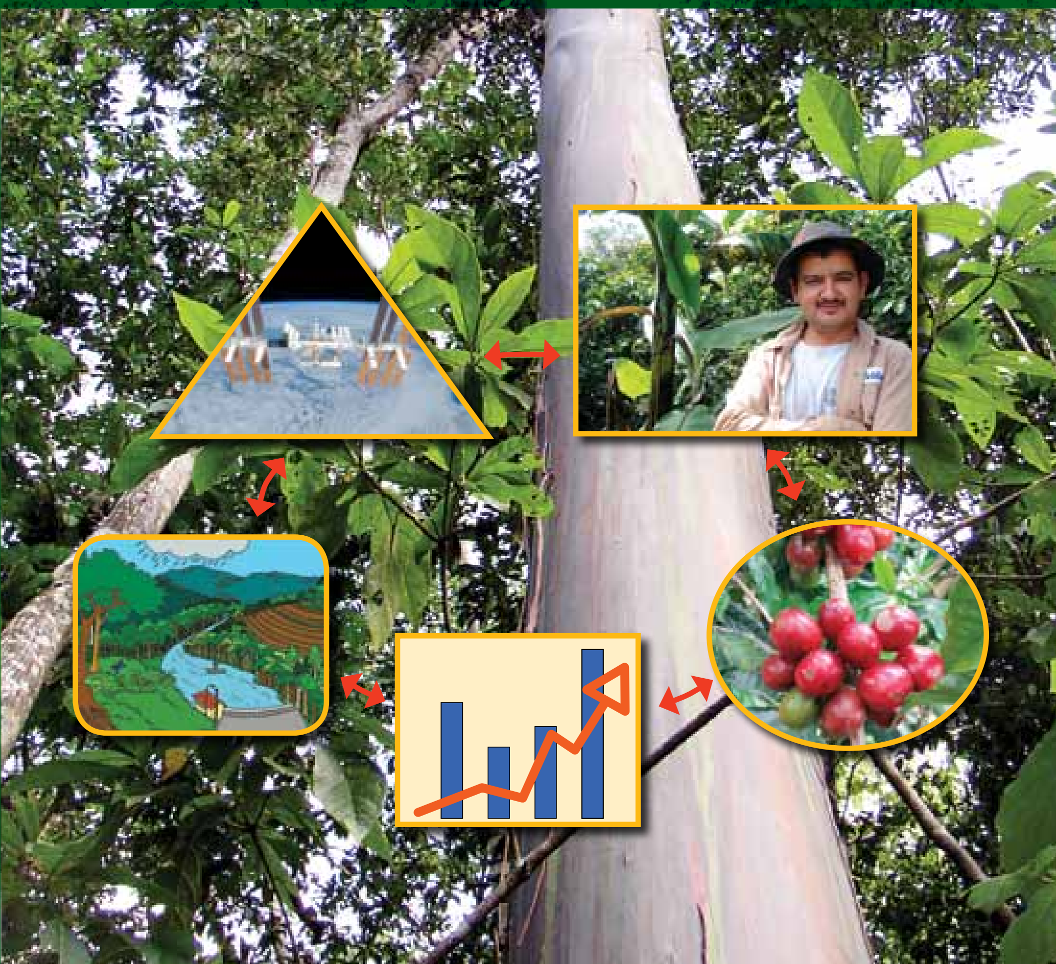
Modelling Agroforestry Systems

Workshop Proceedings

CATIE, Costa Rica, 25–29 February 2008

Editors: Bruno RAPIDEL, Olivier ROUPSARD,
Muriel NAVARRO



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All the following presentations are in English with abstracts in English and Spanish.

Mesoamerican Scientific Partnership Platform "Agroforestry Systems with Perennial Crops"

The Mesoamerican PCP was signed on April 2007 by CIRAD, CATIE, INCAE, CABI and PROMECAFE to increase the competitiveness and sustainability of the agricultural sector of Mesoamerica through the quantification, valuing and development of all the potential products and environmental services of agroforestry systems with perennial crops (in particular coffee and cocoa). At the end of 2007, Bioversity also joined the PCP.

This platform is an initiative to bring together scientists from the six partners to address these challenges as a strong, multidisciplinary, group and achieve significant research and developmental results.

The organization of the PCP is structured around:
ß Steering Committee with an official representative of each partner
ß Coordination Unit located in CATIE, Costa Rica
ß Scientific Team of researchers, experts and students around five main themes.

Theme 1: Agroforestry Systems (AFS) as providers of environmental services (including carbon sequestration, biodiversity, soil and water conservation)

Theme 2: Competitive, sustainable and diversified AFS management strategies (includes adaptation to suboptimal conditions and long-term environmental change)

Theme 3: Impacts of AFS on rural livelihoods

Theme 4: Strengthening small and medium farmers' business organizations for increased benefits from AFS

Theme 5: Improving value chains, markets and product differentiation of AFS products and their environmental services

Its budget comes from the partners, but one of the PCP goals is to increase the capacity of the partners in finding external funding for PCP activities.

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PCP Partners

Centro Agron mico Tropical de Investigaci n y Ense anza

Tropical Agricultural Research and Higher Education Center

CATIE is a regional nonprofit institution created in 1973 through an agreement between the Inter-American Institute for Cooperation on Agriculture (IICA) and the Government of Costa Rica. In alliance with local, national and international organizations, CATIE contributes to rural poverty reduction by promoting competitive and sustainable agriculture and natural resource management through higher education, research and technical cooperation. It has 13 member countries in Latin America and the Caribbean.

With 481 staff members and an annual budget of approximately USD 22 million, CATIE manages more than 100 research and development projects in 17 countries through the divisions of research and development, agriculture and agroforestry; natural resources and environment and the graduate education and training program.

The new themes promoted by CATIE are protected agriculture (greenhouses), climate change, adaptive co-management of watersheds, rural ecoenterprise development and integrated development of productive chains and value chains, ecosystems approach, resource management at the landscape level, payment for environmental services and restoration of degraded ecosystems.

Key expertise of CATIE for PCP: Agroforestry research and development, natural resource management, biodiversity assessment, development of certification schemes, teaching center.

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Centre de coop ration Internationale en Recherche Agronomique pour le D veloppement

Agricultural Research Centre for International Development

CIRAD is a research centre that specializes in Tropical and Mediterranean agriculture.

Its operations encompass the life and earth sciences, social sciences and engineering sciences applied to agriculture, forestry, animal production, food, natural resources and rural territories.

CIRAD has three scientific departments: Biological Systems (BIOS), Performance of Tropical Production and Processing Systems (PERSYST) and Environments and Societies (ES).

It has a staff of 1,800, including 800 researchers, who work with more than 90 countries worldwide. It receives and trains about 800 researchers and technicians from these countries each year. It has a budget of 203 million euros, with two-thirds provided by the French government.

Key expertise of CIRAD for PCP: Coffee and cacao, disease management, ecophysiology of tropical crops, cropping system design, biodiversity and connectivity, crop system modelling.

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CAB International

CAB International (CABI) is a not-for-profit organization specialising in scientific publishing, research and communication.

CABI improves people's lives worldwide by providing information and applying scientific expertise to solve problems in agriculture and the environment.

CABI started as a commonwealth organization in the early 20th century in a small way but soon developed into a world service in agricultural information, pest identification and biocontrol.

With more than 400 staff working from 10 locations around the world, CABI covers a broad range of subject areas within the life sciences: agriculture (animal production and welfare, horticulture, crop science and protection, applied economics and rural studies); environmental science (biodiversity, ecology and climate change, forestry, soil science, and hydrology); plant science, including biotechnology, plant biology, breeding and genetics, and plant protection); Animal and veterinary science (animal nutrition, welfare, parasitology and infectious diseases, aquaculture and equine science); microbiology and parasitology (mycology, bacteriology and virology); human health and nutrition (public health and communicable diseases).

Key expertise of CABI for PCP: Coffee, cocoa; IPM with biocontrol focus; biodiversity assessment; knowledge generation and dissemination; farmer training.

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INCAE Business School

INCAE is a private, nonprofit, multinational, higher-education organization devoted to teaching and research endeavors in the fields of business and economics aimed at training and instructing, from a worldwide perspective, individuals capable of successfully holding top management positions in Latin America.

INCAE was founded in 1964 by the business community and the governments of the Central American nations. Since its inception it has had the technical supervision of the Harvard Business School.

INCAE is presently focused on three key activities:
- Master's programs in areas critical for Latin American development
- Executive training programs and seminars
- Research projects on competitiveness in the region

Its mission is to promote the comprehensive development of the countries served, enhancing leadership skills within the key sectors by improving management practices, attitudes and values.

INCAE is present in Argentina, Bolivia, Brazil, Caribbean, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Germany, Guatemala, Honduras, India, Mexico, Nicaragua, Panama, Paraguay, Peru, United States of America, Venezuela.

Key expertise of INCAE for PCP: Business administration, marketing, supply chain management, policy assessment.

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Programa Cooperativo Regional para el Desarrollo Tecnológico de la Caficultura en Centroamérica

Regional Cooperative Programme for the Technological Development and Modernization of the Coffee Industry

PROMECAFE is a network of investigation and cooperation formed by the coffee institutions of Guatemala, El Salvador, Honduras, Costa Rica, Panama, Dominican Republic and Jamaica, along with IICA and CATIE.

Established in 1978, its mission is to cooperate with the partner organizations of the program to develop a coffee industry that is competitive and sustainable in aspects related to the development of agrobusiness, coffee quality, technological innovation and equity in the distribution of income, contributing to the reduction rural poverty, conservation of natural resources and environmental quality in all the countries of the programme.

The programme functions with the support of IICA, member countries, CATIE and CIRAD, along with support from the Common Funds for Commodity-International Coffee Organization (CFC-ICO); from the European Union (EU) and from the Regional Fund for Agricultural Technology (FONTAGRO) in specific projects.

Key expertise of PROMECAFE for PCP: Coffee production and transformation in Central America, federation of the Coffee Research Institutes of Central America.

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Bioversity International

Bioversity International is a nonprofit research organization dedicated solely to the conservation and use of agricultural biodiversity.

In 2006, the International Plant Genetic Resources Institute (IPGRI) and the International Network for the Improvement of Banana and Plantain (INIBAP) merged and founded Bioversity International, as a part of the Consultative Group on International Agricultural Research (CGIAR)-system.

Bioversity International has a staff of about 320 working in 16 offices around the world on projects in more than 100 countries.

Bioversity undertakes research aimed at improving people's lives through the use and conservation of agricultural biodiversity. The main themes developed are agricultural ecosystems; communities and livelihoods; conservation and use; crop wild relatives; economics; forests and trees; genebanks; germplasm collection, documentation, and health; neglected and underutilized species; nutrition; policy and law.

Key expertise of Bioversity International for PCP: Genotype, environment and post-harvest management for cocoa quality; soil, root and plant health and cropping systems in banana; knowledge platforms and networks.

