adopt them. Table 13, which presents a subset of the columns appearing in the complete ASB matrix for Brazil (provided in full in Table 14, Section 5), quantifies the parameters influencing farmers' decisions. (See Section 1.5 for a general description of the ASB matrix.)

As discussed in Vosti and Witcover (1996) and in the Indonesia Phase II report (Tomich et al, 1998b), smallholders' economic concerns regarding new or current LUS were classified in three categories: concerns about profitability, labour and food security. The policy analysis matrix (PAM) technique provided the framework for estimating profitability indicators as well as the indicators of labour requirements and cash flow constraints discussed below. The PAM is a tool for organizing and analysing information about agricultural and natural resource policies and markets. The matrix is created by comparing multi-year LUS budgets calculated at private and social prices (Monke and Pearson, 1989).[22]

Primary factors affecting the adoptability of each LUS include its relative profitability as well as its feasibility in terms of the labour, capital and land available to farmers.[23] The ASB matrix reveals which LUS are most profitable for farmers, capturing their relative profitability by measuring each system's economic returns to land and labour. The inputs and outputs needed to generate these returns determine the relative productivity of the system. The matrix also notes factors beyond sheer financial attractiveness that can affect farmers' ability to adopt. These include total labour requirements (noting seasonal bottlenecks in boldface type), institutional constraints to adoption (market- and non-market-related, described in a footnote to the table), and the potential effects of adoption on household access to food via production and/or price risk (Vosti et al, 2000).

## 4.1 Profitability

In assessing the relative profitability of systems, farmers measure financial returns to both land and labour. In relatively labour-scarce environments (such as the one studied here), returns to labour would be expected to outweigh returns to land in farmers' decisions to adopt. Figure 11 illustrates returns to labour on the vertical axis. *All* of the systems shown yield higher returns to labour than forests (traditionally exploited through the extraction of Brazil nuts and minimal logging); this is almost certainly the primary factor behind farmers' decisions to convert forest

[22] Private prices are the prices that households and firms actually face, so private profitability—the net present value (NPV) at private prices—is a measure of production incentives. Social profitability, calculated at economic (shadow) prices, removes the impact of policy distortions and market imperfections on incentives for adoption and investment. Thus social profitability—the NPV at social prices—is an indicator of potential profitability (or comparative advantage). Divergences, the differences between private profitability and social profitability, are indicators of distortions arising either from policy or from market imperfections and failures. While the ASB matrix involves using social prices in some profitability calculations, the calculations presented here use solely private prices, owing to the lack of data on social prices.

[23] Product mixes and/or LUS intensification falling within reach of the average smallholder with reasonable market access may lie outside the means of a sizeable number of other, less well situated and/or less well endowed farmers (in the field study, such farmers numbered roughly half the sample).

**Table 13. Evaluation of selected LUS: farmers' concerns**

| | Profitability[1] | | Labour requirements[2] | Institutional requirements[3] | | Food security[4] |
|---|---|---|---|---|---|---|
| **LUS** | Returns to land (R$/ha) | Returns to labour (R$/person-day) | Labour (person-day/ha/yr) | Market | Non-market | Entitlement path |
| Forest (AC) | -2 | 1 | 1 | o | - | n/a |
| Managed forest (AC) | 416 | 20 | 1.2 | inp, lb, k, o | N, R, S | $ |
| Traditional pasture (AC) | 2 | 7 | 11 | inp, o | eq | $ + consumption |
| Improved pasture (AC) | 710 | 22 | 13 | inp, lb, k | N | $ + consumption |
| Annual crop/fallow (AC) | -17 | 6 | 23 | lb | le | $ + consumption |
| Improved fallow (AC) | 2056 | 17 | **21** | LB | n | $ + consumption |
| Coffee/bandarra (RO) | 1955 | 13 | **27** | inp, o, lb, k | n, eq | $ |
| Coffee/rubber (RO) | 872 | 9 | **59** | inp, o, lb, k | n | $ |

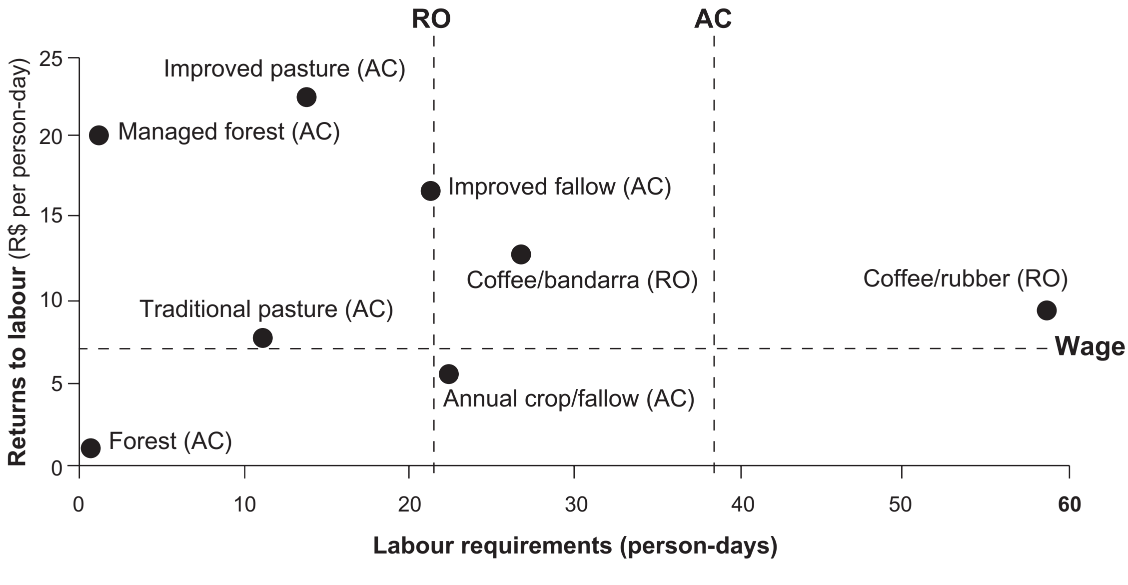
[1] Prices are based on 1996 averages and expressed in December 1996 R$ (US$ 1 = R$ 1.04).
[2] A bolded figure indicates seasonal competition for labour with other agricultural activities (including deforestation).
[3] Letters indicate institutional constraints to, or impacts of, adoption (upper case indicates a serious problem; lower case indicates a relatively minor problem): *Market*: inp = input markets; o = output markets; lb = labour markets; k = capital markets. *Non-market*: n = information; r = regulatory issues; p = property rights issues; le = local environment constraint/problem; eq = equity implications; s = social cooperation required for adoption.
[4] 'Consumption,' and '$' reflect, respectively, whether the technology generates food for own-consumption or income that can be used to buy food, or both.

Source: Derived from Vosti et al (2000)

into agricultural land.[24] Among alternative LUS, a broad array of returns to land and labour exist. Systems at or below the average rural daily wage for unskilled labour, approximately R$ 7 (US$ 1 = ± R$ 1), are unlikely to be attractive to farmers, although imperfections in the labour market, the seasonality of labour demand and heterogeneity of labour within the household make this a less than firm rule.[25] Indeed, the annual crop/fallow shifting cultivation system, which is no longer practised, yields slightly lower returns than working for wages, while the traditional pasture/cattle system, which is the most prevalent in the study area, yields slightly higher returns than wage labour. Of the two coffee-based systems, the one with the higher return to labour (coffee/bandarra) generates about twice the wage rate. Improved pasture/cattle and managed forestry systems bring in returns to labour nearly three times higher than those of the traditional pasture/cattle system. With the exception of disturbed forest and the non-existent annual crop/fallow systems, all systems generate positive returns to land (Table 13, column 2). Moreover, all intensified systems appear more financially attractive than their less-intensive counterparts.

Farmers more interested in returns to labour than to land would probably select improved pasture/cattle systems, while those more concerned with per hectare asset values (including

**Figure 11. Returns to labour and labour requirements of different LUS**




Notes:
1. All prices in R$, December 1996; US$ 1 = R$ 1.04.
2. Evaluations of AC and RO systems used prices and parameters from Pedro Peixoto (Acre) and Theobroma (Rondônia) respectively.
3. Returns do not take into account known difficulties in marketing.
4. The horizontal 'wage' line represents the daily wage for hired labour in the area; the vertical 'RO' and 'AC' lines represent person-days per cleared area for a typical farm household.
5. Labour requirements (person-days/ha/yr) are based on total requirements over the life of the LUS.

Source: ASB field data, 1994-97

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[24] This conclusion is supported by Homma (1993).

[25] For example, Brazil nut extraction, at returns near R$0, does occur. The activity peaks during a trough in labour demand that may lower the household opportunity costs of labour off the farm to near zero. Moreover, children, for whom the opportunity cost of labour is lower than the prevailing wage, also engage in this activity, so extraction might be observed even if the labour market worked perfectly.

improvements in current production systems) might prefer systems scoring high on both counts, such as managed forest, improved fallow and coffee/bandarra.

## 4.2 Labour requirements

Returns are not the only issue governing the feasibility of adoption; to achieve those returns, specific conditions will need to be met at different times during the production cycle. These conditions, or factor specificities, may be in relation to land (that it be of an appropriate agronomic profile), but are more critical in relation to labour, due to its relative scarcity in the western Amazon, and in relation to capital, at least for those systems requiring purchased inputs.

LUS with high returns to labour may be out of reach for many small-scale farmers, given the current scarcity of labour and the region's imperfectly functioning labour markets. The coffee/rubber system demands by far the most labour—nearly 60 person-days per ha per year (Table 13, Figure 11). At the other end of the spectrum lie the traditional and more intensive forest extraction systems in Acre, which require only about 1 person-day per ha per year to manage. The system currently at the bottom of the land use trajectory, traditional pasture/cattle, requires the least labour of any system other than the forest systems, approximately 11 person-days per ha per year; its intensified version, improved pasture/cattle, needs only a little more than this (Vosti et al, 2002). Clustered at 1.5 to 2.0 times the labour requirements of these systems are two other intensified systems, coffee/bandarra and improved fallows, as well as the vanished shifting cultivation (annual crop/fallow) system.

Figure 11 reveals the LUS that might fail to meet farmer adoption criteria due to their excessive labour requirements. The data on system labour requirements from Table 13 are plotted on the horizontal axis in relation to two vertical dashed lines marking the actual availability of household labour observed for the two colonization projects studied.[26] The vertical axis of the same figure shows the returns to labour, while the horizontal dashed line indicates the average wage.

Since households in Theobroma (RO) are smaller and older than their counterparts in Pedro Peixoto (AC) and have, on average, about a third less available household labour (22 person-days per year, compared with 38 in Acre), they may not have the family labour necessary to adopt LUS that are feasible in the 'younger' colonization project in Acre. One of the alternative coffee systems that performs well relative to the prevailing wage—the coffee/bandarra system—fits this profile, as also does the defunct annual crop/fallow system. The other coffee-based system (coffee/rubber) is less attractive in terms of returns to labour and lies far beyond a typical household's ability to manage without hired labour, even in Acre. Yet the overall picture favours the adoption of intensified systems. Those systems with the highest returns to labour (improved pasture and managed forestry, followed by improved fallow) fall *within* the limits imposed by on-farm labour availability—a combination seen in the upper-left quadrant of the figure. These systems may, however, exceed the limits currently imposed by capital and credit constraints.

[26] Household labour availability is measured in terms of the mean person-days available for economic activities (on or off the farm) per ha of cleared area per year, averaged over the life of the system, adjusting for the gender and age characteristics of the average household and for the leisure patterns prevalent among small-scale farmers (for details, see Vosti et al, 2002). Labour requirements may differ widely between the establishment and operational phases for some systems, or from one month to the next for others. These variations substantially affect adoptability (for details, see Muñoz Braz et al, 1999).

## 4.3 Institutional requirements and food security

The last three columns of Table 13 address the other issues that condition the adoptability of LUS, either by affecting profitability or by exposing farmers to increased production or price risks, perhaps threatening their livelihoods or food security. Substantial institutional obstacles confront farmers attempting to establish and operate some systems, their degree and type varying widely by system. Imperfections in the labour market have already been discussed and are considered a constraint to adoption in all intensified systems, particularly the improved fallow system. Beyond this, though, practically all intensified systems include reliance on other markets, themselves plagued by imperfections, including the capital market and markets for specific inputs and outputs. The exception is precisely the system most dependent on labour—improved fallows. In particular, high start-up costs (mostly large capital investments for establishment), multi-year delays in achieving positive cash flow and substantial maintenance requirements may place a system out of reach for many smallholders who do not have access to medium- or long-term credit.

Non-market institutional issues can also impede or facilitate the adoption of intensified systems. The regulatory environment, for instance, may or may not be friendly, and the knowledge needed to apply the necessary new technology may represent either a small step beyond farmers' existing practices or a major investment in new thinking and skills. Although all the intensified LUS were deemed to face some non-market institutional obstacles, the number and severity of those faced by managed forestry—an otherwise attractive system in terms of returns to labour and labour requirements—were remarkable. Sustainable extraction from forests calls for expertise on forest species and felling techniques not readily available in the project areas. It also demands a high level of social cooperation in order to achieve economies of scale in production, establish processing enterprises and protect the system against unsustainable exploitation, either within the group or by outsiders. Practitioners must also navigate the regulations that currently serve to limit or monitor extraction from forest reserves. The improved pasture/cattle system also calls for knowledge of new techniques and for seeds of new legume species, but these innovations can be adopted piecemeal, with an initial focus on aspects more similar to traditional pasture/cattle practices. The non-intensified counterpart of managed forestry, low-level forest extraction, a system long practised in some areas, has the fewest institutional obstacles.