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Introduction to the Workshop

Bruno RAPIDEL,[1,2] Olivier ROUPSARD[1,2] and Muriel NAVARRO[2]

Agroforestry was very probably the first form of agriculture in the world, when hunters and collectors gradually selected plants in the forest and reproduced them to produce food. Since then, agriculture has become more specialized and what we imagine under the word *agriculture* now are fields of pure crops. Resisting the specialization pressure, agroforestry systems have been maintained in multiple places of the developing world.

Nevertheless, acknowledgement of agroforestry as a major agricultural practice is relatively recent (about 40 years in CATIE, one of the pioneering research institutions on these systems). At its beginning, the published research was essentially descriptive: the goal was to elucidate the reasons why those systems resisted the pressure of the Green Revolution, measuring their productivity and resilience to factors of change. From a biophysical point of view, the concept of Land Equivalent Ratio (LER) was proposed to compare the production of an agroforestry system with diverse crops over separate plots of pure crops (Mead and Willey, 1980).

In the last two decades, agroforestry research has tried to depart from this descriptive approach—although for the most complex agroforestry systems, it remains largely undone and necessary—and enter in an experimental approach to foster the improvement of these systems. On the biophysical side, a few multiannual experiments have been set around the world and produced very useful data but in a narrow range of environmental conditions. The research

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on interactions between species in an agroforestry system involves complex methods to separate flux between species, like N dilution methods or sap-flow measurements. Many studies have focused on the interactions between roots in the soil (Schroth, 1998).

On the socioeconomic side, efforts have been carried out to take stock of the indigenous knowledge (for example see Walker and Sinclair, 1995). Whereas indigenous knowledge is important for any agricultural system, it is interesting to note that many methodological improvements have been made on agroforestry system case studies. The LER concept has been extended to take into account the duration of land occupancy by crops—area x time equivalence ratio, ATER (Hiebsch and McCollum, 1987)—or to incorporate monetary returns—monetary equivalent ratio, MER (Adetiloye and Adekunle, 1989).

Recently, research on agroforestry systems (AFS) has focused on their contribution to public goods, supported by the monetary evaluation of services provided by ecosystems to the society (Costanza et al., 1997). Their contribution to biodiversity conservation, climate and water regulation has generated abundant literature. On the biophysical side, the inherent complexity of agroforestry systems is here multiplied by the upscaling issue: the activity that provides the service is done at a scale that is lower than the one relevant to evaluate the service (usually at landscape scale). On the socioeconomic side, the monetary evaluation of contribution to public goods brings specific and challenging issues (Pearce and Mourato, 2004).

Simulation models are called upon in the different very active fields of agroforestry research:

ß Models are identified as useful tool to explore complexity. One could expect an emergence of model to try to make the better use of the costly and scarce results from experimentations and provide useful insights to better target experimentations, or to nurture participative innovation processes.

ß One of the major drawbacks of promoting the contribution of agroforestry systems to public goods through incentives is the transactions costs involved when evaluating the services. Models can be an efficient way to reasonably evaluate the services at a limited cost.

ß Risk alleviation and resilience has been proposed as a major advantage of agroforestry systems (Malézieux et al., 2008). Models have been used to enhance the range of environmental or economical conditions to which agricultural systems are exposed and therefore make more accurate estimations of risks. This is particularly true in case of systems with perennial plants, where experimentations incur in significant costs.
ß Finally, mitigation and adaptation to climate change are fields where models are definitely needed, to explore the scenarios of future change and elaborate relevant strategies.

Nevertheless, such has not been the case, and very few agroforestry models have been developed and used for practical purposes. This was one of the main conclusions of the 2nd Multistrata Symposium for Perennial Crops held in CATIE (http://web.catie.ac.cr/AFS/Symposium/17–21 of September 2007).

It is thus necessary to intensify efforts on integrative modelling of agroforestry systems.

PCP is a recent initiative, and models are cited as important tools in each of its scientific themes. Therefore, a description of the state of the art in modelling in agroforestry systems was needed.

The main objective of the workshop was to elaborate the strategy of the PCP concerning the modelling efforts that will be done for the coming years:
ß reviewing the modelling needs for AFS within the PCP-CATIE
ß highlighting the specificities of AF modelling
ß reviewing the available modelling tools designed for AFS
ß enhancing synergy and integration between modelling disciplines,
ß connecting available information and databases on AFS and available models

We focused on the needs, goals and choice of models.

A second objective was to define the resources needed to implement this strategy and begin to pave the ways toward the consecution of these resources.

Finally, we also wanted to enhance present and future collaborations between PCP and modelling partners.

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Scientific Framework of the Mesoamerican Scientific Partnership Platform (PCP) for Agroforestry Systems with Perennial Crops

Bruno RAPIDEL,[1,2] Philippe VAAST[1] and John BEER[2]

Abstract

The natural resources of Mesoamerica have been identified as a foundation stone for the development of this region and of particular importance for the livelihoods of the rural poor. The Mesoamerican Biological Corridor (MBC) is an exemplary effort to protect natural renewable resources while promoting sustainable development. Nevertheless in the rural areas of the MBC around protected zones, agricultural expansion and intensification have resulted in a progressive fragmentation of forest habitat, loss of landscape connectivity, increased pollution of rivers and aquifers by agrochemicals and extensive loss of biodiversity.

The implementation of environmentally friendly agroforestry practices may reduce the productivity of crops; for example, decreasing coffee and cacao productivity when shade-tree cover is increased above a certain threshold to enhance environmental benefits. On the other hand, these practices are associated with reduced impacts on the environment and can qualify the products for ecological and other certifications as well as offer diversification options.

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Revenue diversification and new marketing opportunities can help reduce the vulnerability of rural communities to the price volatility of export crop products, thereby improving the economic sustainability of agroforestry systems.

The exploration of the trade-offs between productivity and the provision of environmental services (ES) opens the way to designing the most appropriate AFS. A key challenge is to produce relevant tools and methods to certify value and sell these ES, so that they can be effectively marketed. At the same time, farmers' organizations must be strengthened to better handle business opportunities for ecoproducts from AFS and improve the livelihoods of the farmers.

The PCP (French acronym for Scientific Partnership Platform) is a platform launched to bring together scientists from CIRAD, CATIE, INCAE, CABI and PROMECAFE to address these challenges as a strong, multidisciplinary, group and achieve significant research and developmental results. The founding agreement was signed on April 19, 2007, for 10 years. Bioversity joined the PCP in December 2007.

The work to be carried out in the PCP includes scientifically challenging issues. Even more challenging is the prospect of building a multidisciplinary and multi-institutional team to develop these themes, particularly the integration and synergy between the themes presented in the scientific framework.

Resumen en español

Plataforma cient fica de socios (PCP) en Mesoam rica Sistemas agroforestales con cultivos perennes

Los recursos naturales de Mesoamérica han sido identificados como piedra angular para el desarrollo de esta región y en particular para los medios de vida de los pobres rurales. El Corredor

Biológico Mesoamericano (CBM) es un esfuerzo ejemplar de proteger los recursos renovables naturales mientras que promueve el desarrollo sostenible. Sin embargo en las áreas rurales del CBM alrededor de zonas protegidas, la expansión y la intensificación agrícolas han dado lugar a una fragmentación progresiva del hábitat del bosque, pérdida de conectividad del paisaje, contaminación creciente de los ríos y los acuíferos por agroquímicos y pérdida de biodiversidad.

La implementación de SAF con prácticas ambientalmente amistosas puede reducir la productividad, como por ejemplo, la disminución de productividad en café y cacao cuando la cubierta de árboles de sombra sobrepasa cierto umbral. Por otra parte, estas prácticas están asociadas a impactos ambientales reducidos y pueden calificar los productos para las certificaciones ecológicas u otras, así como ofrecer opciones de diversificación.

La diversificación de ingresos y las nuevas oportunidades de comercialización pueden ayudar a reducir la vulnerabilidad de comunidades rurales a la volatilidad del precio de los productos agrícolas de exportación, de tal modo que mejoren la sostenibilidad económica de los SAF.

La exploración de los compromisos entre la productividad y la provisión de servicios ambientales (SE) abre la vía para diseñar los SAF más apropiados. Un desafío clave es de producir las herramientas y los métodos relevantes para evaluar, certificar y vender estos SE, para poderlos comercializar eficazmente.

Al mismo tiempo, las organizaciones de productores deben ser consolidadas para aprovechar las oportunidades de negocio de los productos ecológicos de los SAF y así mejorar las condiciones de vida de los productores.

El PCP (sigla en francés para plataforma científica de socios) es una plataforma implementada para reunir científicos de CIRAD, CATIE, INCAE, CABI y PROMECAFE para enfrentar estos desafíos con una masa critica de competencias interdisciplinarias y así lograr resultados significativos en cuanto a investigación y desarrollo. El convenio fundador fue firmado el 19 de abril de 2007, para 10 años. Bioversity adhirió al PCP a finales del 2007.

El trabajo que se realizará en el PCP incluye temas que representan desafíos científicos. Aún más alentadora es la perspectiva de construir un equipo multidisciplinario y multi-institucional para desarrollar estos temas, particularmente la integración y la sinergia entre los temas presentados en el marco científico.

Introduction and background

The natural resources of the earth are under increasing pressure, particularly in tropical countries, as world population continues to grow. Economic, social, institutional and environmental issues need to be addressed together to achieve development that does not jeopardize the right of future generations to enjoy these resources. Agroforestry systems (AFS), wherein different plant species, including perennials, are cultivated together in the same plots, can play an important role in sustainable development. These systems have the potential to achieve a higher efficiency than monocultures in terms of productivity and sustainable use of natural resources. However the economic and ecological advantages and disadvantages of AFS in comparison to monocultures, for all the potential species mixtures, management regimes, site and framework conditions, cannot be quantified; thus, general lessons of value for future research and development need to be derived from the existing and ongoing AFS case studies.

The natural resources of Mesoamerica have been identified by many organizations as a foundation stone for the development of this region, and of particular importance for the livelihoods (actual and potential) of the rural poor. The Mesoamerican Biological Corridor (MBC) is a flagship collaborative initiative of the governments of the region that has been recognized worldwide as an exemplary effort to protect natural renewable resources at the same time as promoting sustainable development. Nevertheless, in the rural areas of the MBC in between and surrounding protected zones (national parks, biological reserves, etc.), agricultural expansion and intensification have resulted in a progressive fragmentation of forest habitat, loss of landscape connectivity, increased pollution of rivers and aquifers by agrochemicals and extensive loss of biodiversity. Coffee or cacao AFS, with shade trees interspersed among the coffee or cacao, are often one of the few (or only) habitats with remaining tree cover within agricultural areas. Fruit trees and banana/plantains are an important component of the shade strata in traditional coffee and cocoa AFS and a substantial source of food and revenue for some farmers. These AFS are recognized as the best ecological option for buffer zone management of agricultural land surrounding or connecting protected areas. They also provide additional products such as wood fuel for rural and urban households, hence reducing pressure on surrounding natural forests. However, the economic performance of these AFS, as measured with traditional financial indicators, may not attract farmers to maintain their AFS or to convert their monocultures to these diverse systems.

Coffee has been the main agricultural crop and source of export earnings from Mesoamerica over the past 100 years. Coffee plantations have large-scale environmental impacts as they cover about 1 million hectares (ha) of the MBC (up to 2 million ha if southern Mexico is included). They are often situated in fragile mountainous ecosystems, mostly in the mid-upper watersheds that supply water to urban centres. Although only covering 63,000 ha (but expanding!) in Mesoamerica, cacao cultivation coincides with key areas of the MBC on the Caribbean coastal plains and has a high potential, both commercially and as a buffer zone around protected areas. Moreover, cacao is of key commercial and cultural importance for poor indigenous groups, located in remote areas with minimal infrastructure. Recent studies have demonstrated the potential to improve the competitiveness and ES of coffee and cacao SAF by considering all the potential products and services that they can provide.

Revenue diversification and new marketing opportunities are needed to improve the economic sustainability of rural communities and to reduce their vulnerability to the price volatility of export crop products. The implementation of environmentally friendly AFS practices may reduce the productivity of crops; e.g., decreasing coffee and cacao productivity when shade tree cover is increased above a certain threshold to enhance environmental benefits. On the other hand, since these practices are associated with reduced chemical inputs and can increase the quality of the products (e.g., coffee beans), they can qualify the products for ecological and other certifications, and hence price premiums, as well as offer diversification options.

The growing demand for ecoproducts (e.g., organic or Rainforest Alliance certified coffee, ecocertified timber) offers opportunities to generate enhanced incomes without compromising the natural resource base. The worldwide value of trade in agricultural ecoproducts has been estimated at about USD 34 billion in 2005, with annual growth rates of 15% over the past eight years. Leading global buyers of coffee and cacao are developing product lines based on organic, fair trade or environmentally friendly certification schemes. However, the effective positioning of small and medium producers and their business organizations in international markets for ecoproducts depends on their access to precise information about market prices, trends and regulatory frameworks, as well as to services that enhance their technical, business and financial capacities. In order to benefit from this new context, farmers need strong organizations that disseminate information, provide training at the farm level and services to members such as credit access, input supply, product transformation and commercialization. Appropriate agricultural and environmental policies, at national or regional levels, are also needed to recognize and reward the ES that AFS can provide to all members of society.

Thus there are good opportunities for significant collaboration, between scientists and the private as well as public sectors, for research and development on sustainable management of AFS and related certification schemes. Coffee and cacao plantations in the MBC cover a large range of cropping systems, from monocultures to highly species rich agroforests. This range offers an excellent scientific opportunity to compare AFS with diverse spatial complexities.

Objectives

The general objective of this scientific partnership platform (PCP) is to contribute to maintaining/increasing the competitiveness and sustainability of the agricultural sector of Mesoamerica through the quantification, valuing and development of all the potential products and environmental services of AFS with perennial crops (in particular coffee and cocoa[3]).

Specific objectives are

ß Develop or adapt methodologies to evaluate **AFS as providers of ES.** This is needed to produce reliable information and tools for the social groups that are willing to promote and reward the provision of ES as well as to design the best AFS practices for a given site and environmental conditions (**Theme 1**).

ß Design, in collaboration with farmers, **competitive, sustainable and diversified management strategies for AFS**, suitable for particular biophysical as well as economic constraints and opportunities. As AFS involve various species in the same fields, products, services and interactions are numerous, and trade-offs must be explored; thus specific modeling tools must be developed (**Theme 2**)

ß Assess, via studies of social and economic issues, the **impacts of AFS on farmer's livelihoods and strategies**. Relevant information on the policies needed to assist decision makers to promote AFS and strengthen rural communities should result (**Theme 3**).

ß Determine the most effective ways to strengthen **farmers' business organizations** so that they can better handle complex issues regarding business opportunities for ecoproducts from AFS that strengthen their livelihoods (**Theme 4**).

ß Increase understanding of the institutional arrangements along **value chains for AFS products and services** and the opportunities for farmer's business organizations to add value. In particular, research is needed on the opportunities to produce and certify environmentally friendly and/or quality products, cost/benefit of such schemes, transaction costs, efficiency, supporting institutions and, again, appropriate policies (**Theme 5**).

Themes

The work to be carried out in these **five themes** is detailed in the following sections. Each of them includes scientifically challenging

[3] For reasons of shared research experience and existing collaboration among the partners, it is proposed to start working immediately, within the framework of the PCP, on coffee and cacao. Other perennial crops of interest, such as rubber, fruit trees or Musacea, may be included later on as new funding opportunities arise and new partners join this PCP.

issues. Even more challenging is the prospect of building a multidisciplinary and multi-institutional team to develop these themes, particularly the integration and synergy between these themes.

Theme 1: AFS as providers of environmental services (including carbon sequestration, biodiversity, soil and water conservation)

The objective of this theme is to develop methods and tools to evaluate environmental impacts of AFS in order to measure and value their contribution to the provision of ES. AFS with perennial crops are generally imbedded in a mosaic of agricultural and forested areas where interactions between these land uses determine environmental functions such as the water quality/yield of a catchment, and biodiversity conservation at the landscape scale. Consequently methodologies for impact monitoring will be developed to scale up and integrate biophysical results from plot and farm level to watershed or other higher levels (e.g., using Geographic Information Services [GIS]). Pilot studies will be carried out in different climatic and soil conditions on at least the following issues: biodiversity inventories, water balance (including runoff and drainage), soil erosion, changes in carbon accumulation in soil and vegetation (including avoiding deforestation) and nitrate leaching. The methods and tools developed in these pilot studies will be targeted to specific users, including scientists, certification agencies, local governments, NGOs and farmers.

The Central American Isthmus is one of the tropical regions where many lessons have been learned on the ES provided by AFS, and on their valuation. The platform partners have developed numerous studies of AFS and produced valuable data for integrated impact assessment. For example, recent studies have shown that mammalian, bird, bat and beetle diversity in cacao AFS in a forested landscape was comparable to adjacent natural forests and significantly higher than for other land uses on the same farms. The Mesoamerican region is a recognized leader with respect to carbon trading and biodiversity inventories as well as protection and commercial use of this biodiversity. Pilot schemes to manage the payment for ES provided by livestock and cacao AFS have been developed and successfully tested, e.g., with indigenous groups. Markets for hydrological ES have been designed and implemented in several Central American countries; in these cases most payments to farmers depend on the adoption of AFS in prioritized areas. A key challenge is to translate the inherent complexity of the evaluation of ES provided by AFS into relevant tools and methods to certify, value and sell these ES at different scales and for diverse stakeholders. The complexity arises from the systems themselves, which combine different species, but the evaluation of a service is also a complex issue, as it requires comparisons (e.g. the well-known CDM mechanism). Additionally the scaling-up issue is challenging, particularly when it refers to water or biodiversity and connectivity between areas within the MBC.

Main potential research and development activities (Theme 1):

- Development and validation, in various ecological and management conditions, of scientific methodologies and plot level models to quantify and value ES and environmental impacts of AFS; e.g., nitrate leaching, N_2O emission, carbon sequestration, biodiversity conservation, soil fertility conservation (includes reduced erosion) and water balances (changes in infiltration, evapotranspiration, runoff).
- Development of models to transfer results respect ES from pilot areas to new areas thereby facilitating the identification of best practices, the generalization of results and, most importantly, reducing the implementing costs of future schemes to pay for ES.
- Development of methodologies to integrate information from plant, plot and farm levels to landscape and watershed levels (e.g., based on Soil-Vegetation-Atmosphere Transfer (SVAT) models, remote sensing and GIS) to support local payment schemes for ES as well as regional and national decision making.
- Development of simplified methodologies, which are cost effective and practical, so that nonspecialists (e.g., local authorities) can estimate ES; e.g., develop and test the value of integrative indicators such as tree cover.
- Development of criteria and methods to prioritize zones, systems and potential environmental services with the highest potential to provide benefits for both farmers and society.
- Establishment of an integral and holistic approach to promote the recognition and appropriation by farmers of the value of the ES provided by their farms. This approach should combine markets for ES with price premiums for adoption of best practices, improved market access through shortened value chains, etc.

Theme 2: Competitive, sustainable and diversified AFS management strategies (includes adaptation to suboptimal conditions and long-term environmental change)

The objective of this theme is the design, in collaboration with farmers, of competitive, sustainable management strategies for AFS that are adapted to local constraints and potentials. The research and development efforts will focus on the complementarities and facilitation between perennial crops, shade trees and other associated species for greater productivity, quality and economic viability. One of the main tasks will be to optimize biophysical tree-crop interactions in order to reduce the incidence of limiting factors (e.g., high temperature, drought, pests and diseases, depleted fertility), as well as competition for light, water and nutrients under the real conditions found in commercial farms of different management intensities. Another main task will be to determine which diversification options have commercial potential. Special attention will be devoted to the development of new tools useful for AFS design: e.g., ecological models to analyze the trade-offs such as SVAT models, sustainability indicators, the relationships between production and environmental quality and participatory methodologies to modify complex systems successfully.

The partners of the PCP have a long history of joint research on AFS biophysical issues. Some of the recent findings indicate that shade in coffee AFS results in more stable production and improved coffee quality when compared to coffee monocultures. The inputs of nitrogen (N) through the association with leguminous shade trees and the potential beneficial effect of this input on coffee production have been quantified for diverse pruning schemes, site and management conditions. Biomass production and soil organic matter can be increased in some coffee and cacao AFS. In cacao AFS, the timber component is presently poorly exploited, although the annual increments can be high. In contrast, sales of timber and fuel wood can account for a significant part of coffee farmers' revenues. Other research activities of the partners, although out of the scope of this platform, will be useful for the design of improved AFS; e.g., their coffee and cacao genetic improvement programmes. A key challenge is how to integrate all the existing and new information into tools that can be used to design AFS that meet the demands of the stakeholders while meeting high standards in terms of conservation of natural resources. This integration will also allow us to identify knowledge gaps that need to be filled to be able to design even better AFS.

Main research and development activities (Theme 2):

- Studies of the physiology of coffee and cacao at the scale of branch, fruit, roots, plants and plantations: e.g., carbon (C) and nutrient acquisition/allocation (including tracers), modeling water balances, and C, N and energy budgets.
- Development and validation, in various ecological and management conditions, of plot-level AFS models for the optimization of light, nutrient and water use to design sustainable coffee and cacao plantations; e.g., compared to monocultures, the resilience of AFS to economic and environmental risk factors such as climate change.
- Identification and domestication of native fruit tree species found in traditional coffee and cacao shade strata that have commercial potential.
- Evaluation of the potential and development of best agricultural/forestry practices to produce quality timber in coffee and cacao AFS.
- Development and validation, for various ecological conditions, of models and decision-making tools on the incidence of pests and diseases with respect to shade management and other agricultural practices in AFS.
- Development of expert models to illustrate the performance of potential tree-crop combinations for different site conditions and the possible responses to long-term environmental changes, considering different biophysical interactions, environmental conditions and management options.