The ability to overcome many of these institutional obstacles is presumably the most restricted for precisely those farmers who are most at risk of food insecurity and who have the fewest resources in terms of time, money and knowledge. Before they adopt a new system, these households especially may need to take stock of any risks implied by its reliance on markets to meet food needs.

# 5. Tradeoffs between objectives

If farmers were to change their product mix and/or choice of production technology in pursuit of higher profitability and higher returns to labour, would this change come at a high cost to the environment? Using data presented in the overall ASB matrix for Brazil (Table 14), this section examines the tradeoffs between selected biophysical and social parameters brought about by changes in land use, both among LUS and within them (through intensification).

The general framework of the ASB matrix was presented in Section 1.5. The systems identified in column 1 of the matrix are displayed in pairs, the first entry representing the traditional LUS, already in use, while the second is a more intensive, often experimental, form of the same system.[27] The exceptions to this treatment are: (a) perennials, for which the existing system is a coffee monoculture which is still under evaluation (the matrix instead presents results for two alternative intercropped coffee-based perennial systems); and (b) the 'traditional' long-term annual crop/fallow cycle of shifting cultivation, which has vanished.[28] With the exception of managed forestry, it was assumed that all the systems summarized in Table 14 start with forest clearing and follow a trajectory, beginning with 2 years of annual cropping, over a 20-year time horizon. A particular socio-economic and geographic setting was also assumed, namely a small-scale farmer with relatively good access to markets (for more details, see Vosti et al, 2002).[29] The LUS were all evaluated for only one of the two study sites—the one in which they were considered most appropriate (Pedro Peixoto in Acre, denoted by 'AC' in the table, or Theobroma in Rondônia, denoted by 'RO' in the table).

## 5.1 Above-ground biodiversity and returns to labour

The evidence from the study area suggests that LUS that increase the returns to labour—one measure of agricultural intensification—appear to be at odds with plant biodiversity.[30] The systems harbouring the most biodiversity (the fallow phase of the annual crop/fallow cycle, and forests) do not include any of the more intensive systems. Indeed, these LUS yield lower returns to labour than simply participating in the (imperfect) hired labour market (see wage reference line in Figure 12). They are therefore unlikely to have a long-term future unless returns to labour can be increased. What is more, among the systems for which biodiversity measures were made, those that score highest in terms of returns to labour, the coffee-based systems, have the lowest biodiversity. The traditional pasture system (where weed invasions can mean higher biodiversity) scored better than the perennial systems. Thus, while replacing traditional pastures

[27] Improved fallow systems, coffee-based agroforestry systems and managed forestry are all at the experimental stage, with some experiments in farmers' fields.

[28] This system was modelled on the basis of current practices for a single annual crop/fallow cycle, with the fallow length adjusted to allow repetition of the system over 20 years. The aim was to demonstrate why such systems are no longer viable and to compare them with an improved fallow system.

[29] LUS are described in Section 1.6 and in detail in Muñoz Braz et al (1999).

[30] Measured in terms of the ratio of species to modi. No 'weights' have been used to favour some species (e.g. those derived from forest) over others in the assessment. 'Degradation' from the farmers' point of view (in terms of output that can be derived from a given area) lends some systems their biodiversity (Gillison, 2000). Summary biodiversity measures for managed forestry, improved pasture and improved fallow are not yet available.

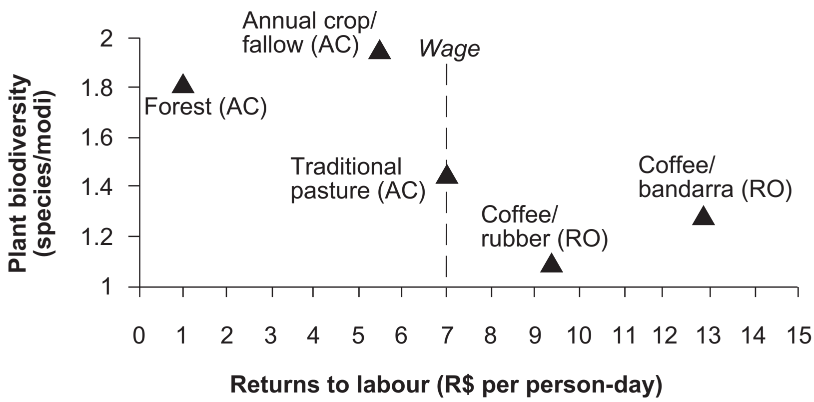
**Table 14. Overall evaluation of LUS in Brazil's western Amazon**

| LUS | Global environmental concerns | | Global and smallholder concerns | | | Adoptability concerns | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Carbon** | **Biodiversity** | **Agronomic sustainability**[1] | | | **Profitability**[2] **(private prices)** | | **Labour requirements**[3] | **Food security**[4] | **Institutional requirements**[5] | |
| | Above-ground t/ha (time-averaged) | Above-ground plants (species/modus) | Soil structure | Nutrient export | Crop protection | Returns to land (R$/ha) | Returns to labour (R$/ person-day) | Labour (person-days/ha/yr) | Entitlement path | Market | Non-market |
| Forest (AC) | 148 | 1.82 | 0 | 0 | 0 | -2 | 1 | 1 | na[6] | o | – |
| Managed forestry (AC) | -148 | nm | 0 | 0 | 0 | 416 | 20 | 1.22 | $ | inp, lb, k, o | N, R, S |
| Coffee/bandarra (RO) | 56 | 1.29 | -0.5 | -0.5 | -0.5 | 1955 | 13 | **27** | $ | inp, o, lb, k | n, eq |
| Coffee/rubber (RO) | 56 | 1.1 | -0.5 | -0.5 | -0.5 | 872 | 9 | **59** | $ | inp, o, lb, k | n |
| Traditional pasture (AC) | 3 | 1.45 | 0 to -1 | -0.5 | -0.5 to -1 | 2 | 7 | 11 | $ + consumption | inp, o | eq |
| Improved pasture (AC) | 3 | nm | 0 to -1 | -0.5 | -0.5 to -1 | 710 | 22 | 13 | $ + consumption | inp, lb, k | N |
| Annual crop/fallow (AC) | 7 | 1.96 | 0 to -0.5 | 0 to -0.5 | -0.5 to -1 | -17 | 6 | 23 | $ + consumption | lb | le |
| Improved fallow (AC) | ~3-6 | nm | 0 to -0.5 | 0 to -0.5 | -0.5 to -1 | 2056 | 17 | **21** | $ + consumption | LB | n |

1 0 indicates no difficulty, -0.5 indicates some difficulty, -1 indicates major difficulty.
2 Prices are based on 1996 averages, and expressed in December 1996 R$ (US$1 = R$1.04)
3 A bolded figure indicates competition for labour with other agricultural activities (including deforestation).
4 'Consumption' and '$' reflect, respectively, whether the technology generates food for own-consumption or income that can be used to buy food, or both.
5 Letters indicate institutional constraints to, or impacts of, adoption (upper case indicates a serious problem; lower case indicates a relatively minor problem): *Market*: inp = input markets; o = output markets; lb = labour markets; k = capital markets. *Non-market*: n = information; r = regulatory issues; p = property rights issues; le = local environment constraint/problem; eq = equity implications; s = social cooperation required for adoption.
6 'na' indicates not applicable; 'nm' indicates not measured.

Sources: Vosti et al (2001a), Muñoz Braz et al (1999), Gillison (2000), Palm et al (2000) and various working group documents with coffee-based systems (as is happening in some parts of Rondônia) will help farmers' incomes, plant biodiversity is likely to suffer.

**Figure 12. Tradeoffs between LUS: plant biodiversity versus returns to labour**




Notes:
1. All prices in R$ in December 1996 (US$1 = R$1.04).
2. AC and RO systems evaluated using prices and production systems relevant for Pedro Peixoto (Acre) and Theobroma (Rondônia) respectively.
3. Returns do not take into account known difficulties in marketing.
4. The vertical 'Wage' line represents the wage for daily hired labour during the study period.
5. Species/modi ratio measurements are taken for the land cover of systems in a stable state; for the annual crop/fallow system, the measurement presented represents the fallow phase.

Source: ASB field data, 1994-97

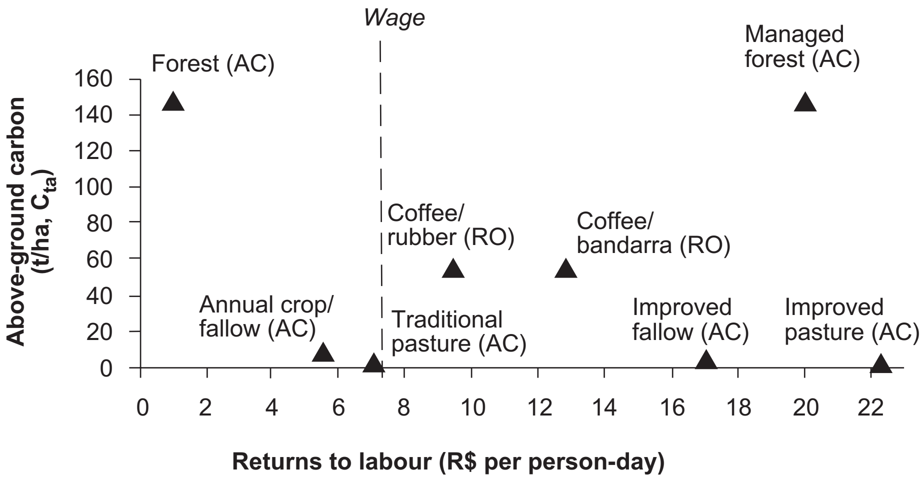
## 5.2 Above-ground carbon and returns to labour

Available evidence suggests that the tradeoff between returns to labour and carbon stocks is even more stark (Figure 13). Forests are by far the best way to store carbon, but extracting Brazil nuts from them yields much less income per person-day than manual labour (the wage reference line). Managed forestry, if it were possible to overcome the institutional constraints, looks promising as an intensive system that retains large amounts of carbon. However, the most attractive system in terms of returns to labour—improved pasture/cattle—is the least effective way of storing above-ground carbon. The coffee-based systems occupy intermediate positions. Moving from coffee/rubber to coffee/bandarra improves returns to labour without sacrificing carbon stocks. Coffee/bandarra is also the more attractive system in terms of labour requirements.

## 5.3 Meta land uses and intensification

Some LUS did better than others with regard not only to farmers' well-being but also to the provision of environmental services, notably carbon sequestration and plant biodiversity. Each intensified system offers some benefits, either to the farmer or to the environment, over the traditional system, but none comes without some tradeoffs or obstacles to adoption. Managed forestry (although still experimental) holds great promise in terms of meeting agronomic sustainability and global environmental concerns, in addition to the concern for income generation. Among the systems with perennials, coffee/bandarra competes closely with more

**Figure 13. Tradeoffs between LUS: above-ground carbon versus returns to labour**




Notes:
1. All prices in RS in December 1996 (US$1 = R$1.04).
2. Evaluations for AC and RO systems use prices and parameters from Pedro Peixoto (Acre) and Theobroma (Rondônia) respectively.
3. Returns do not take into account known difficulties in marketing.
4. The vertical 'Wage' line represents the daily wage for hired labour during the study period.

Source: ASB field data, 1994-97

intensive pure stands of coffee in terms of profitability (if start-up costs can be covered) and will almost certainly sequester more carbon. For pasture, an improved system involving changes in both pasture species and cattle management can dramatically boost incomes, but establishment costs are high and the environment will suffer much more than it would under tree-based systems. An annual crop/fallow cycle using improved fallow could prove viable, given its higher profitability; carbon gains would be negligible, but plant biodiversity would benefit.

Despite these apparent differences, the intensified systems also have some features in common, particularly as regards their adoptability. As mentioned above, all intensified systems increase returns to land and labour (compared with traditional systems) and, except for managed forests, raise no major new problems as regards non-market institutional obstacles or food security. They do, on the other hand, entail higher levels of labour and capital inputs (except for the improved fallow system) and heightened dependence on the markets for these. From the farmers' perspective, they all offer some benefits, but their adoption also presents obstacles that are not easily overcome. Capital, and perhaps labour, barriers might be eased if more attention were paid to technologies that could be adopted piecemeal or could be easily adapted by farmers given their current knowledge, thereby reducing the perception of risk so prevalent in a frontier environment (Faminow, 1997; 1998; Faminow et al, 1999).

# 6. Trends in land use patterns and impacts

This section examines trends in deforestation and land use among smallholders in the western Brazilian Amazon, and presents agro-ecological and socio-economic factors identified as influencing these trends. It then discusses probable future trends if the current policy, technology and socio-economic contexts remain unchanged.