Theme 3: Impacts of AFS on rural livelihoods

The main objective of this theme is to assess, via social and economic studies, the impacts of AFS on farmers' livelihood strategies. Studies will focus on knowledge, perceptions and values, practices and economic dependency of local populations on AFS. A subobjective is to formulate and disseminate to decision makers information and relevant recommendations on the policy changes needed to promote

AFS that improve rural livelihoods. These livelihoods, to varying degrees, depend on on-farm and off-farm income; those based on cacao and coffee production are vulnerable to the volatility of world market prices for these crops. They are also vulnerable to changes in norms and regulations governing exports and imports of agricultural products. Wood fuels derived from AFS are an important resource for many rural and urban households in the region. Shade trees also provide intangible cultural benefits/services (e.g., spiritual and aesthetic functions, particularly for indigenous communities) as well as significant amounts of timber, fruits and other nontimber products (natural medicines, fibers, etc.), the latter being of particular value for women, children and the elderly. Thus the trees in AFS can contribute to the diversification of farmers` revenues and improve rural livelihoods in many ways.

Main research and development activities (Theme 3):

ß Analysis, classification and modeling of trade-offs for different livelihood strategies in a given area to determine the importance of AFS for each strategy.
ß Gender analyses of actual and potential AFS: e.g., *ex-ante* evaluations of the consequences, particularly for women, children and the elderly, of different certification schemes and/or of replacing traditional diversified shade strata with a simplified shade stratum of one commercial species.
ß Evaluation and documentation of the economic and sociocultural values of native trees and of traditional knowledge as well as the perceptions of the management and uses of associated species in coffee and cacao AFS.
ß Assessment of the economic potential of value-added options to offer remunerative employment opportunities; e.g., potential value added by local primary processing of products from coffee or cacao AFS such as charcoal, local timber milling, fruit pastes and juices, and niche market coffee/cacao products.
ß Participatory assessment of farmers' constraints and potentialities for maintaining and/or adopting environmentally and biodiversity-friendly AFS: e.g., assessment of the factors, such as legal constraints, that condition the development of the AFS practices and marketing of products derived from AFS; study of the compatibility of different certification schemes with livelihood strategies.

ß Evaluation of the potential contribution of perennial AFS to the sustainable livelihood strategies of small producers under conditions of ecological and economical variability: e.g., climate change; the influence of increasing off-farm income, particularly remittances; and of changes in market regulations due to free trade agreements, etc.
ß Preparation of guidelines for decision making in the commercial as well as political spheres through economic comparisons of AFS versus monocultures. These guidelines will include and contrast estimated values for costs, products and services, available over short, medium and long periods, for different biophysical and/or socioeconomic conditions. Sensitivity analyzes and modelling techniques will be used to evaluate the consequences of different assumptions.

Theme 4: Strengthening small and medium farmers' business organizations for increased benefits from AFS

The objective of this theme is to promote the strengthening of farmers' business organizations (FBO) to handle the complex issues related to development and strategic positioning in value chains for ecoagricultural and forest products. Competent FBO are essential to facilitate access of small and medium farmers to specialty markets (organic, fair trade, gourmet, certified timber, etc.) for the agricultural and forest products they produce in AFS. Among the services that FBO provide to their members are relationships with buyers and processors; technical, business development and financial services; input supplies; and information on markets and training opportunities. However, the majority of FBO face difficulties of different types. Internally, they may suffer from weak participation by members; lack of effective leadership, technical and management skills; and insufficient financial capital. Externally, they face political-legal frameworks that are cumbersome and outdated, which often impose high business transaction costs.

Main research and development activities (Theme 4):
ß Determine the compatibility of livelihood strategies with FBO and ways to minimize potential trade-offs between business development and livelihood security.
ß Identify the critical success factors for the development of FBO in specialty markets for agricultural and forest products from AFS,

the key elements of political-legal and regulatory frameworks for successful FBO development and the successful organizational forms and business models of FBO.

ß Strengthen the capacity of FBO to identify market opportunities and negotiate with stakeholders inside the supply chain to increase value adding by FBO.

ß Development of information-sharing platforms and mechanisms for improving coordination and cooperation along value chains that lead to reduced costs and improved quality management of FBO; identification and definition of standards compatible with AFS and farmers constraints; design of common cost analyses.

ß Identify the FBO demand for and supply of market intelligence on specialty products produced in AFS: e.g., compare levels and types of information currently provided; frequency of updates; communication media and channels (Internet, service providers, business leaders). This would include reviewing past market studies, accessing and integrating diverse information sources, creating databases and developing models of price trends for different sectors of each market, taking into account local and national limiting factors that determine farmer income.

ß Develop and test training/technical assistance options to strengthen FBO: e.g., compare the costs and impacts on sales, quality, profitability, etc., for coffee and cacao cooperatives and associations, of different approaches to strengthening FBO such as remote (electronic) versus traditional (face to face) training or workshops and short courses versus on-the-job training.

Theme 5: Improving value chains, markets and product differentiation of AFS products and their environmental services

The objective of this theme is to enhance the linkage of sustainable AFS management and environmental benefits with increased producers' remuneration through improved access to and successful participation in national and international markets. In order to increase the economic benefits accruing from value chain integration, the following strategies will be investigated and developed: (1) promising institutional arrangements between value chain actors; (2) improved marketing strategies for environmentally friendly products and environmental services; and (3) opportunities to reduce costs and/or add value to AFS products, including ES payments. Actor specific recommendations will be formulated and disseminated to political decision makers, private sector representatives and NGOs regarding the policy mix needed to stimulate production in AFS and sale of environmental services: e.g., adapting certification schemes for environmentally friendly and quality products; developing green purchasing policies and ES payments under local (e.g., watershed arrangements, ecotourism) or global schemes (e.g., carbon markets, biodiversity incentives).

Main research and development activities (Theme 5):

ß Carry out case studies to document and analyze exemplary value chains for certified quality labeled AF products, including timber, coffee and cacao. Identification of factors in value chains leading to success or failure, including demand orientation, information and communication flow, and risk and benefit sharing mechanisms among key chain actors.

ß Identify the critical success factors for buyers of environmentally friendly AFS products, including importers, supermarket chains, and alternative trade promotion organizations, in particular regarding their preferences in terms of quality and certification criteria, minimum volumes and contractual arrangements. Special emphasis will be put on (dis)satisfaction with the existing offer of certified products and price premiums available for different kinds of certification, in both producing and developing countries. Surveys of business intermediaries regarding barriers to increasing their services and impacts on first, second- and third-tier FBO.

ß Evaluation of potential markets for ES provided by AFS, at local, national and international levels, with identification of constraints, requirements and transaction costs of different options. Evaluate the impact of such markets on the profitability of AFS relative to other systems.

ß Analysis of the costs and benefits, along the whole value chain, of converting conventional farming systems into AFS and of complying with the requirements of different certification schemes.

ß Comparisons and contrasts of communication channels, respect the cost, effectiveness, efficiency and flexibility of different options to promote communication: e.g., among actors along the value chains; between consumers and producers; between producer groups (to

achieve critical mass and bargaining power); and of R+D professionals as well as business service providers with different actors along the value chain.
- Studies and documentation to promote the certification of AFS within the framework of the Clean Development Mechanism (CDM) of the Kyoto Protocol, considering that the AFS can be classified as "forests" (COP Marrakech, 2001), that "reforestation" can occur on degraded lands, that AFS provide a renewable fuel, that AFS may represent a carbon sink and that using AFS helps prevent deforestation (COP Nairobi, 2006).

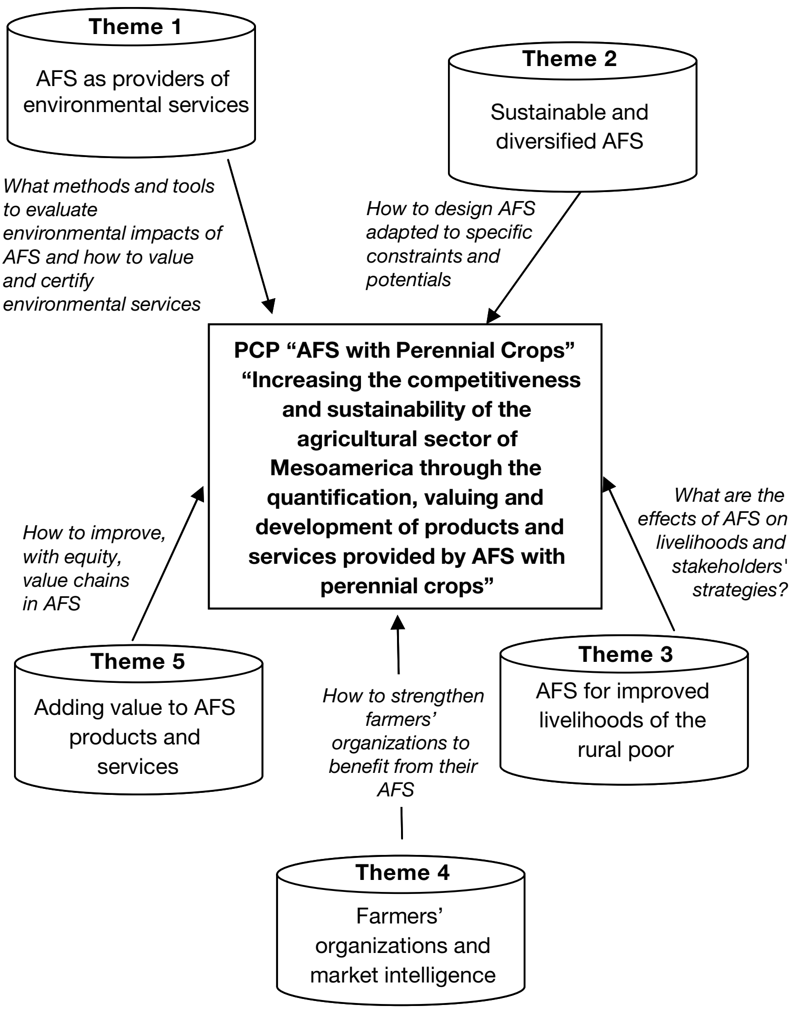
Outputs

- Innovative Agroforestry Systems
- Increased capacity of producers, professionals, organizations, scientists, and graduate students
- Decision making tools and recommendations on policy guidelines
- Scientific and technical publications
- Extension and training materials
- Significant contribution to postgraduate education

Partners

- CABI
- CATIE
- CIRAD
- INCAE
- PROMECAFE

Conclusion: Conceptual Framework of the Agroforestry Systems (AFS) - PCP



SESSION 1

Biophysical Modelling

Chairman: Fergus Sinclair (U. of Wales, Bangor)

The APSIM Experience in Australia: From Research Model to Farmer Application

Neil I. HUTH[1] and Peter S. CARBERRY[1]

Abstract

The Agricultural Production Systems Simulator (APSIM) is a modular modelling framework that has been developed by the Agricultural Production Systems Research Unit (APSRU) in Australia. Modules have been developed for a diverse range of crops, pastures and trees, soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. While APSIM was originally developed to simulate biophysical processes for farming systems research, it has grown a role in assisting land managers in agricultural and agroforestry systems. Initially this was achieved using participatory action research (PAR) approaches involving farmer groups and agribusiness professionals. Web-based tools now make use of up-to-date daily weather information providing farmers and their advisors with forecasts of likely responses of management interventions within a variable climate.

Many of the problems facing Australian land managers have been caused by excessive clearing of perennial vegetation from much of the agricultural landscape. As a result, plantation and farm forestry are being investigated for the benefits they may provide and the simulation framework has evolved to address these systems. A simple spatial capability is provided to enable the simulation of

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interactions between management units. Modelling approaches are also being developed to incorporate biodiversity benefits of agroforestry into a wider systems analysis.

In this paper we briefly describe APSIM's history and capabilities and provide an agroforestry example to demonstrate the growing range of model applications within Australia. This includes an on-farm PAR study of the economics of farm windbreaks and an example of the emerging approaches to incorporate biodiversity benefits into agroforestry studies.

Resumen en español

La experiencia de APSIM en Australia: desde un modelo para la investigaci n hasta la aplicaci n por los productores

El Simulador de Sistemas de Producción Agrícola (Agricultural Production Systems Simulator—APSIM) es una plataforma modular de modelaje que ha sido desarrollada por la Unidad de Investigación de Sistemas de Producción Agrícola (Agricultural Production Systems Research Unit—APSRU) en Australia. Se han desarrollado módulos para un diverso rango de cultivos, pasturas y árboles, procesos de suelos incluyendo balance de agua, transformaciones de N y P, pH de suelo, erosión y un rango completo de operaciones de manejo. Mientras que APSIM fue originalmente desarrollado para simular procesos biofísicos en la investigación de sistemas agrícolas, ha evolucionado hacia un papel de asistencia a administradores de tierra en sistemas agrícolas y agroforestales. Inicialmente esto se logró utilizando enfoques de Investigación-acción participativa (PAR) involucrando a grupos de agricultores y profesionales del sector agrícola. Las herramientas a través de la Web actualmente utilizan información climática diariamente actualizada, proveyendo a los agricultores y sus consejeros pronósticos de respuestas probables de intervenciones de manejo dentro de un clima variable.

Muchos de los problemas que los administradores de tierra australianos enfrentan han sido causados por eliminación excesiva de la vegetación perenne en gran parte del paisaje agrícola. Como resultado, las plantaciones forestales y la producción forestal en fincas están siendo investigados por los beneficios que puedan proveer y la plataforma ha evolucionado para atender estos sistemas. Una capacidad espacial simple es provista para facilitar la simulación de interacciones entre las unidades de manejo. Enfoques de modelaje también se están desarrollando para incorporar los beneficios de la biodiversidad de la agroforestería dentro de un análisis más amplio de sistemas.

En este documento describimos brevemente la historia y capacidades del APSIM y damos tres ejemplos agroforestales para demostrar el rango creciente de las aplicaciones del modelo dentro del territorio australiano. Esto incluye un análisis de sistemas de la viabilidad de bosques de regadío dentro de ambientes salinos, un estudio de PAR a nivel de finca sobre las finanzas de las barreras rompevientos en las fincas, y un ejemplo de los enfoques emergentes para incorporar los beneficios de la biodiversidad dentro de estudios agroforestales.

Introduction

The Agricultural Production Systems simulator (APSIM) is a process-based production systems model developed by the Agricultural Production Systems Research Unit (APSRU) (Keating et al., 2003). APSIM uses a component-based design to allow individual models to interact via a common communications protocol, usually on a daily time step. In this case, the plant module communicates with existing modules for soil processes such as carbon and nitrogen cycling, surface litter dynamics, water and solute fluxes and soil temperature (Probert et al., 1998). APSIM has previously been used to study the impacts of tree-crop interactions (Huth et al., 2002), effluent irrigation (Snow et al., 1999), drought-induced mortality (Huth et al., 2008) and saline water tables (Paydar et al., 2005) on eucalyptus plantations.

APSIM has been used in a wide range of application settings ranging from traditional scientific systems research methodologies through to use with small farmer groups or agribusiness professionals. However, the passage from research model to information tool for land managers was not straightforward. The history of APSRU's exploration of the issue of model extension is described by (McCown et al., 2002).

Several decades ago models were largely considered to be tools, or indeed playthings, for scientists. However, a view evolved that they should also be useful to land managers for assisting in management decisions. Out of this belief came the numerous efforts to develop decision support systems (DSS). While many DSS were built and provided to managers, it became clear that DSS had fallen far short of the great expectations held by model developers (McCown et al., 2002). However, through the use of participatory action-research methods, such as in the FARMSCAPE project (Carberry et al., 2002), means of incorporating simulation models into farmer decision-making processes have been successfully developed. These techniques have been employed in various settings from farmer groups in the Third World through to services deployed via the Internet (Hunt et al., 2006).

A case study

These participatory methods have also been employed in agroforestry systems. An example of this is described in Huth et al., 2002. In this case study the likely production impacts of *Eucalyptus argophloia* windbreaks on dryland cropping systems were investigated for the northeastern Australian wheat belt. APSIM was configured to simulate the production impacts of shelter from wind and competition for water upon agricultural crops by the trees within the windbreak.

Figure 1 shows an example of the range of simulated production losses next to the trees and the variation in soil water as a result of competition for soil water by the eucalypts.

These predicted impacts on production were then incorporated into discussions on the economic implications of these tree plantings with farmers, or farmer groups.

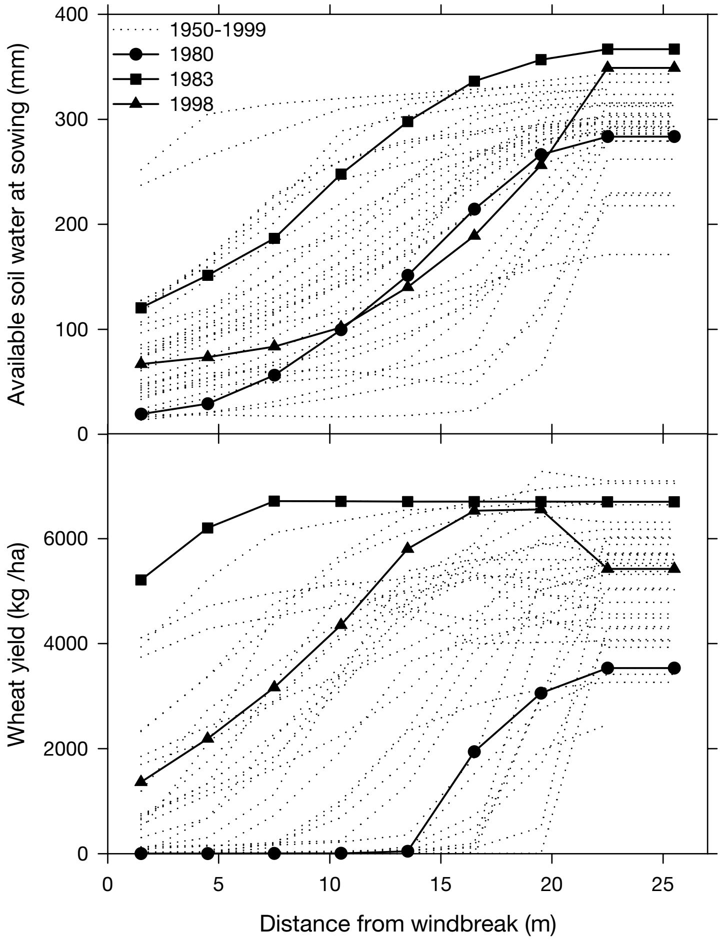

Figure 1. Transects of predicted plant available soil water content at sowing and resultant wheat yield for a wheat field next to a windbreak of *Eucalyptus argophloia* near Dalby, Qld.

Discussions were able to consider issues of cash flow, long term financial impacts and considerations of alternative management options (Figure 2).

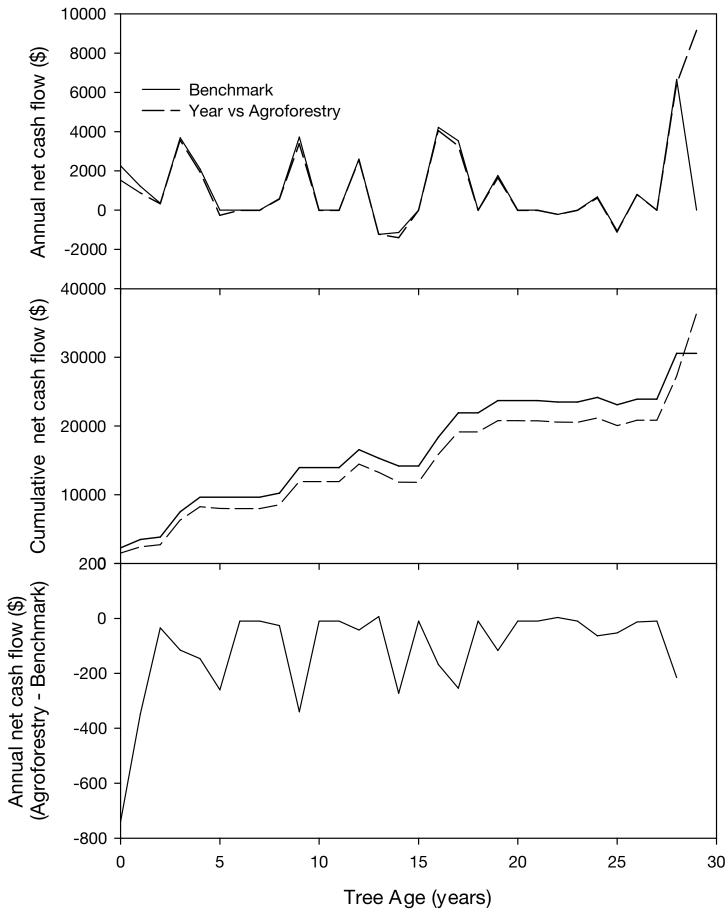

Figure 2. Cash flow for a 30-year tree belt growing cycle. a) annual cash flow for benchmark system (solid line) and agroforestry system (broken line); b) cumulative cash flow-symbols as for a); and c) difference in annual cash flow between benchmark and agroforestry systems for years 1 to 29 of the investment.

These were evaluated against the environmental benefit of the trees provided by reductions of deep drainage of water and therefore reduced risk of salt mobilization into the water table (Figure 3).

Feedback from land managers, and extension professionals involved in efforts to increase the adoption of agroforestry or environmental tree planting stated that the ability to evaluate various system designs and management options across the economic and natural resource dimensions was of great value.

One of the main reasons for revegetation of farming systems is the biodiversity benefit that these systems will have for the farm and the local landscape. In order to incorporate these aspects into discussions, simple models of biodiversity benefit are currently being developed and tested (Huth and Possingham, 2007). These approaches apply a habitat scoring approach (Figure 4) to the "virtual woodlot" in order to provide an estimate of the habitat value of an agroforestry enterprise at various stages of growth, as well as for various woodlot sizes and configurations. This information can then be used in cost utility analyses of the woodlots as providers of habitat for woodland-dependant bird species. Evaluation can compare various terms of economic or biodiversity value (Table 1).