## 6.1 Intensifying land use while protecting forests

The underlying question that motivates our examination of trends in deforestation and land use is whether farmers can derive better livelihoods from their land when this is kept as forest. Earlier sections highlighted farmers' objectives in adopting a particular LUS on a particular plot of land. Such decisions, made repeatedly on all farmers' plots, are a major factor determining the speed at which forest falls and the costs and benefits of forest conversion. This subsection explores this dynamic in more detail.

### Smallholder land use patterns

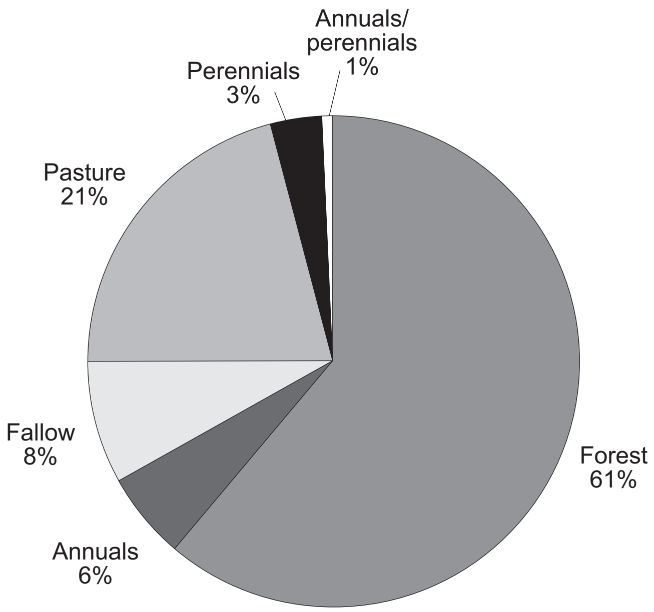
Figure 5 (in Section 1.6) sets out the land use trajectory of a plot of land from forest to its end use as pasture, showing the amounts of time that different uses typically remain in place. The figure notes the observed periodicity of forest felling and the average size of plot felled on sample farms in the project areas during the 1994 field survey. As noted in Section 1.6, smallholders on average deforest about 4.7 ha of forest every other year. Private lots are usually deforested from the front of the lot (facing the road) to the back (Fujisaka et al, 1996), with the area in pasture steadily accumulating.

Figures 14 and 15 document the conversion from forest to pasture in smallholders' lots, based on recall data from the 1994 and 1996 surveys. On average, holdings that were 88% forested upon their owners' arrival were only 61% forested in 1994 (Figure 14) and 56% forested in 1996.[31] The 1996 average includes the 35% of the sample farms that had less than half their operational holding still in forest and the 10% that had less than a quarter still forested. While 60% of sample farmers reported deforesting every second year and an additional 25% reported deforesting every third year, the patterns revealed by data analysis often deviated from reported frequencies. Deforestation was less prevalent in 1996 (when about a third of the sample cut down some forest and nearly a quarter felled secondary forest fallow) compared with 1994 (when 60% of the sample deforested and nearly 70% razed secondary forest). Thus, the spike in deforestation rates observed by some researchers in the Amazon in 1994 and 1995 (Lele et al, 2000; INPE, 2000) also emerged in this sample. The mean area felled for all farmers dropped from 2.5 ha in 1994 to 1.5 ha in 1996 for the forest, and from 3 to 1 ha over the same period for secondary forest re-growth. Among those who deforested, however, the mean area felled held steady at between 4 and 4.5 ha in both years for both forest and re-growth, although with substantial variation across households. Over the entire period since their arrival, 1996 owners had deforested on average 3.1 ha per year, but in many cases lots had been deforested at an average rate of 2.5 ha per year since their initial settlement by previous owners. Lots opened

[31] It is, however, possible for the proportion of land in forest to rise if the owner buys more land.

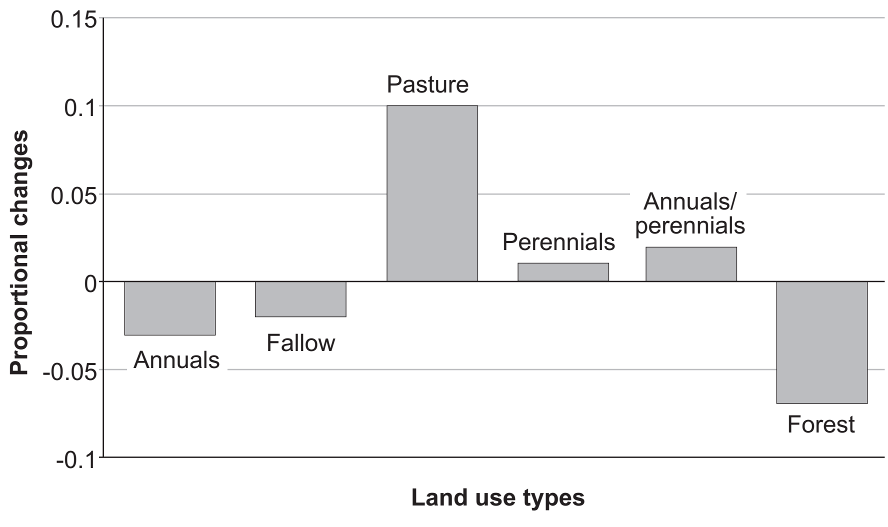
more recently, but which had not yet changed hands, had significantly higher average annual deforestation rates.

**Figure 14. Land uses on sample farms, 1994**




Source: ASB field data, 1994

**Figure 15. Changes in land use on sample farms, 1994 to 1996**

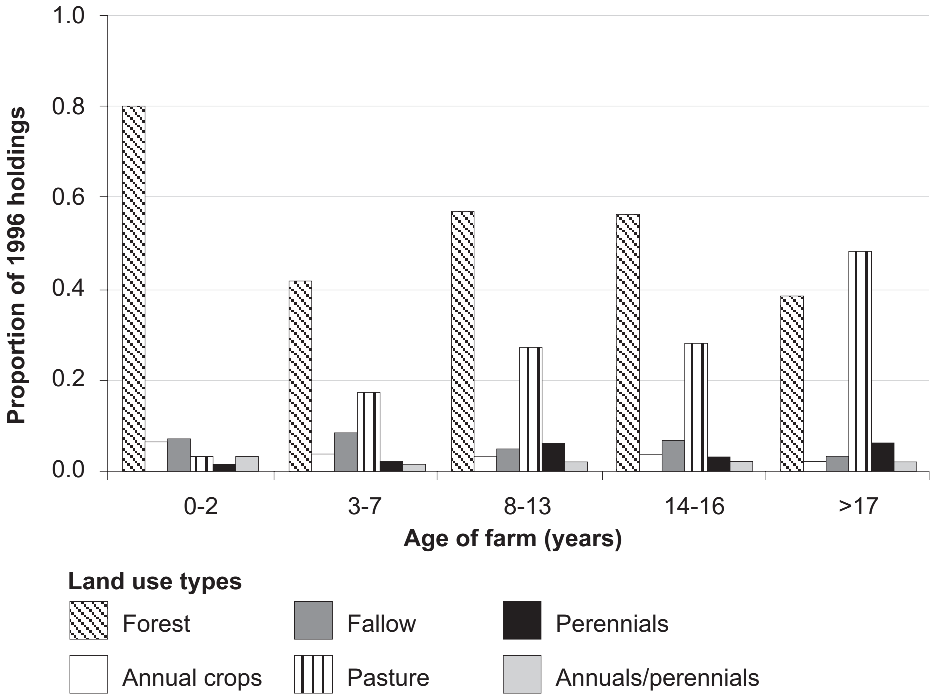



Source: ASB field data, 1994-97

Pasture, on the other hand, grew from an average of 3% of the land, when settlers arrived, to 21% in 1994 (Figure 14) and 27% in 1996. Between 1994 and 1996 alone (Figure 15), forest area decreased by a mean of 7% of the operational holding at the household level, while pasture area rose by 10%. There was also a slight expansion in the area of perennial systems.

A snapshot of land use (taken in 1996) on farms initially settled at different times (of different 'vintages', in Figure 16) confirms a striking pattern in line with expectations if the land use trajectory described above, from forest to pasture, were played out continuously on one plot of land after another. ‘Old’ farms have much less forest than ‘young’ farms; and while deforestation patterns are less obvious for some ‘middle-aged’ farms, a clear and positive link between ‘time since opening’ and area in pasture is evident for all farms.

**Figure 16. Land use by farm ‘vintages’**




Cross-sectional field data show that sample farmers on average generate outputs of higher value from cleared than from forested land in a given year. This too is expected, given the land use trajectories described above. Using field data on the land uses adopted by an average farm household and market prices for 1994 as a basis, the value of total output (VTO) for the 1993/94 season was estimated to have averaged R$ 3448,[32] which is a reasonable proxy for net returns given the low level of production costs. Figure 17 reports the distribution of on-farm VTO across groups of activities: just under half (45%) of VTO was derived from cattle-based activities (milk plus the value of growth in animals younger than 5 years), while 47% was from annual cropping and less than 10% from extractive activities. Analysis for 1996 yielded similar results.

For the average family size in the sample (five members), a return of R$ 690 per capita (R$ 3448 divided by 5) ranks above the Brazilian minimum wage as well as the World Bank estimated poverty line for 1995, indicating that, on average, farmers in projects roughly 15 to 25 years after their establishment have little incentive to leave farming to enter the off-farm labour force (Vosti et al, 2002; Faminow et al, 1999).

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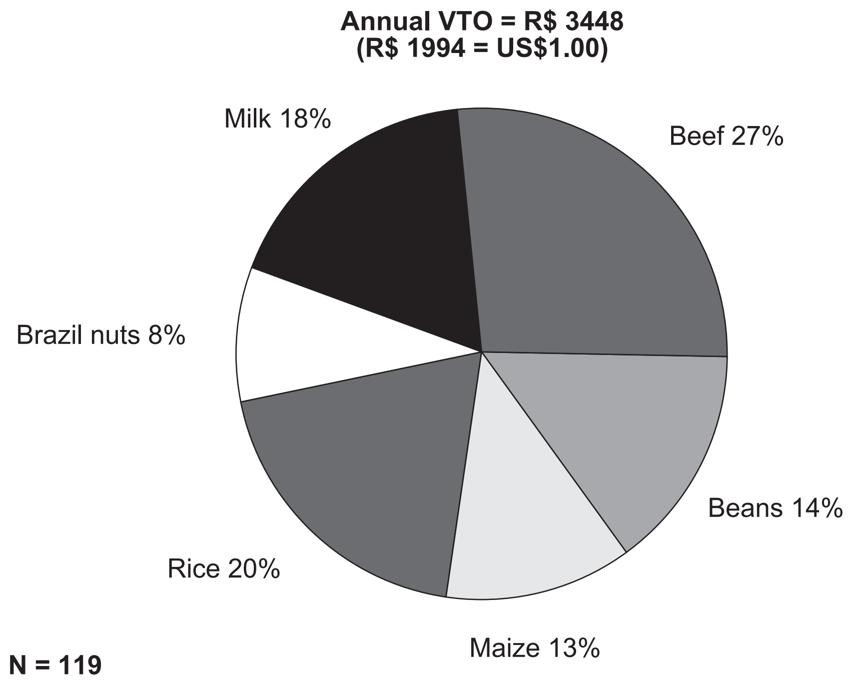
[32] All currency in this section is expressed in December 1996 reais. Note that the estimate assumes that the same local prices were faced by all sample farmers, so differences in VTO across farms are due solely to differences in production. The prices used were derived from the price series for markets near the Acre study area, which were on average somewhat higher than prices in markets around Theobroma, Rondônia.

**Figure 17. Distribution of on-farm income by activity**




In summary, the analyses of field data suggest that, in the absence of major changes in the prices, policies, institutions and technologies prevailing in the region, the area in pasture will continue to increase, while that in forest will continue to decline and swidden agriculture, with a long fallow period, will not be practised (Vosti and Valentim, 1998). A potential candidate land use with promise to slow deforestation—perennial cropping—may have appeared on the horizon, but more area in perennial crops does not necessarily guarantee more area in forest. Rather, the decision to invest in pasture or perennials appears finely balanced, with the balance at present tipping towards pasture. Evidence suggests that, in the years leading up to 1996 at least, a mixed pasture/perennial farm had a significantly lower standard of living than the more prevalent pasture-dominated farm. Hence, the area in perennials is not expected to increase significantly as a proportion of cleared area in the foreseeable future.

The general trend in land use—of conversion from forest to pasture—held despite evidence of substantial variation in production technologies, particularly in the case of pasture. There was some evidence of intensification via intercropping and improved pasture management, while intensification via purchased inputs was rare.

Deforestation rates varied but seemed to have accelerated since time of opening, with more than a few farms crossing the '50%-of-farm-in-forest' barrier decreed by law (in effect at the time of the survey, but rarely enforced). This finding is in keeping with the idea that pressures to deforest are greater in an environment with higher population and access to markets than in one where farmers must rely on their land and household labour alone for subsistence. However, while the amount of land cleared on each occasion stayed relatively constant, the timing of clearing varied—providing a potential entry point for policy measures seeking to slow deforestation by reducing the frequency of clearing.