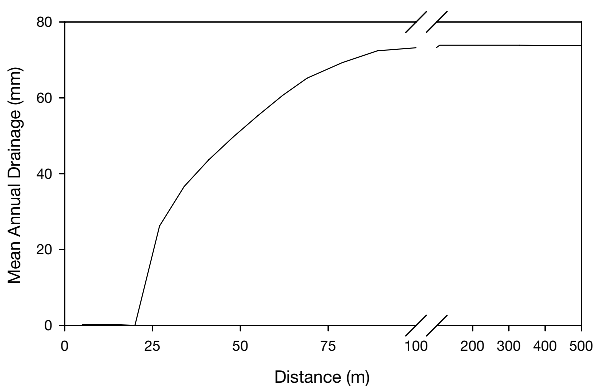

Figure 3. Reduction of deep drainage (and therefore water table salinisation risk) at various distances from the tree windbreak.

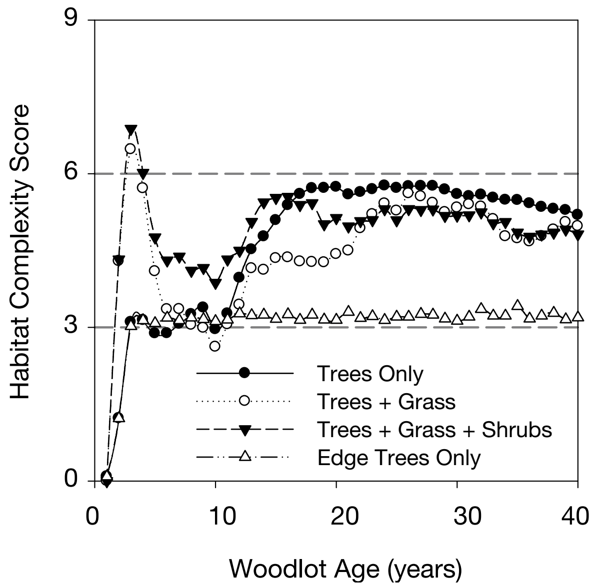

Figure 4. Habitat complexity score over time for four simulated woodlots demonstrating marginal return on biodiversity value of various woodlot designs.

Table 1. Outcomes from analysis of Tree Only (T), Trees+Grass (TG), Trees+Grass+Shrub (TGS) and Tree Edge (TE) scenarios.

	Scenario			
	T	TG	TGS	TE
Wood Volume (m^3/ha)	300	150	150	300
Time to Harvest (y)	40	29	53	15
Future Value (Annuity) of Lost Production (ha.y)*	155	74	349	23
Break even value of timber for lost production (y/m^3)	.52	.49	2.3	.07
Mean Habitat Score	4.7	4.3	4.9	2.8
Quality Adjusted Habitat Years (y)	12.5	8.3	17.2	2.8
Mean Bird Species Richness**	7.0	6.4	7.3	4.3

* Assuming interest rate of 6%

** Assuming 5 ha woodlot

Conclusion

Our experience in case studies like the one described above is that while models have a proven track record in scientific systems analysis, they can also provide a useful tool for informing landholders on the costs and benefits of agroforestry systems. For this to be successful, participatory approaches should be employed within the networks currently used by farmers to inform their decisions. Within these processes, models can be used in a discussion-support approach.

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CASTANEA: A Forest Process-Based Model of Carbon and Water Balances

Guerric LE MAIRE,[1] Hendrik DAVI[2] and Eric DUFRENE[3]

Abstract

CASTANEA is a physiologically multilayer process-based model completed with a carbon allocation model and coupled with a soil model. It simulates the carbon and water balances of a homogeneous forest stand.

The presentation will focus on three main parts:
(1) Presentation of the model: canopy photosynthesis and transpiration, maintenance and growth respiration, seasonal development, partitioning of assimilates into leaves, stems, branches, coarse and fine roots, evapotranspiration, soil heterotrophic respiration, water and carbon balances of the soil. This model was calibrated and validated on different European species.

(2) Its use under climate change scenarios: the model was run on six different forest stands in France and validated with flux-tower measurements. Then it was run using the 1960-2100 climate

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simulated with the ARPEGE climate model. The effect of CO_2 increase, water stress, phenology and other climate changes on forest carbon and water fluxes were independently assessed with CASTANEA.

(3) Its use on a large managed forest: the model was run on the ~3000 stands of a French temperate forest considering that there were no interactions between stands. The main issue of this study was the parameterization of such a complex model at that scale. Sensitivity analyses combined with *a priori* knowledge and ground measurements of inter-stand parameter variation allow us to select key parameters for spatialization. These parameters are then obtained by different methods using forest inventories, soil pit inventories and remote sensing.

Resumen en español

CASTANEA, un modelo forestal basado en procesos de balances de carbono y agua

CASTANEA es un modelo multiestratos basado en procesos fisiológicos completado con un modelo de alocacion de carbono y acoplado a un modelo de suelo. Este modelo simula balances de carbono y agua de parcelas de bosque homogéneas.

La presentación enfocará tres partes principales:
(1) Presentación del modelo: fotosíntesis y transpiración de la copa, mantenimiento y crecimiento de la respiración, desarrollo estacional, división de asimilados en hojas, tallos, ramas, raíces gruesas y finas, evapotranspiración, respiración heterotrófica del suelo, balances de agua y carbono del suelo. Este modelo fue validado con diferentes especies.

(2) Su uso bajo escenarios de cambio climático: este modelo fue operado en seis diferentes parcelas de bosque en Francia y validado con medidas de torres de flujo. Luego fue operado

utilizando el clima 1960-2100 simulado con el modelo climático ARPEGE. El efecto del incremento del CO_2, escasez de agua, fenología y otros cambios climáticos en los flujos de carbono y agua de los bosques fueron evaluados independientemente con CASTANEA.

(3) Su uso en un bosque administrado de gran extensión: el modelo fue operado en 3.000 parcelas de bosque de un bosque templado francés considerando que no había interacciones entre parcelas de bosque. El tema principal de este estudio fue la parametrización de este modelo tan complejo a esa escala. El análisis de sensibilidad combinado con el conocimiento a priori y medidas del terreno de variación de los parámetros entre parcelas nos permite seleccionar parámetros espaciales claves. Estos parámetros son luego obtenidos por diferentes métodos utilizando inventarios forestales, inventarios de suelo y sensores remotos.

Model description

CASTANEA is a physiologically multilayer process-based model completed with a carbon allocation model and coupled with a soil model. It simulates the carbon and water balances of a homogeneous forest stand. A detailed description of the model, with equations, is given in Dufrêne et al. (2005).

Pools and fluxes of carbon and water of the stand are simulated (Figure 1). Light interception is calculated with a multilayer canopy description. Six pools are considered: five represents organs; the last one represent carbohydrate storage. One averaged tree is considered representative of the whole stand. The soil water balance is a three-layer bucket model. The soil carbon model is similar to CENTURY (Parton et al., 1987) but with two independent layers. Two time-steps, half-hourly and daily, are used in the model. Most variables involving fluxes are simulated half-hourly; all state variables plus growth and phenology are daily simulated. Input meteorological driving variables (global radiation, temperature, rainfall, humidity, wind speed) can be either half-hourly or daily.

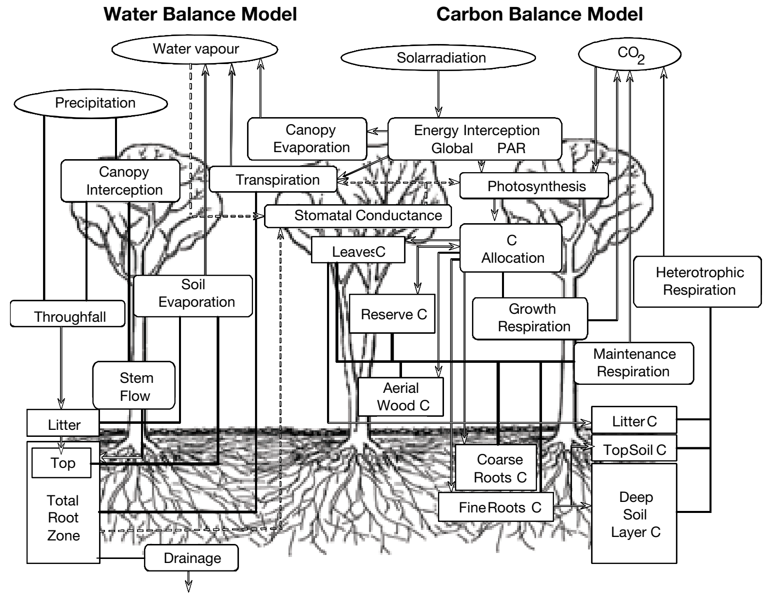

Figure 1. Flow diagram for both water (left) and carbon (right) submodels, adapted from (Dufrêne et al., 2005).

CASTANEA includes most of submodules generally used in those types of stand-level models but also have some particularities (Table 1). These submodules are succinctly described in the following sections, which are a summary of Dufrêne et al., 2005.

Model detailed validation at one forest site

The model was parameterized and main processes of the model were validated from organ to stand scale on a beech (*Fagus sylvatica*) forest in Hesse, north-east of France (Davi et al., 2005). An exhaustive list of input parameters values are reported in Dufrêne et al., 2005 and Davi et al., 2005.

The model validity is assessed by comparison between net CO_2 and H_2O fluxes simulated and measured by the eddy flux technique over one year. In addition, most of the submodels describing the main

Table 1. Main processes and their references used in CASTANEA.

Process	Model
Radiation interception	derived from SAIL (Verhoef 1984, 1985), (Francois 2002)
Leaf photosynthesis and stomatal conductance	(Farquhar et al., 1980), (Ball et al., 1987), (Wulschleger 1993)
Canopy photosynthesis	leaf photosynthesis integration over canopy
Phenology	day-degree and day duration function
Allocation	system of priorities
Maintenance respiration	(Ryan 1991), (Damesin et al., 2002)
Growth respiration	(Penning de Vries 1975; Penning de Vries et al., 1974)
Water fluxes	(Monteith 1965; Penman 1948; Rutter et al., 1971), bucket model
Effect of soil water status on canopy gas exchange	(Ball et al., 1987)
Heterotrophic respiration and soil organic matter cycle	derived from CENTURY (Parton et al., 1987)

processes are tested using independent measurements from the same forest stand: tree growth, branch photosynthesis, wood and soil respirations, sap flow and soil water content. Most of the input parameters (both weather and plant characteristics) are measured in the same experimental site (i.e., Hesse forest) independently of the validation dataset (none has been fitted to match the output data, except rainfall interception parameters); some are from other beech sites or from literature.

Concerning the radiative transfer, the model reproduces the measured exponential PAR extinction and provides a good estimate of the net radiative budget, except during winter. At the branch scale, simulated photosynthesis and transpiration of sun-leaves are close to the measurements.

At stand scale, a good correlation was obtained between simulated and observed fluxes both on a half-hourly basis (Figure 2) and on a daily basis (Figure 3). Except at the end of the leafy season, the model reproduces reasonably well the seasonal pattern of both CO_2 and H_2O fluxes.

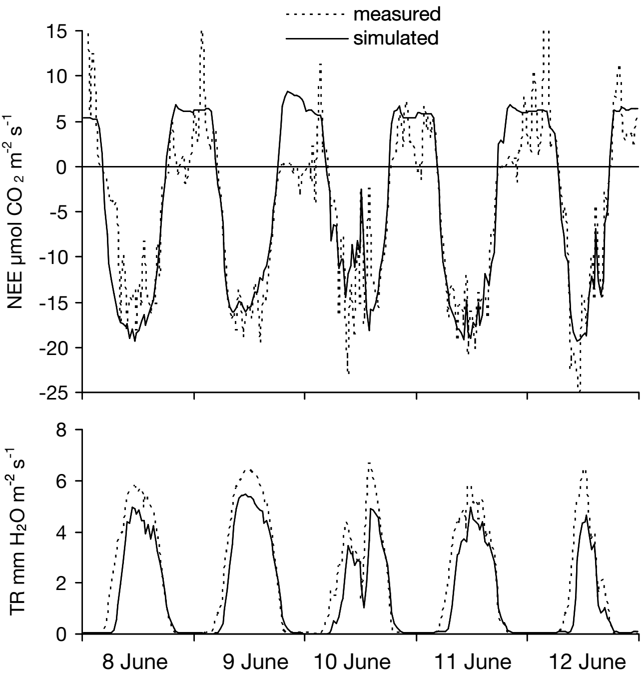

Figure 2. Measured and simulated half-hourly net ecosystem exchange (NEE) and transpiration (TR) in Hesse in 1997. Daily pattern of simulated and measured fluxes, from May 23 to May 27 (adapted from (Davi et al., 2005).

Finally, even if there are some discrepancies between model simulations and fluxes measured at stand scale by eddy covariance or other methods, the model simulates properly both annual carbon and water balances when compared with the sum of the measured local fluxes (Table 2). The remaining differences question the scaling up process when building such a model and the spatial footprint of eddy fluxes measurements.

Model validation for other sites and species

A test of the model on three other forest sites and species has been done in Davi et al., 2006.

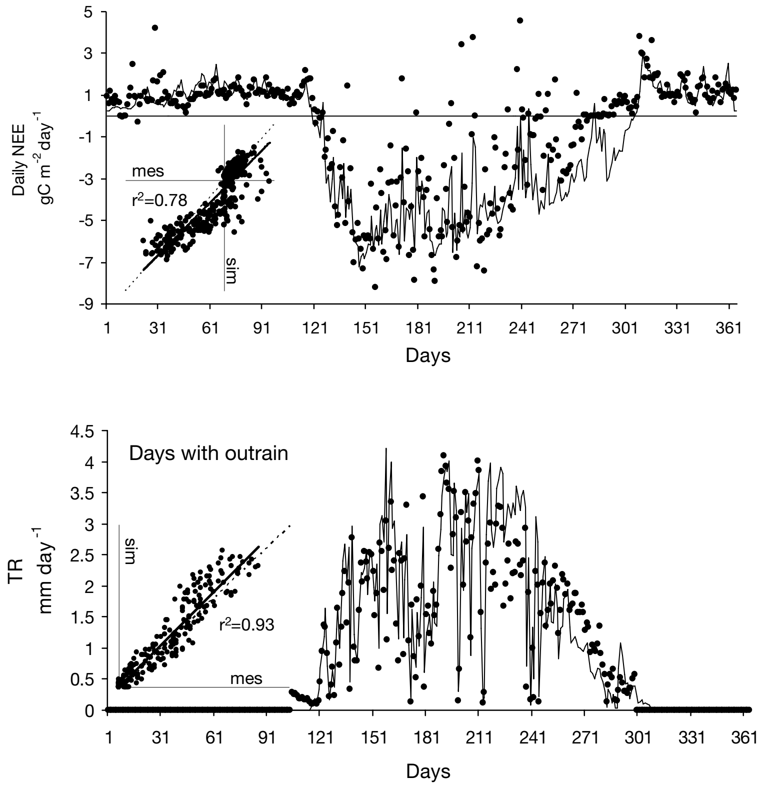

Figure 3. Measured (black dots) and simulated (solid line) daily net ecosystem exchange (NEE) and transpiration for days without rain (TR) in Hesse in 1997 (adapted from (Davi et al., 2005).

The other sites that belong to the Carboeuroflux network (le Bray, Puechabon and Loobos) were chosen in order to validate the model against eddy covariance fluxes for three other species (*Pinus pinaster, Quercus ilex, Pinus sylvestris*) in four contrasting climates. To analyse the generality and the accuracy of the model in predicting the carbon and water balances of different forests, the simulations were compared to eddy covariance measurements (Table 3).

Table 2. Comparison between annual simulated and measured carbon fluxes and biomass increment (every value in gC.m^{-2} year^{-1}) with two different approaches: sum of separated fluxes and integrated flux by eddy covariance measurements. From (Davi et al., 2005).

Variable	Simulated	Measured Integrated fluxes	Measured Separated fluxes
Sum of separated fluxes			
Biomass increment aerial wood	358		379
Biomass increment coarse roots	82		76
Biomass increment leaves	171		131
Biomass increment fine roots	165		171
Increment of carbohydrate storage	56		-
Rroots	212		325
Rm stems	78		77
Rm branches	75		75
Rc wood	136		130
Rm leaves	184		168
Rc leaves	29		26
GPP	1,514	1,245	1,558
Rheterotrophic	317		338
Reco	1,030	988	1,139
NEE	484	257	419

CASTANEA and climate-change scenarios

The effects of climate changes on carbon and water fluxes of some European forest ecosystems are quantified using CASTANEA. Detailed descriptions of these simulations and results are given in Davi et al., 2006, and this section is a summary of this article.

Simulations were conducted on six French forest ecosystems representative of three climatic areas (oceanic, continental and Mediterranean areas) dominated by deciduous species (*Fagus sylvatica, Quercus robur*), coniferous species (*Pinus pinaster, Pinus sylvestris*) or sclerophyllous evergreen species (*Quercus ilex*). The six ecosystems are located in four different sites (Le Bray, Puechabon, Hesse and Fontainebleau)

Table 3. Goodness of fit of the model predictions expressed as explained variance (R2), total root mean square error (R.M.S.E.) and mean bias in % of daily net ecosystem productivity (NEP) and evapotranspiration during days without rain (ETR). Adapted from Davi et al., 2006)

	NEE				**ETR**			
	n	r^2	RMSE	Bias	n	r^2	RMSE	Bias
Hesse	365	0.90	1.28	-6.0	151	0.91	0.62	+24.1
Bray	365	0.72	1.13	+15.0	142	0.42	0.96	+11.7
Puéchabon	294	0.48	1.21	-5.6	297	0.65	0.35	+10.6
Loobos	294	0.69	1.03	+7.2	165	0.87	0.23	-5.0

The model is driven by the results of a meteorological model (ARPEGE) following the B2 scenario of IPCC. From 1960 to 2100, the average temperature increases by 3.1°C (30%) and the rainfall during summer decreases by 68 mm (-27%) (Figure 4). These tendencies are followed in the four sites.

Simulations for 1960–2100 are performed with annual reinitialization of wood biomass and soil carbon, so that there are no age, carryover effects, nitrogen feedbacks, acclimatation taken into account, but only the climate and CO_2 effects.

For all sites, between the two periods, the simulations predict on average a gross primary production (GPP) increase of 513 g(C) m^{-2} (+38%). This increase is relatively steep until 2020, followed by a slowing down of the GPP rise due to an increase of the effect of water stress. This GPP increase is mainly due to the atmospheric CO_2 rise that increases carbon assimilation (Figure 5). Contrary to GPP, the ecosystem respiration (Reco) raises at a constant rate (350 g(C) m^{-2} i.e., 31% from 1960 to 2100). This raise is mainly independent of the atmospheric CO_2 increase (Figure 5). The dynamics of the net ecosystem productivity (GPP minus Reco) is the consequence of the effect on both GPP and Reco and differs per site. The ecosystems always remain carbon sinks; however, the sink strength globally decreases for coniferous (-8%), increases for sclerophyllous evergreen (+34%) and strongly increases for deciduous forest (+67%) that largely benefits by the lengthening of the foliated period (Figure 5).

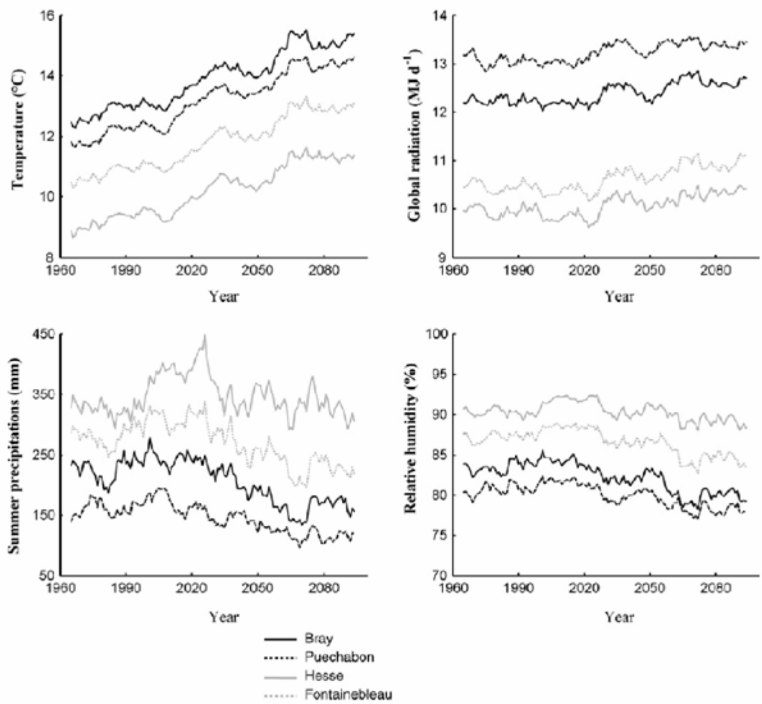

Figure 4. Comparison of the climatic variables simulated by ARPEGE models over four French sites (presented results are moving average over 10 years) From (Davi et al., 2006).

In the water balance, ETR decreases of 13.7% in the coniferous stands while no significant trends are found for the broadleaves species. As expected the water use efficiency increases strongly by about 50%. Indeed, the fertilization due to the CO_2 raise enhances GPP, without changing ETR (Figure 5).