Some farmers in the sample were quite well-off—buying new lots and consumer durables, achieving yields comparable to those of research stations and selling their output. Other farmers had fewer signs of wealth, lower yields and more limited access to, and participation in, labour and output markets. This suggests an important bimodality in the sample in terms of those who are succeeding and those who are not. While the gap between successful and unsuccessful farm households is expected to persist, the proportion of less successful farmers in this rural population is expected to decline, since members of this group will tend to migrate to other areas, rural and urban.

**Future trends suggested by the ASB matrix**

The results for Brazil presented in the ASB matrix (Table 14, Section 5) support farmers' rationale for continued deforestation. The profitability (especially when measured in terms of returns to labour) of *all* agricultural pursuits on cleared land is higher than that of traditional extraction from forests. Forests will continue to fall for as long as this remains true and the regulatory environment remains unchanged. However, forecasting future trends in the use of cleared land using the matrix alone is difficult, for several reasons. Returns to land and labour are not perfectly correlated across LUS and we do not know the precise nature of farmers' objectives; thus, depending on the relative importance of returns to land versus labour, different LUS will be more or less attractive. Perhaps more important, market imperfections and/or other institutional issues that undermine profitability are not likely to affect all LUS in the same ways, to the same degree or at the same points along the LUS trajectory, with the result that profitability estimates are an imperfect guide to future land use patterns. Moreover, the market context itself will doubtless evolve over time. That said, the matrix suggests that cattle production will continue to expand, absorbing an ever increasing proportion of cleared land. These pasture systems (traditional and improved) require little labour, depend less on imperfect labour and capital markets than most alternatives, and (even when practised inefficiently) still generate returns to land and labour that considerably exceed those from traditional forest extraction (Vosti et al, 2001b).

## 6.2 Modelling land use systems

While the ASB matrix is suggestive regarding probable future land use and deforestation trends, it falls short of taking into account some critical factors shaping farmers' decision making. Resource constraints—especially limited labour and capital—can be expected to affect farm-level land use in particular ways as farmers allocate scarce resources to their best advantage, especially given an institutional context involving limited labour markets and some output quotas. The ASB matrix suggests whether or not such constraints are likely to influence adoption decisions, but says nothing about the broader land use patterns that might result or about farmers' ability to overcome certain constraints, such as capital, by marshalling their own resources.

The matrix also takes as given the economic context within which farmers must operate, such as input prices and labour availability. These factors are linked to broader trends in the national economy, since national and international prices and exchange rates affect the local prices faced by farmers for traded goods. While the matrix results can be recalculated to reflect different price scenarios, it is impossible to predict in a broader sense how macro-economic policy or unexpected economic shocks will affect markets and prices in the study region (and thus deforestation and land use). This is because such changes reverberate throughout the national economy, affecting different regions and sectors in different but interconnected ways. Ignoring the importance of these indirect effects on local markets can result in misleading conclusions.

This subsection takes a look at two models—a farm-level bio-economic model and an economy-wide model—that attempt to extend the ASB matrix approach so that this sheds light on the probable role of various factors (resource constraints, strategic planning over time, and links to the national economy) in future deforestation and land use trends.

### Simulating land use decisions over time

To evaluate the net effects of policies and/or technologies on farm income and hence on future deforestation and land use requires an analytical tool capable of considering: (a) both the biological and the economic forces at work; (b) competition at farm level for labour, land and cash; and (c) the forward-looking, profit-maximizing nature of smallholders' decisions.[33] This section describes a farm-level bio-economic model that is used to predict smallholder deforestation and land use patterns over the next 25 years if current policies, technologies and prices persist over that period.

The model characterizes the decision making of a typical small-scale farmer endowed with land, labour and cash with which to maximize the discounted value of the household's consumption stream over a set time horizon via the production of agricultural and extractive products for home consumption and sale. These decisions are subject to an array of technology- and endowment-related constraints, including soil quality and how this changes because of management. They also take into account the financial benefits of various activities, including the hiring in or out of household or non-family labour for agricultural purposes.[34] In the model, the farmer knows: (a) all the relevant production parameters for alternative systems, and the input use and yield implications of alternative production practices and technologies; (b) the impacts on soil nutrient availability of different cropping systems and the implications for crop yields of changes in nutrient availability; and (c) input and output prices, including the costs of labour hired in and the returns to family labour hired out. Future land use decisions are conditioned by past ones, which alter the composition and quality of household resources available to support economic activities. The model includes a 'subsistence constraint', according to which minimal consumption needs (as identified by household size and composition and local food habits) must be met in each period. Since leisure time is imposed as part of this subsistence constraint (again based on usual patterns in the area), household consumption of leisure does not shift as incomes change. Family demographics, farm size and farm ownership remain constant over the time horizon.[35] Unless otherwise stated, the time horizon in simulations is 25 years—sufficient to capture farm-level adjustment to the scenarios presented as well as to assess the model's stability under these conditions.

Whether forested or cleared, land can be put to various uses, but the profitability of these uses will be conditioned either by the decline in yields that occurs as soils degrade or by the increased cost of arresting this decline through purchased inputs. Because of the nutrients released by burning, land taken out of forest can initially go into any production activity without the need for purchased inputs. However, when land is put into annual crops and no inputs are applied, severe declines in yield occur after 3 years at the latest, forcing farmers to switch to fallow, perennials or pasture.

Soils in the project areas, while generally of poor quality for agricultural purposes, are heterogeneous in ways that affect yields and the length of time agriculture can be practised on

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[33] For a review of farm modelling approaches used in the context of deforestation research, see Kaimowitz and Angelsen (1998).

[34] For a detailed description of the model, see Appendix B to Vosti et al (2002).

[35] Initial conditions were derived from field data collected in 1994 from the Pedro Peixoto project. Farms were clustered on the basis of characteristics deemed to be exogenous to farmers' decisions on land use (for example, soil type, distance to market and age of settlement of land). Each cluster can be thought to represent a farm type. Characteristics for a relatively well situated farm in terms of access to markets were used to generate the model baseline (farm type A). This cluster of farms was dominated by soil types of medium quality—that is, soils with some inherent restrictions to agricultural productivity (fertility problems, and/or mild slope or rockiness).

particular plots, as well as the types of external input needed to correct for nutrient deficiencies (Sanchez, forthcoming). Based on the results of soil tests, three categories of soils (good-, medium- and poor-quality) were identified.[36] Amendments to correct for inherent soil infertility or other problems cost money to purchase and time to apply, and may benefit weeds as well as crops, implying higher labour costs for controlling weed growth. The model weighs these financial considerations in determining farmers' product mix and production technology (and, implicitly, their use of purchased inputs). Unless otherwise stated, simulations assume medium-quality soils throughout the farm.

Interviews with farmers located on soils where soil testing was done (or on similar soils), combined with interviews with extension agents and scientists, were used to estimate crop- and technology-specific yield coefficients for each of the three qualities of soils. The model specifies three types of technology for most products—V1 being the most rudimentary and using no purchased inputs, V2 being a more advanced technology using some purchased inputs, and V3 being the most advanced and using relatively large amounts of purchased inputs. All technologies are assumed to have constant returns to scale, and there is no substitution among inputs for a given technology (although expanding the range of fixed-coefficient technologies available to the farmer for a given product does permit a kind of substitution).

The model also includes soil nutrient recovery rates, allowing tree-based fallows to recover a fixed proportion of lost nutrients each year, achieving complete recovery (nutrient level commensurate with forest) after 5 years. These nutrients are again available for agriculture if the fallow is cleared and burned.

Finally, in an effort to capture the policy and socio-economic context in which smallholders make decisions, the model limits certain input and product flows onto and off the farm to reflect market imperfections and has the capacity to impose or waive regulations regarding forest use. For example, while the model assumes that all output is potentially marketable, quotas constrain milk sales to 50 litres per day. This quota was imposed by processors at the time of our survey because of marketing bottlenecks, which have since persisted. To take another example, the hired labour that can be acquired in any given month is limited to 15 person-days, reflecting labour scarcity in the project areas. In keeping with survey responses regarding access to credit (as opposed to loans), the only credit allowed in the model is within-season borrowing to meet subsistence needs.

To reflect the policy environment, the model includes some forestry policies but excludes others. For example, in the baseline model small-scale farmers are *not* allowed to harvest timber products from their forested land.[37] In addition, a 50% rule (in effect but rarely enforced during the study period) that no more than half of any farm be cleared for agricultural purposes is *not* enforced in the model simulations.[38]

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[36] Soil samples were taken from land under different uses (e.g. forest, annual crops, perennial tree crops and pastures), but priority in the analysis was given to samples taken from pastures and forests. The soil quality categories presented here were derived from the analysis of this priority subset.

[37] Although technically permissible by law, the bureaucratic obstacles to harvesting timber in farmers' legal reserves have in practice proved insurmountable. Recent changes in certification requirements may ease the situation.

[38] The federal law requiring land owners to retain 50% of their holdings as forest reserves (*reservas legais*) and to obtain deforestation permits for all forest felling is law number 4.771, dated 15 September 1965, of the Codigo Florestal Brasileiro. This law was modified in 1997 by presidential decree, which stipulated that in states lacking approved zoning plans, farms must retain 80% of their land in primary forest. Small-scale farms were eventually exempted from this decree, but a more recent decree removed the exemption. This decree established an 80% rule for all farms in the region. In practice, many farmers retain less than 50% (or 80%) of their land in forest and fines are rarely imposed on them.

Table 15 reports the effects of selected farm, market and other factors on deforestation, use of cleared land and household income; 'no' indicates no important effect, 'yes' indicates an important effect, which could be positive or negative.[39]

**Table 15. Effects of selected model variables on deforestation, land use and incomes**

| | Does this variable affect.... | | |
|---|---|---|---|
| | Deforestation | Use of cleared land | Income |
| Soil quality | No | No | Yes |
| Labour availability | Yes | No | Yes |
| Prices | No | Yes | Yes |
| Discount rate | No | No | No |
| Distance to market | Yes | No | Yes |
| Market access | Yes | Yes | Yes |

We now use the model to 'look forward' and examine deforestation, use of cleared land and the income of a typical household over a 25-year time horizon.[40] Figure 18 depicts the land uses generated by the model under baseline conditions (a well situated farmer with medium-quality soils under the market and policy setting for Pedro Peixoto, Acre during the 1994 survey). Several conclusions emerge from this baseline scenario. The amount of forest retained clearly declines over time, finally disappearing in about year 25, despite the small but positive revenue provided by the extraction of Brazil nuts (an activity currently undertaken by about half the sample farms). In terms of area, cattle production remains the dominant activity, and the pasture to support it, most of which is *brizantão* associated with tropical kudzu, eventually occupies about 85% of the farm. Annual crop production occupies about 8% of the farm throughout the 25-year time horizon, with V1 (low-technology) rice/maize intercropping co-existing with V2 (medium-technology) rice alone. The farmer does not choose to grow any perennial tree crops (coffee and banana are options), but only cassava (classified in the model and figure as a perennial because its production cycle spans more than 1 year), which over time takes up about 1 ha of land. Secondary fallow weaves in and out of the baseline scenario, becoming more significant as forests disappear. Extractive activities are a diminishing source of income, again reflecting the steady disappearance of forest.[41]

The dominance of pasture on the typical farm merits discussion. The model replicates the dual dairy-beef operations prevalent in the sample. Dairy production begins early in the 25-year

[39] For a detailed examination of the effects of a broad array of farm, farmer, price and other factors on model outcomes, see Vosti et al (2002).

[40] The results of baseline model simulations were compared with field data on land use and forest retention for a cross-section of farms of different ages, beginning with those opened around 13 years before the study (our typical farm's point of departure). The progression of predicted uses of cleared land and the amount of forest retained in any given year did not deviate substantially from the average patterns observed on sample farms of comparable age and size, but were slightly more rapid. The model was also validated through tests of its stability to changes in prices and other parameters, comparing shadow prices with prices in the model; some of these validation results appear later in this section as policy simulations or are referred to in the discussion in the section below on model sensitivity to changes in parameters.

[41] The supply of Brazil nuts is directly linked to the amount of forest cover remaining on farms. The 1994 survey data used to identify farm types were also used to estimate Brazil nut offtake.

**Figure 18. Baseline land uses of a typical smallholder over 25 years**


scenario and plays an important role throughout: once the milking herd is established (say by year 10), roughly 77% of income is derived from dairy operations. These occupy an average of 42% of available household labour in each month except May, when pasture and animal care account for 128% of available household labour, implying that 15 person-days (the maximum allowed by the model) must be hired in. Beef production emerges in year 9, and its contribution to income peaks in year 18, when it represents 25% of household income but on average occupies just 4% of available household labour each month.

Labour emerges as a critical determinant of land use and deforestation. Unlimited labour supply at 1994 wage rates would lead to rapid and complete deforestation. The 15 person-day per month constraint on hiring in and out reflects the fact that labour markets are not perfect in these remote areas. Labour can be hired in and hired out simultaneously in a given month, but only adult male labour. In addition, some tasks can be performed only by adult males. Households generally cannot hire as much labour as they might choose to and can afford. The model suggests that the households will generally take maximum advantage of off-farm labour opportunities, almost regardless of season.[42]

Farm profits (consumption plus savings; the latter can be negative) are net of the cash value of basic food needs and the cash required for minimal living expenses, with minimum consumption in the model determined by regional food habits and household size.[43] Savings

[42] Wages vary seasonally in the model: during peak season months (May and June), the daily wage is R$ 7; in months when demand is relatively high (March and April), it is R$ 5.60 , and in the off-peak months it is R$ 3.70. When the household hires labour, an additional 12.5% per day is added to reflect supervisory costs.

[43] Households were asked how much they spend per month on fixed cost items, such as sugar, salt, cooking oil, clothes and hoes. Households are required to have sufficient food (either in kind or in cash to purchase it) to feed family members each season (seasons were 6 months long, one ‘rainy’ and one ‘dry’). Borrowing (i.e. negative savings) to meet consumption needs is allowed, but must be repaid by the end of the calendar year in which the loan is taken out.

during the first few years allow subsequent investments that boost consumption in later years. Large investments (negative savings) are required in years 5, 9 and 11 to expand the pasture area. Nominal profits plateau in about year 13, at a level of approximately R$ 9000.[44] The NPV of the 25-year profit stream is R$ 50 635 (at a 9% discount rate), yielding an annuity value of R$ 2025 (R$ 50 635 divided by 25, the number of years in the simulation).[45]

For an average family (mean size 5.6 people), these profits (undiscounted) amount to R$ 1619 per capita per year once they hit their plateau, and approximately R$ 364 per capita per year when smoothed over the 25-year horizon. Although the model contains simplifying assumptions that make comparisons with profits from other sources subject to caveats,[46] this annuity figure falls considerably below the Brazilian 1995 per capita gross domestic product (GDP) of approximately R$ 3640, but above a World Bank (1997) estimate of the country's poverty line at R$ 269 per person (Faminow et al, 1999). This confirms the financial incentives for the poorest in Brazil to migrate to the western Amazon to establish farms. However, the costs and risks associated with migration itself would need to be taken into account before the picture is completely clear.

In summary, the baseline scenario suggests that, if nothing changes, the conditions facing smallholders in the western Amazon will result in the complete deforestation of their farms in about 25 years.[47] This typical farm would thus *fail* any test of environmental protection that requires that some of its area remain in primary forest. But it would *pass* a test related to sustaining livelihoods, as demonstrated by the increased and sustained flows of income generated by the combinations of agricultural, extractive and off-farm activities that are possible over the model's 25-year time horizon.

**Linking the regional and national economy**

In the past, much deforestation in the Brazilian Amazon was the result of public policies that promoted migration and the establishment of large-scale farm enterprises. While many of those policies are no longer in place, they are being replaced by other policies and/or economic trends that may have even greater impacts on deforestation, land use and human well-being in the Amazon. Among the recent events whose impact needs to be analysed are:

- A major devaluation of the Brazilian real and structural adjustment following an exchange rate crisis;
- Improvements in regional integration in the Amazon; and
- Changes in agricultural technology outside the Amazon region.

Studying the impact of such phenomena requires an economy-wide view, since economic activities in other sectors and regions of the Brazilian economy are increasingly linked to those

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[44] This figure and the rest in this report are in 1996 prices, when the Brazilian real was worth about US$ 1 (World Bank, 1997).

[45] The 9% discount rate was selected in consultation with local researchers and farmers, and does not reflect variation among smallholders in the cost of capital due to varying circumstances and access to credit. The sensitivity analysis below, however, reveals that the land use patterns seen in the baseline scenario were robust across a range of discount rates.

[46] The profits calculated in the baseline scenario may fall in the upper range of probable conditions on the ground, given that the model does not account for risk and does not incorporate results for farmers more distant from markets (described in Carpentier et al, 1999). Additional profits could, however, come from realistic off-farm investment opportunities, which are not currently an option in the model. The simulations presented here do not explicitly involve changes in these variables.

[47] Recall that this rate of deforestation may be an upper limit because of assumptions regarding risk and farmer turnover, plus the fact that the model depicts only farmers relatively well situated in relation to markets (roughly half our sample).

in the Amazon. Moreover, since the Amazon now contributes approximately 11% of national GDP, it is no longer simply a 'price taker' from—or a source of inputs to—southern Brazil.

To assess the impacts of major macro-economic policy changes on development in the Amazon, a regionalized computable general equilibrium (CGE) model was developed in which the Amazon, Northeast and Center-West regions and the Rest of Brazil (the aggregate of the South and Southeast regions) are identified as separate production entities producing for a single national market. Economic agents enter the model via production decisions, trade, migration and investment. Relative product prices, factor availability, transportation costs and available technology are all assumed to influence land use, as also are biophysical processes, which act in concert with changes ensuing from decisions made by economic agents. Agricultural production activities are disaggregated by region, sector and size of operation (smallholder, large-scale enterprise). A deforestation sector produces an investment good called 'arable land' which is complementary to agricultural production activities. Within the above framework, land uses and processes (including deforestation), incomes and wage rates (among many other aspects of the economy) can be estimated and differentiated by region.[48]

Since deforestation is a process, models assessing the impact of changes in policies, technologies and prices on deforestation must in one way or another deal with the issue of time. This CGE model does so by altering the amounts of factors of production (especially labour and capital) allowed to 'flow' across regions and across economic activities. In the simulations presented below, 'short-term scenarios' represent a situation of limited inter-regional and inter-activity labour and capital flows, while 'long-term' ones allow complete flexibility for factors of production to 'find' their most productive use.

*Exchange rate devaluation and structural adjustment*

The effects of a 40% reduction in the value of the real—close to what happened during the 1999 Brazilian financial crisis—were examined. Generally speaking, a major devaluation dramatically increases the value of internationally traded goods relative to non-traded goods, together with the returns to land, labour and capital involved in the production of traded goods. Consequently, demand declines sharply for products that depend heavily on imported inputs and are consumed domestically. Results suggest that nationally:

- GDP decreases: aggregate economic activity declines by about 5.5%.
- Poverty increases in the urban sector of the economy: under the current government response plan, the real income of poor urban households falls by 5.8%, while for medium-income urban households the decline is 4.2% and for high-income households 1.3%. In contrast, low-income rural households *gain* 15% and medium-income ones 12%. In other words, income distribution improves in rural areas and worsens in urban areas.
- Future growth may be undermined: investment declines by 15% under the current plan, whereas it could have decreased by up to 68% if no action had been taken by government to fill the investment gap left by the flight of foreign capital.
- The production of tradable agricultural goods increases: these goods include coffee and other perennial crops, along with sugar, soy, horticultural products and other annual crops.

The specific implications of the 40% devaluation for the Amazon region are:

- Deforestation rates depend on the government response plan: if the government succeeds in making up the shortfall in private consumption by increasing public expenditure, deforestation rates should decline in the short term (-10%) and increase slightly in the long term (2%). On the other hand, a scenario of government inaction and capital flight would probably lead to a 6% increase in deforestation in the short term and to a substantial increase in the long term (20%, equivalent to an increase of 4000 $km^2$/year).

[48] For a detailed description of the model and the results of model simulations, see Cattaneo (forthcoming).

- Logging increases: logging in the Amazon increases by 16% under the current government plan and by 20% if no action is taken.
- The Amazon fills the gap in domestic agricultural demand created as other regions shift to export crops: agricultural expansion in the Amazon centres around the production of a variety of annual crops and livestock, as other regions expand the area dedicated to coffee, soybeans, horticultural products and sugar.

*Reduced transport costs*

The Brazilian government's strategy for Amazonian development, articulated in its Avança Brasil plan, includes an ambitious programme of infrastructure investments amounting to US$ 45 billion over the next few years (1999 to 2006) (Government of Brazil, 1998). Assuming this programme generates a 20% reduction in transport costs for all agricultural products from the Amazon, deforestation rates will increase by approximately 15% in the short term and by 40% in the long term. The return to arable land would increase, thereby increasing the incentive to deforest. The increase in the profitability of agriculture in the region would lead, in the long term, to a 24% increase in production by smallholders and a 9% increase in production by large-scale farms. However, welfare effects at the national level are likely to be very limited (nationally, rural households' incomes would increase by only about 0.6 to 0.9%), as increased production in the Amazon offsets production in other areas of Brazil.

*Technological change outside the Amazon*

The type and extent of technological change in agriculture occurring outside the Amazon could affect deforestation greatly. For example, model simulations of the technological innovations that have already occurred (between 1985 and 1995) indicate that these have lowered annual deforestation rates by between 6% to 17%. This suggests strongly that agricultural innovation outside the Amazon could help conserve forests.

Where such innovation occurs is, however, less important than the sector in which it occurs. Improvements in cattle production technology outside the Amazon would decrease deforestation in the region, while productivity increases in annual and perennial tree crops would tend to increase it, wherever they occur outside the Amazon. The impact of widespread technological change in agriculture occurs mainly through changes in the terms of trade for agricultural goods produced in the different regions and the flows of labour and capital in response to these changes.

When technological change was considered separately for each region and sector, livestock improvement in the Northeast emerged as a possible win-win proposition, since it would improve income distribution between small-scale and large-scale farms in the Northeast, have only a small negative impact on national agricultural income, and reduce deforestation rates in the Amazon. All other improvements involve much starker tradeoffs. For example, technological change occurring outside the Amazon at the same pace for all agricultural activities causes the largest decrease in the deforestation rate, but comes at the expense of agricultural incomes in the Amazon. The effectiveness of this scenario in slowing deforestation is due to the fact that no factor or activity is 'pushed' into the agricultural frontier in the Amazon.

# 7. Promoting sustainable intensification

## 7.1 Entry points for policy action

The land use flow diagram that emerged from the field data analysis (Figure 5, Section 1.6) demonstrated the limited number of land use options actually being deployed by smallholders in the western Brazilian Amazon. Farmers' adoption concerns, as presented in the ASB matrix (Table 13, Section 4), provided the insight as to why this was so: the very low profitability of traditional forest extraction compared with all other forms of agriculture sound the death-knoll for the forest, while labour scarcity combined with ease of adoption lead inexorably to the spread of the traditional pasture/cattle LUS. Can either or perhaps both of these patterns be altered, and if so, how and with what consequences for deforestation and farm household income?

It is possible to increase the profitability of forest extraction, but policy changes and large institutional investments will be needed to make this happen. The ASB matrix highlighted the potential of small-scale managed forestry to boost the returns to forest-based activities in ways that are compatible with household labour constraints. If this LUS were introduced alongside the necessary institutional and organizational changes, it would enable forests to 'compete' more effectively with agricultural alternatives.

The ASB matrix also demonstrated the profitability of several other LUS besides traditional pasture/cattle, some of which—the tree-based systems—also ranked relatively high in terms of carbon sequestration. Most of these systems already form part of the landscape, but none has been broadly adopted. Again, the ASB matrix points to why this might be so: the coffee-based systems require too much labour to manage. Improved transport infrastructure and modifications to labour laws could reduce labour costs, especially the transaction costs associated with hiring labour. Finally, policy action can help relieve the two major constraints to the more widespread adoption of improved pasture/livestock systems, namely credit limitations and farmer knowledge.

However, with the exception of small-scale managed forestry, policy action to enhance the adoption of all LUS risks increasing deforestation, since increased profitability only increases the incentives to deforest. Improvements in the enforcement of existing laws could help protect the forest, but would require unprecedented policy action.

It is sometimes argued that extending the life of other activities along the pathway from forest to pasture would benefit farmers and take some pressure off the forest. For example, annual cropping, usually done for at most 2 years on a given plot, might last 4 years with improved seeds and/or soil management practices. Since farm households usually manage only one plot of annual cropped land at a time, this might, it is argued, extend the periodicity of deforestation from about every other year to every fourth year. Alternatively, legumes could be used to speed up the ability of fallows to regenerate the productive capacity of soils, thereby increasing the frequency with which a plot could be used for annual crop production. Having one or more such plots continually available for annual crop production would ease the demand for newly deforested land. This would require technological options that improve soil productivity in the cash- and labour-scarce western Brazilian Amazon. Even if such options were available, however, they might miss the mark, since farmers deforest largely in order to increase the amount of land dedicated to other uses (such as perennials or pasture). Policy measures that target only the annuals part of the land use trajectory will probably not be effective in reducing deforestation.

Modelling exercises that build on knowledge of current land use patterns to simulate the probable effects of policy changes on farmer behaviour and the broader economy can help reveal which policy and technology options could have unintended effects in terms of deforestation (and how large these effects may be). This in turn can point the way towards more appropriate targets for policy and technology innovations.

## 7.2 Evaluation of options: farm-level bio-economic model

This subsection reports the results of policy experiments run using the farm-level bio-economic model. In each case, one or more important parameters and/or constraints in the model are modified for the entire 25-year simulation period. The experiments were designed to assess the farm-level consequences of the following policy shifts: (a) effective implementation of the 50% rule; (b) direct payments to smallholders for retaining forest; (c) permitting small-scale managed forestry; (d) the complete absence of technological change in agriculture; and (e) an array of fertilizer subsidies.[49+50]

The following subsections present these experiments and discuss their implications for land use and other factors in relation to the baseline simulation.

### The 50% rule

The baseline simulation did not ‘enforce’ the federal law prohibiting deforestation beyond 50% on small-scale farms. Introducing this prohibition into the model (while also maintaining the prohibition on timber sales) greatly alters the land use outcomes obtained using the baseline simulation (Figure 19). If 50% of the forest is maintained, the farmer allocates virtually all remaining land to the pasture/cattle system, with the area dedicated to annual crop production decreasing sharply and that in cassava remaining roughly constant. Secondary fallow follows annual crop production up to about year 15, then expands slightly. In short, when prohibited from deforesting more than 50%, the farmer is forced to choose between pasture and annuals (plus the fallow needed to support them) and finds pasture more attractive.

With these limits on deforestation, average annual profits fall to about R$ 7000 (R$ 2000 less than in the baseline scenario). Labour hiring patterns change drastically: labour is hired for tree felling only up to year 9, after which hiring falls to zero until small amounts of labour are again hired for felling secondary fallows after about year 18. The household makes almost full use every month of the option of hiring out up to 15 person-days of labour. Perhaps most importantly, the composition of cattle production changes markedly. While the size of the dairy herd remains roughly the same as in the baseline scenario, under the 50% rule scenario no beef production is undertaken. This is because dairy production is more profitable and when pasture availability is constrained all the available land and labour are devoted to the more profitable enterprise.

For society as a whole, the private financial losses incurred by small-scale farmers are at least partially offset by increases in carbon sequestered and biodiversity preserved. Using mean values for carbon measurements in specific LUS (Palm et al, 2000), the typical farm would, by the end of the 25-year period, double carbon stocks from 4120 tonnes under the baseline

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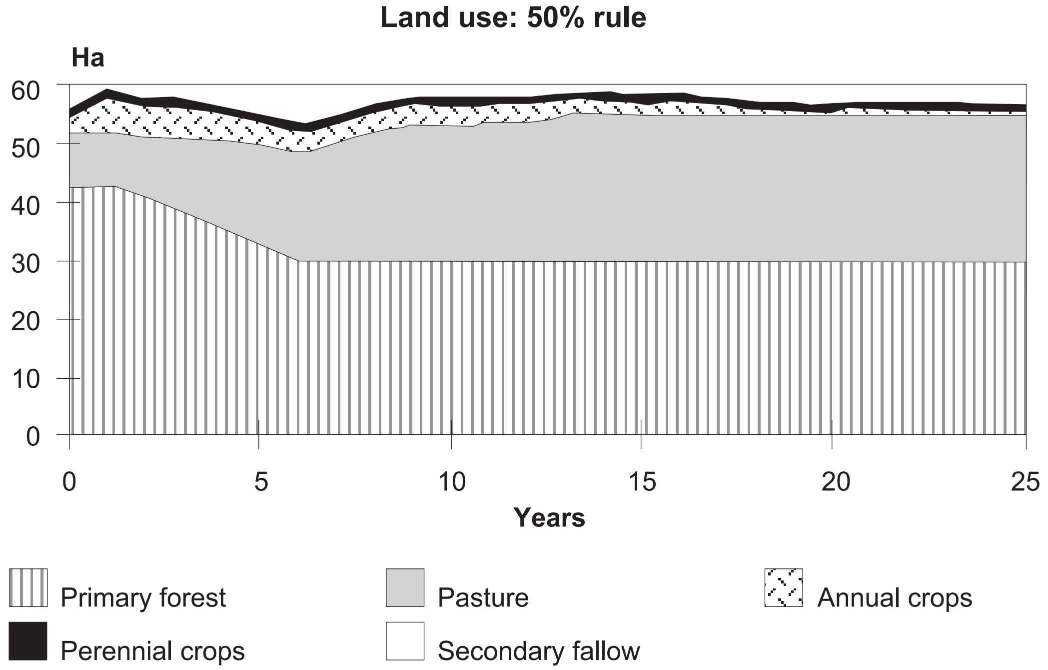
[49] All the policy experiments reported here use 1994 prices. The same experiments were run on an alternative baseline using 1996 prices, with similar effects.

[50] Additional policy experiments were run using the farm-level bio-economic model. For a more complete set, see Vosti et al (2002).

**Figure 19. Policy experiment 1: implementing the 50% rule**




scenario to 8140 tonnes under the 50% rule scenario.[51] The total private cost to our typical farmer of this policy is estimated to be R$ 6475 (R$ 50 635 minus R$ 44 160).

### Subsidizing forest conservation

Once the issue of compensating farmers for income losses linked to regulatory policies (for example, the 50% rule) is up for discussion, other compensation schemes can be considered. For example, policy makers might decide to pay farmers on a per hectare (of forest) or per tonne (of carbon) basis to retain forested areas. Alternative uses for forested land (and their expected returns) will determine the appropriate price that will maintain a certain amount of land in forest. In the baseline scenario, the private value of the forest under current policy, price and technology conditions is low (the net value of extractive activities per year is about R$ 2.25 per ha) and leads to complete deforestation in about 25 years. Deforestation and the use of cleared land would change as depicted in Figure 20 if farmers were offered R$ 100 per ha per year (or about R$ 70 per tonne of carbon per year) for retaining forests. Deforestation would be slowed significantly compared with the baseline scenario and the stock of forest retained in year 25 would be 15.6 ha (compared with zero).

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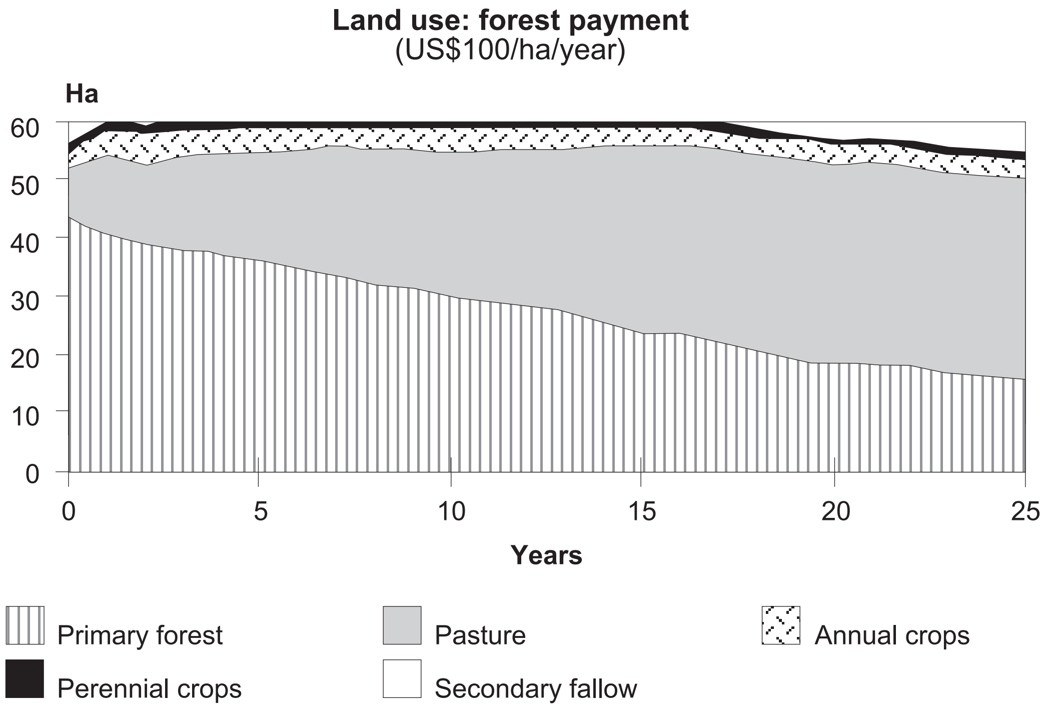
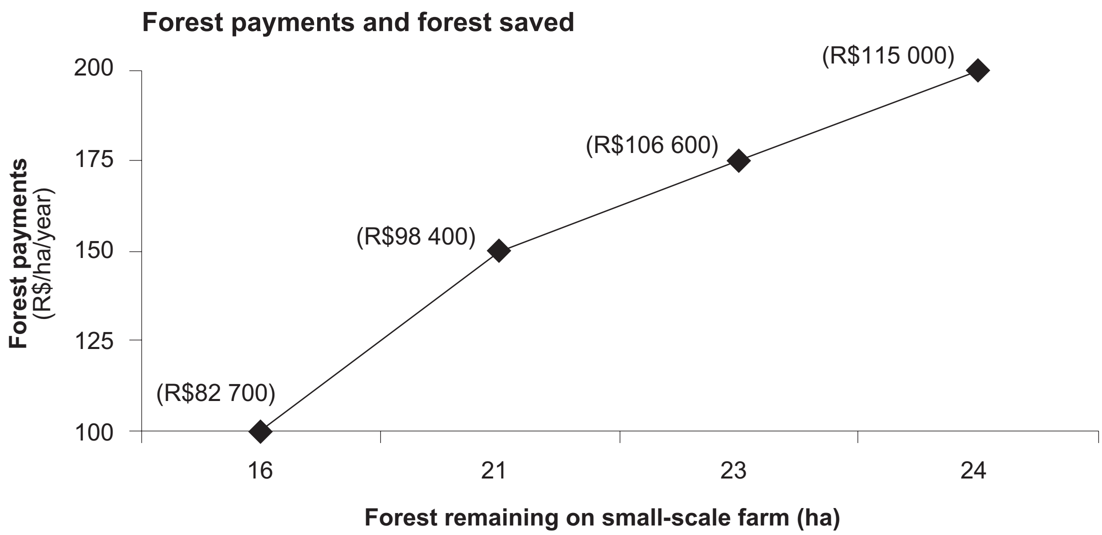
[51] Calculated as follows: (0 ha x 206 t/ha for forest) + (50.6 ha x 65 t/ha for pasture) + (3.7 ha x 72 t/ha for annuals) + (1.1 ha x 72 t/ha for cassava) + (4.6 ha x 84 t/ha for secondary forest fallow) = 4021 t for the baseline scenario. Using the same method (and the same order of land uses), but different areas, derived from the 50% rule: (30 ha x 206 t/ha) + (25.2 ha x 65 t/ha) + (1.1 ha x 72 t/ha) + (2.9 ha x 84 t/ha) = 8141 t. The carbon savings implied by the 50% rule are thus 8141– 4021 = 4120 t. The carbon amounts used here come from measurements taken in Acre by ASB Brazil via Divonzil Gonçalves Cordeiro (see Vosti et al, 2002, for details). Perennials with cycles longer than cassava (for example, coffee) had slightly higher carbon measurements (80 t/ha).

**Figure 20. Policy experiment 2: paying farmers to retain forests**




Several additional simulations were run to gauge smallholder response in terms of forest retained at higher per hectare (or per tonne) prices. Figure 21 presents the results in terms of the stocks of forest retained in year 25 at different per hectare prices paid to farmers. Doubling the price (to R$ 200 per ha per year) would lead to about a 56% increase in forest retained in year 25—an own-price elasticity of 0.56. The per-hectare compensation would lead to large increases in household income (reported in parentheses in Figure 21).

**Figure 21. Amount of forest saved at different per hectare payment levels**

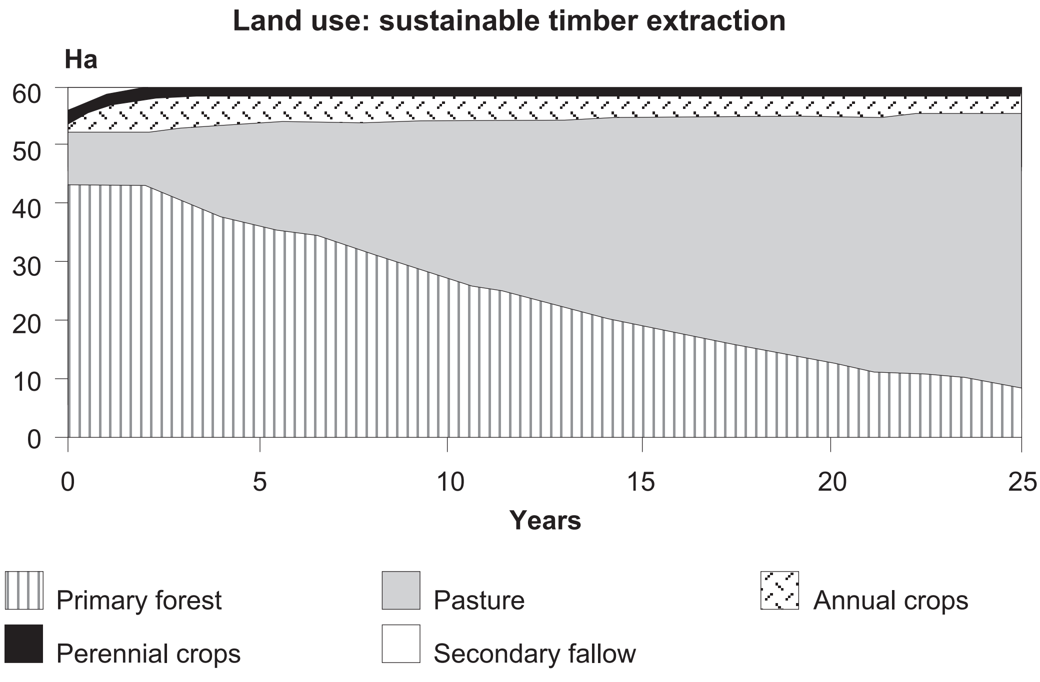


**Small-scale managed forestry**

Attempting to enforce the 50% rule would be difficult and expensive in Brazil, particularly because farmers have strong financial incentives to behave differently, as the scenarios above imply. Increasing the financial returns to forest activities could reduce reliance on regulations to slow or halt deforestation (Browder et al, 1996; Uhl et al, 1991), but only if returns are sufficient to alter land use patterns, given the demonstrated profitability of annual crop and cattle production. The model simulated the simultaneous removal of the 50% rule and the adoption of sustainable timber extraction from private forests.[52] Land uses resulting from this simulation appear in Figure 22. The land held in forest by year 25 is approximately 10 ha (versus the baseline of zero area in forest by year 25). The area in annual and perennial (cassava) crop production resembles that in the baseline scenario, but the amount of land in fallow goes to zero if sustainable timber extraction is allowed. In summary, when sustainable timber extraction is possible, more forest is retained, fallow is eliminated and pasture is slightly reduced.

The managed forest scenario also generates differences in other relevant parameters. Both seasonal labour hiring patterns and the absolute numbers of person-days hired change. Much more labour is hired generally (still subject to the 15 person-day per month limit), and seasonal labour use reflects large increases in the manpower dedicated to timber extraction over the May-September period (dry season), concentrated in July and August (due to fewer competing

**Figure 22. Policy experiment 3: small-scale managed forestry**



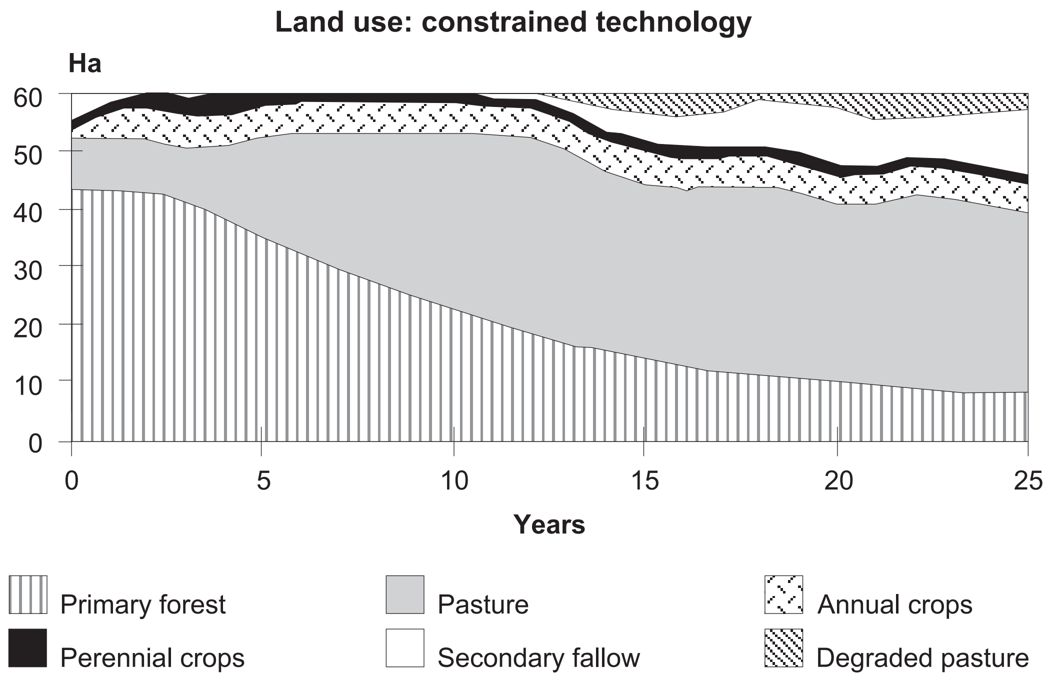

[52] Technically, managed forestry can be legally pursued in Brazil. However, detailed management plans must be submitted to gain official approval, and preparing such plans is generally beyond the abilities and means of smallholders. This simulation limits the offtake of timber products to a predetermined rate (10 $m^3$ of timber from selected trees per ha per year) judged by foresters to be sustainable over a 30-year wood production cycle. No effort was made to assess the financial wisdom of adhering to this limit (an indicator of how difficult enforcement might be) (Araujo, 1998; Embrapa, 1999b; Santos et al, 1999).

activities on farm). Engaging in small-scale managed forestry increases farm income, especially during years 5 to 9, prior to which substantial start-up costs reduce cash flow. The NPV of profit under this policy experiment is approximately R$ 55 000, against a baseline figure of R$ 50 635—a gain of about 10%.

### Technological decay: a default scenario

The model can also contribute to the debate about whether the introduction of new technologies can take pressure off the forests or will actually increase deforestation, and what the implications are for farmer welfare (Carpentier et al, 2000). Figure 23 depicts the land use and deforestation patterns that emerge by making the model allow farmers to adopt only the most basic (but still frequently observed) technologies for deforestation, ranching, extractive activities and annual crop production. The area in pasture is considerably lower than under the baseline scenario, and roughly 10 ha remain in forest in year 25. The area dedicated to annual and perennial crops expands, with a large increase in secondary fallow beginning in about year 13.

**Figure 23. Policy experiment 4: no technological change in agriculture**




These changes in land use bring dramatic changes in other key variables. Average (undiscounted) annual farm profits fall by approximately 80% (to R$ 1381, compared with R$ 6979). Income sources shift dramatically towards annual crops (which provide approximately 50% of the NPV of total output, compared with about 20% under the baseline scenario). Beef cattle production begins in year 5 instead of year 9, though the proportion of beef cattle to milk cows remains similar to that of the baseline. The technologically constrained farm requires less labour than does the baseline farm, except during February, March and April, when labour amounts roughly equal to those in the baseline scenario are allocated almost exclusively to annual crop production. The policy implications are clear: *depriving small-scale farmers of new technologies and better market access will slow deforestation over the short and medium terms, but this environmental gain carries with it large reductions in farm income and welfare.*

**Subsidies for chemical fertilizers**

If, as is sometimes alleged, small-scale farming operations at the margins of tropical moist forests are primarily nitrogen-harvesting processes, whereby farmers convert standing forest into soil nutrients for agricultural production, then identifying alternative and cheaper sources of soil nutrients could take the pressure off standing forests. Scenarios that gradually reduce the price of chemical fertilizers from their 1994 market price to 50% or 25% of that price, or even to zero (making this input free to farmers) were compared with the results using the baseline scenario (with fertilizer prices approximately R$ 1.20 per kg).

The results of a simulation involving a 50% reduction in fertilizer prices (Figure 24) and a second simulation in which fertilizers are provided free to farmers (Figure 25) appear below. A 50% reduction slightly reduces deforestation rates, but the end effect on the stock of forest in year 25 is quite small (only 2.2 ha). The NPV of farm household profit increases to R$ 55 248 (from R$ 50 635 under the baseline scenario).

More striking is Figure 25's depiction of land use patterns under the free-fertilizer scenario: only about 7 ha remain in forest by year 25 and other land use patterns remain about the same, but the NPV of profit rises to R$ 77 115. For this group of land owners at least, the results do not support the nitrogen harvesting (or biologically driven) rationale as the primary driving force behind smallholder deforestation, but rather point to demand for cleared land. Thus, *efforts to increase on-farm nitrogen availability via improved fallows or fertilizer subsidies are not likely to slow deforestation,* although they may boost incomes.

## 7.3 Evaluation of options: economy-wide model

Simulations using the economy-wide model presented in Section 6 focused on examining trends in deforestation and land use based on policies in effect and technologies available during the study period. In what follows, we report the results of simulations run to examine

**Figure 24. Policy experiment 5: 50% reduction in fertilizer costs**

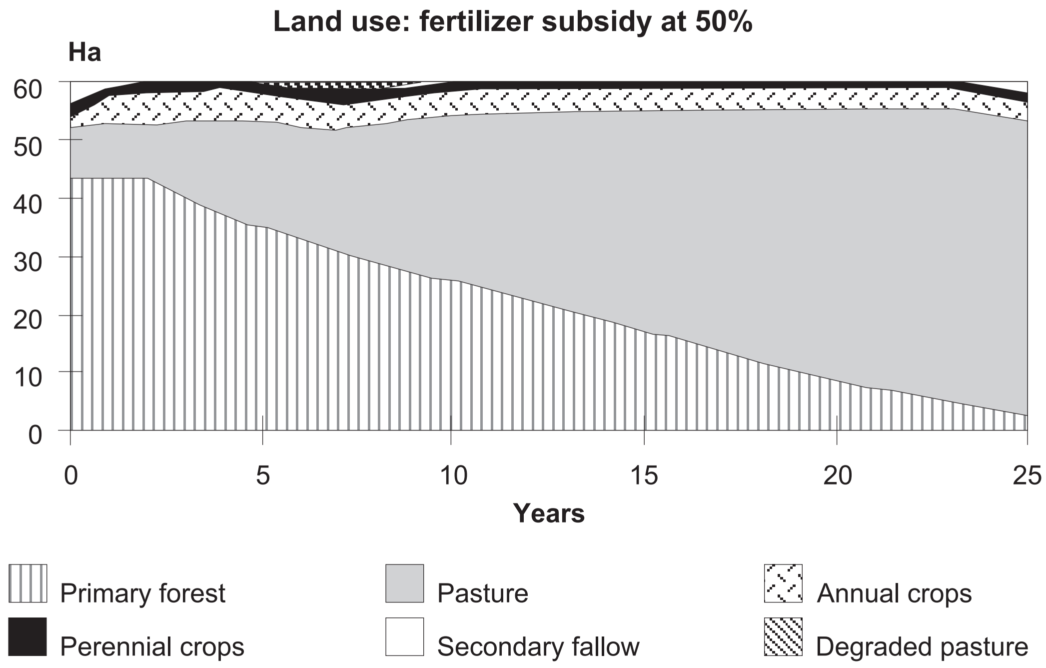
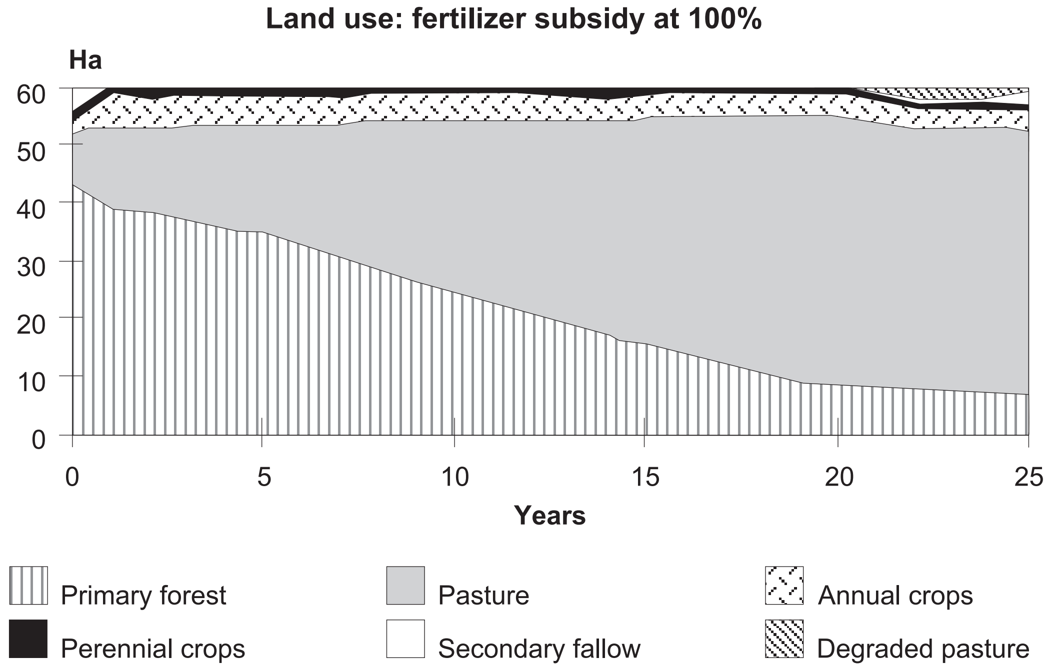


**Figure 25. Policy experiment 6: free fertilizer**




alternative policies regarding technology within the region and the financial incentives to conserve forested land.

## Technological change in Amazonian agriculture

Agricultural technologies play an important role in determining the relative profitability of alternative land uses, and hence of deforestation. The model was used to examine the effects of the following policy-induced technological innovations, assuming they were widely adopted:

- *Improvements in pasture/cattle management systems.* These generate large financial returns for all agricultural producers in the Amazon and improve food security in the region. However, they also dramatically increase deforestation in the long run, provided labour is mobile.
- *Improvements in perennial crop technology.* These reduce deforestation considerably, especially if the productivity of labour is increased. However, the reduction is muted in the long run if labour is mobile. *The equity effects of improving perennial crop technology would be progressive: small-scale farmers' incomes would rise disproportionately.*
- *Improvements in annual crop technology*. These have little potential in the region, would probably increase deforestation in the short run (with some reductions in deforestation in the long run if levels of intensification were very high), and would have minimal income effects.

## Financial incentives to farmers to reduce deforestation

A final set of simulations was run to assess the effects on deforestation and land use of taxes and transfer payments aimed at correcting prices for the non-market benefits and costs stemming from different land uses. Applying a logging tax in the Amazon, even taking into consideration the link between logging and deforestation, would *not* lead to a decrease in the deforestation rate, but it would have a considerable negative impact on the logging industry. A deforestation tax, on the other hand, would prove more effective: in the case of a tax of R$ 50 per ha on deforestation (equivalent to a 0.25 R$ per tonne carbon tax), deforestation would be reduced by approximately 9000 $km^2$ per year, with logging being only minimally affected. Extractive activities and agents pursuing them would gain from this tax and would expand output by about R$ 60 million (a 25% increase). Smallholder incomes would, however, be reduced by this policy.

An alternative would be to support forest conservation by subsidizing the extraction of non-timber forest products (NTFPs). Simulation results suggest that a subsidy of R$ 240 per ha to NTFP activities would reduce deforestation by approximately 30%; a subsidy of R$ 150 per ha would lead to a 12% reduction, while R$ 360 per ha would bring about a 50% reduction. *From a welfare standpoint, all regions of Brazil stand to gain from NTFP subsidies, especially the Amazon.* Even at the highest subsidy rate, which would total about R$ 388 million in payments to NTFP producers, the nationwide market benefits (R$ 481 million, in this case) would be more than sufficient to cover the costs of the subsidy. As in the case of the deforestation tax, if an Amazon-wide reduction in deforestation rates were to be promoted under the Kyoto Protocol, interesting options for trading under the protocol’s Clean Development Mechanism (CDM) would be opened up by introducing the conservation subsidy. The subsidy is equivalent to a payment of R$ 1.2 per tonne of carbon, which is much lower than the marginal cost of reducing emissions in developed countries.

# 8. Impact: local action, global lessons

This study has revealed no single recipe for success in saving the Amazon while raising farmers' incomes. Rather, it has identified the tradeoffs between different options, pinpointing the need for policy, technology and institutional changes if those options are to be effectively realized. The sustainable intensification of agriculture without continued deforestation may be possible in the Amazon, but it requires real economic and policy incentives as well as the appropriate technological base and marketing infrastructure to support such a development path. Research and policy action can increase the chances for sustainable intensification, but considerable capital investment will be required. The following section summarizes some promising steps in this direction, taken by researchers and farmers working together at the local level.

## 8.1 Technology and policy breakthroughs

Supported by ASB, Embrapa scientists have taken the lead in finding ways of striking the much-needed balance between agricultural development, poverty reduction and environmental protection. While Embrapa has continued its research on the economics of traditional agriculture on cleared land, it has expanded its work on the development and testing of new technologies to include those that can be practised on forested lands, reflecting increased awareness that adding value to the forest is fundamental to saving it. In addition, Embrapa has broadened its focus from crops and practices imported to the region from other areas of Brazil, such as upland rice and bean production, to those involving native species, primarily woody perennials. Examples include the cultivation of *Pimenta longa*, a native bush containing important essential oils used in the manufacture of perfumes and biodegradable pesticides. Research on these emerging products focuses not only on sustainable cultivation but also on post-harvest processing and marketing issues.

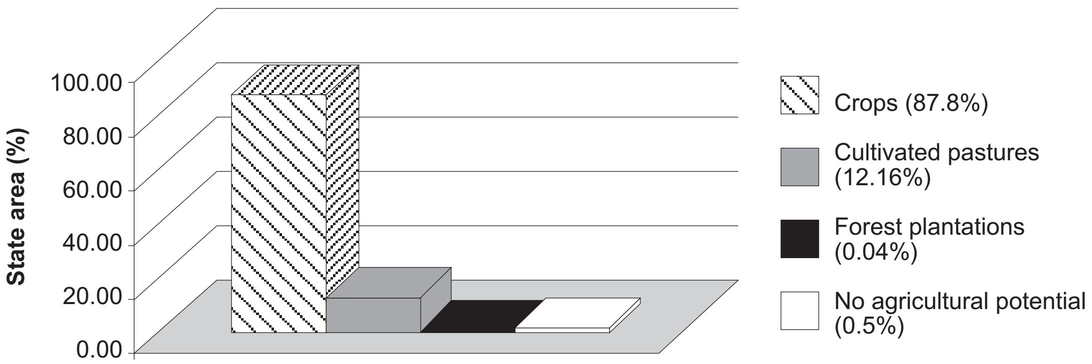
Given the demonstrated attractiveness to local smallholders of dual-purpose cattle ranching, Embrapa is also leading special efforts to make these systems more agronomically sustainable, with the intention of limiting the need and incentives to expand pasture land. For example, research on the use of solar-powered electric fences for managing pastures and cattle herds is under way with the Ramal da Enco farmers' association in Acre. Preliminary results suggest that pasture carrying capacity can be increased and pasture life extended by using these fences, which are relatively inexpensive to establish and maintain (Valentim et al, 2000 and personal communication). To take another example, new legumes (e.g. perennial peanut, *Arachis pintoi*) are being tested to replace tropical kudzu (*Pueraria phaseoloides*), which does not persist under intensive grazing with stocking rates above 2.5 animal units per ha.

Embrapa's contribution to local, state, regional and national policy debates has also been strengthened, allowing it to offer more concrete policy advice on a broader array of issues and to help avoid costly policy mistakes (Valentim and Vosti, forthcoming). In most cases, the mechanisms for Embrapa's input into policy making predate its collaboration with ASB, but it was the ASB programme that helped bring policy implications to the forefront in research design and that seeks to extract policy-relevant lessons from all research projects. The predictive power of the household and economy-wide models developed by ASB has given Embrapa a more credible voice in policy debates. The following are examples of the types of policy debate to which Embrapa is contributing.

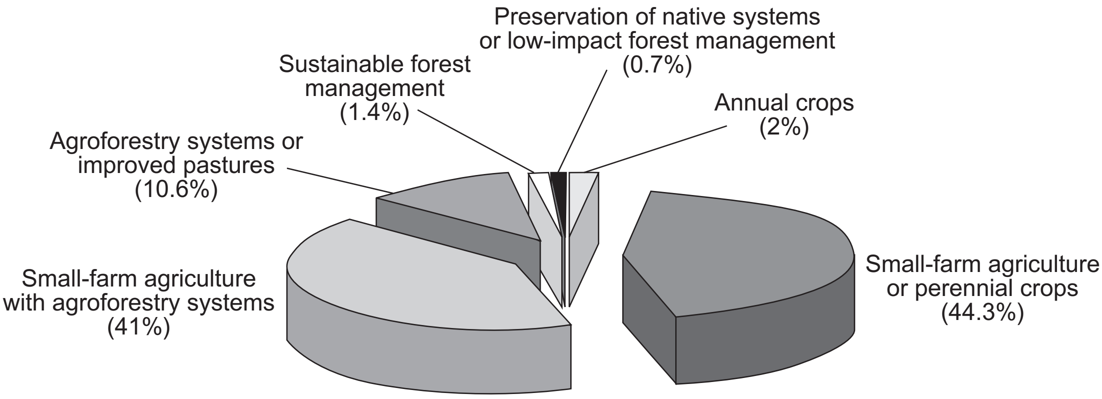
Land use zoning was undertaken during the early period of modern occupation in Acre and the resulting recommendations appear in Figure 26a. At that time, much of the state's land was deemed suitable for nearly any type of agricultural pursuit, on any scale. An Embrapa-led re-evaluation of land use potential (carried out with some ASB assistance) revealed a very different set of land use options, this time highlighting the limits to traditional large-scale agriculture and the major role that small-scale farmers, agroforestry and forestry should play (Amaral et al, 2000; Figure 26b). This updated land use assessment is one of the cornerstones of state development planning and policy making today.

**Figure 26. Impact of Embrapa and ASB in changing land use recommendations, 1970s (a) and 1999 (b).**

(a) **Land use potential in Acre in the 1970s**




(b) **Land use potential in Acre in 1999 (% area)**




Source: Amaral et al (2000)

A separate set of Embrapa-led land use zoning exercises has helped identify large areas where subsoil impediments to drainage are causing the death of *Brachiaria brizantha* pastures (Valentim et al, 2000). Research is under way to identify replacement grasses for this very commonly used species.

Embrapa is routinely asked to provide suggestions for targeting subsidized agricultural credit in the region. In Rondônia, Embrapa studies on the constraints to small-scale coffee and milk production have resulted in increased support (both technical and financial) for farmers wanting to engage in these activities but unable to do so because of labour, credit and technology constraints. On the basis of results of collaborative research, Embrapa has now proposed that farmers or farmer cooperatives planning to implement small-scale managed forestry schemes be eligible for special credit from a fund managed by the Amazonian Regional Bank. Ongoing studies of agroforestry systems are attracting increasing attention to these promising best bet LUS, which can provide both global environmental services and poverty reduction.

In May 1999, the Federal Government of Brazil and the State Government of Acre organized a workshop involving government and non-government organizations and representatives of the private sector to discuss a 'Positive Agenda for the Brazilian Amazon', aimed at addressing growth, poverty and environmental issues. Embrapa was asked to provide the scientific and technical basis on which regional and state-level policies could be developed. Research results, methods and experiences emerging from the collaboration with ASB greatly assisted Embrapa in this task. The most important proposals to emerge from the workshop were:

- To seek to decrease deforestation rates in Acre;
- To establish a targeted amount of cleared land, initially set at 14% of total state area, to be reached by the year 2020; and
- To establish policy disincentives to convert forest for agricultural purposes, and policy incentives to reclaim degraded land and increase the efficient and sustainable use of forests.

Although it attracts less attention now than in the past, the formal colonization process in the region still continues, albeit on a much smaller scale than in earlier decades. The problems of where and how to settle smallholders and what sorts of support are required to increase their chances of success remain. Supported by ASB research results and tools, Embrapa is changing the way colonization projects are conceived and implemented.

For example, a settlement project recently approved for joint implementation in the Seringal São Salvador by Embrapa-Acre and other partners envisions land distribution, and land and forest use patterns, quite different to those implemented under traditional colonization schemes. In these schemes, land was allocated to farmers without much thought being given either to the characteristics of the natural resource base or to the socio-economic circumstances of migrant families. Legal reserve areas were established within individual plots and left for farmers to manage as they saw fit. In contrast, the new approach to settling smallholders pays much more attention to: (a) the *a priori* assessment of the natural resource base to determine land use potential and constraints; (b) the possibility that some land may not be suitable for settlement at all and should therefore be set aside for conservation/preservation; (c) the socio-economic circumstances of candidate families; (d) farmers' participation in planning and implementation; (e) the potential for delineating legal reserves so as to ensure that continuous blocks of forest remain in or around colonization projects; and (f) the management of these reserves for the sustainable production of timber and NTFPs. This approach reduces settlement costs and, in principle, limits deforestation to no more than 30% of the total colonization project area (as opposed to the 50% allowed in traditional schemes). Embrapa also played an important role in providing the scientific and technical support needed for the federal government's decision, in November 1999, to prohibit any further establishment of new settlement projects in the forests of the Brazilian Amazon.

Finally, Embrapa input, some of which was based on ASB research results and tools, has provided a sounder basis for establishing price policy at state and regional levels. For example, policy makers in Acre were contemplating a subsidy for upland rice and bean production, alleging that it would reduce deforestation. ASB/Embrapa research based on model simulations demonstrated that such a policy measure would *not* reduce deforestation, though it would improve smallholders' incomes. The choice was left to policy makers, but with the predicted impact of the proposed policy change more clearly articulated.

## 8.2 Lessons for other forest margin settings

The results of ASB-Embrapa research are relevant for small-scale farming not only in the western Brazilian Amazon but also in other areas with similar factor endowments—particularly labour scarcity and land abundance amid imperfect credit markets—and in the general economic context of growing but as yet incomplete links between farmers and markets. The research methods and tools developed and deployed for this study will be relevant for a broader set of circumstances in which the issues of poverty, environment and growth must be addressed simultaneously. These circumstances can be characterized as follows:

- *Agro-ecological zones and economic conditions.* Soils in the western Brazilian Amazon are poor, labour is scarce and the potential for intensive forest-extractive activities is limited by the low natural occurrence of commercially valuable products, and high storage and transportation costs. These factors, which characterize many forest margin areas in Latin America (and in other regions), were found to influence deforestation rates and the use of cleared land. This suggests that studies focusing on market analysis alone may omit important aspects of land use in remote areas in other developing country settings too. That said, the specific findings must also be placed in their proper overall economic and agronomic contexts. Our study sites are characterized by expanding links to markets with profit opportunities created by growing regional demand. However, differences in critical economic factors could make our findings less relevant in other settings.
- *Ranges of factor endowments.* Population densities in the rural areas of our study sites are low—only 3 people per $km^2$ for the state of Acre—but if policy efforts to reduce access to forest areas are successful, these densities will increase, to levels more in line with those of other areas in Brazil and in the developing world as a whole (for example, there are 33 people per $km^2$ in the medium-density areas of Cameroon). Policy makers throughout the humid tropics should be aware of such dramatic potential declines in land availability and should look outside their borders for clues as to how to manage this transition in ways that will protect the forest and sustain livelihoods.
- *Policy setting.* The western Brazilian Amazon is a frontier area, characterized by the general absence of strong government, lack of effective policy instruments, incomplete knowledge regarding the natural resource base and its possible uses, high transportation costs and a lack of public-sector institutions and services. We would expect the importance of communally based resource management, the length of time forest margin areas have been inhabited, and the distance to markets to alter the effects of changes in policy or technology on land use in other settings.

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