The separately quantified effects of the main variables (temperature, length of foliated season, CO_2 fertilization, drought effect) show that the magnitude of these effects on NEP depends on the species and the climatic zone. Figure 6 shows that the positive effect of CO_2 increase occurs for all sites, whereas the deciduous forests benefits

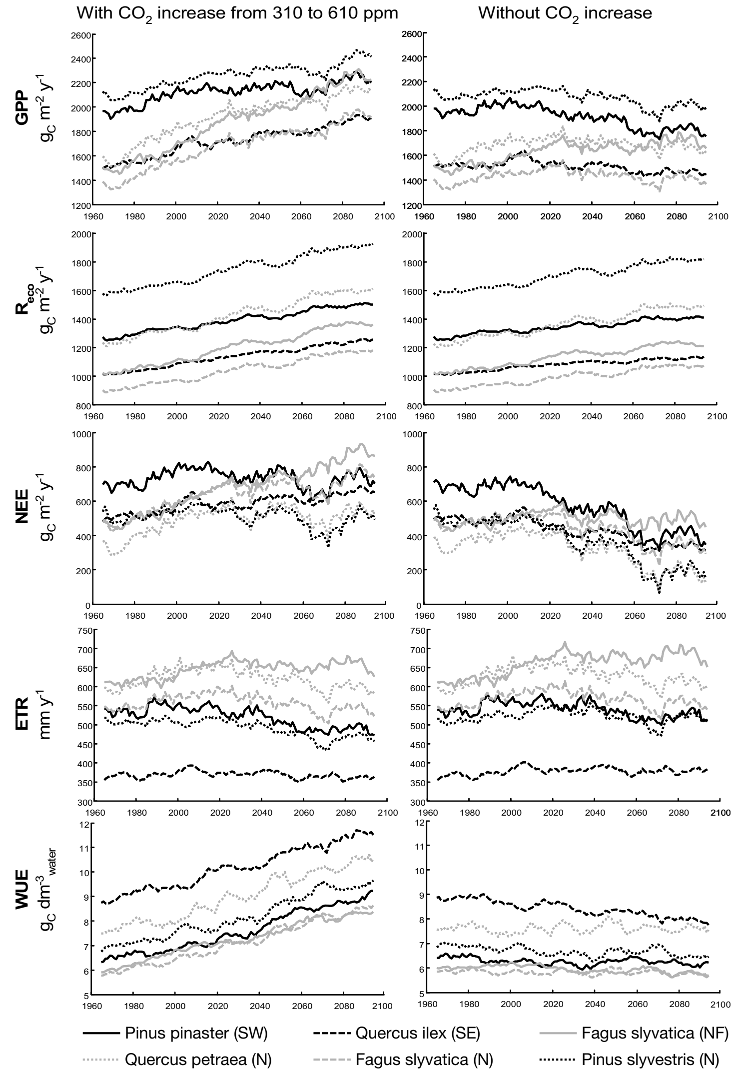

Figure 5. Gross primary production (GPP), ecosystem respiration (Reco), net ecosystem productivity (NEP), evapotranspiration (ETP) and water use efficiency (WUE) simulated from 1960 to 2100 with (left) or without (right) taking into account the atmospheric CO_2 raising (presented results are sliding average over 10 years). Adapted from Davi et al., 2006.

furthermore from the increase of the vegetation season length (called *phenology effect* in the figure). Water stress effects together with other climatic effects (temperature, air humidity) tend to lower the NEP. The water stress effect is very variable from site to site because it strongly depends on the water holding capacity of the soil. It is also interesting to note that the Q. Ilex stand is at present already adjusted to water stress and an increase in water shortage does not seem to effect the functioning of this ecosystem.

CASTANEA spatialisation

This section is a summary of the article by le Maire et al., 2005. We evaluated annual productivity and carbon fluxes over the Fontainebleau forest, a large (17,000 ha) heterogeneous forest region in terms of species composition, canopy structure, stand age, soil type and water and mineral resources (Figure 7).

The model used is CASTANEA, a process-based model that simulates carbon and water fluxes and stocks on homogeneous forest stands (Dufrêne et al., 2005).

Few attempts have been made to spatialize process-based forest models like CASTANEA at the regional scale. These models contain numerous parameters, making their application difficult at regional or larger scales because of the large amount of data required for model parameterization (CASTANEA has more than 170 parameters).

Many published studies use much simpler models for applications at large scales (e.g., Monteith approach). However these models are most of the time too simplistic to take into account (1) the forest carbon pools affecting the total ecosystem respiration, (2) the integrated effect of climate and soil conditions on fluxes and pools dynamics (for instance in a climate change context), and (3) to go back to the processes that cause these carbon and water dynamics for a research perspective.

In this study, the simulations were done on the entire Fontainebleau forest stand by stand, i.e., ~3,000 forest management units of simulation. There are no interactions between stands taken into account

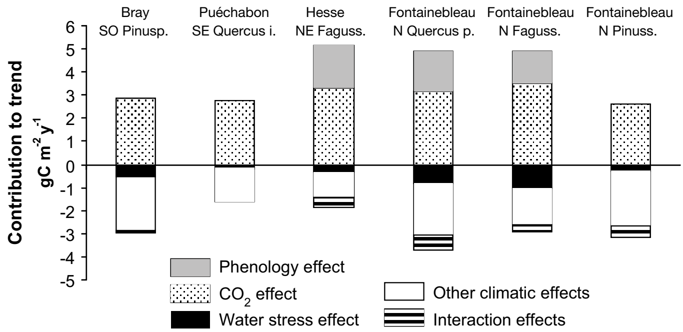

Figure 6. Summary of the role played by each factor in the determination of the simulated trends defined as the slope of the linear regression of NEP against the year between 1960 and 2100. Adapted from Davi et al., 2006.

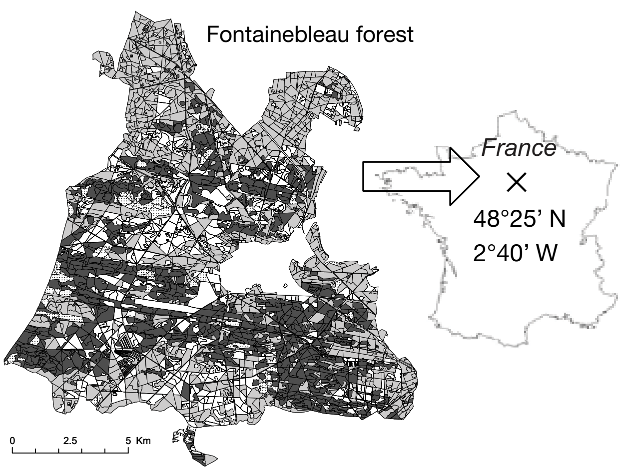

Figure 7. Forest map of the Fontainebleau forest (located southeast of Paris): *Pinus sylvestris* (dark gray), *Quercus petraea/ Q. robur* (light gray), *Fagus sylvatica* (white) and other species (stipple). Adapted from le Maire et al., 2005.

and the climate is considered to be the same on the region. These two hypotheses are suitable for carbon fluxes and stocks estimations in this forest that is mainly flat and very sandy.

The simplification of the model for upscaling is done by selecting the parameters that can be set to an average value (by species or for all species), i.e., parameters that do not vary from one stand to another. This is done in two steps: a sensitivity analysis of the model, followed by a selection of the parameters invariant from stand to stand. The first step allows us to sort all CASTANEA parameters by their order of importance, from the more sensitive to the less sensitive ones. Many parameters that are not sensitive (below a chosen threshold) are fixed to their average values. These values either come from ground measurements or from literature. The second step separates sensitive parameters that are stand-dependent and stand-independent. This separation is done based on ground measurements on a subselection of 50 stands of the forest that is representative of the forest variability, or based on forest and soil inventories. The stand-independent sensitive parameters are set to average values whereas stand-dependant sensitive parameters are obtained for each of the 3,000 stands.

These stand-dependant sensitive parameters were calculated for each stand from forest inventory attributes, a network of 8,800 soil pits, satellite data and field measurements. These parameters are (1) vegetation attributes: species, age, height, maximal leaf area index of the year, aboveground biomass and foliar nitrogen content; and (2) soil attributes: available soil water capacity, soil depth and soil carbon content.

A detailed description of the methodologies that were employed to estimate these parameters are given in le Maire et al., 2005 and le Maire et al., 2006. Other parameters were obtained after the le Maire et al., 2005 publication: budburst date(Soudani et al., 2008), leaf mass per area and leaf chlorophyll content (le Maire et al., 2008).All these parameters estimations require large GIS databases of forest and soil inventories, together with satellites images from different satellites (Spot, Hyperion, MODIS). The main principle of parameter estimation is to correlate the required input parameter with spatially available data (i.e., inventories and satellite images) by using a 50-stands subselection of stands in the Fontainebleau forest. The extrapolation to the 3,000 stands is therefore easy.

Main outputs of the simulations are wood production and carbon fluxes on a daily to yearly basis. Results showed that the forest is a carbon sink, with a net ecosystem productivity of 371 gC m^{-2} $year^{-1}$ (Figure 8). Net primary productivity is estimated at 630 gC m^{-2} $year^{-1}$ over the entire forest.

Reasonably good agreement was found between simulated trunk relative growth rate (2.74%) and regional production estimated from the National Forest Inventory (IFN) (2.52%), as well as between simulated and measured annual wood production at the forest scale (about 71,000 and 68,000 m^3 $year^{-1}$, respectively) (Table 4).

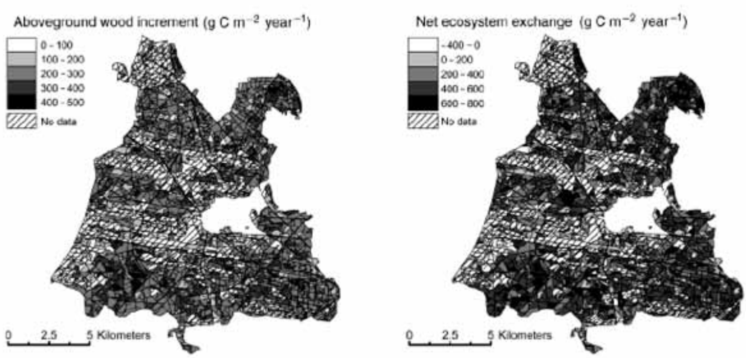

Figure 8. Maps of annual aboveground wood increment and net ecosystem productivity simulated over the Fontainebleau forest in 1995. Adapted from le Maire et al., 2005.

Table 4. Comparison of the wood volume (parametrization) and relative volume growth estimated by the National Forest Inventory (IFN) and by simulations with CASTANEA over the Fontainebleau forest (from le Maire et al., 2005).

	Parameterization		**Results**	
	Volume (IFN)	Estimated volume	Relative growth (IFN)	Estimated relative growth
	m^3	m^3	% $vol.y^{-1}$	% $vol.y^{-1}$
Oaks	1,297,000	1,344,000	1.8	2.1
Beech	414.000	326,000	3.4	2.8
Scots pines	733,000	637,000	3.0	3.9
Other species	266,000	295,000	3.0	3.1
Total Forest	2,711,000	2,602,000	2.5	2.7

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Why Is Agroforestry So Challenging for Modellers? How to Conciliate Complexity, Interactions, Accuracy and Upscaling. A Proposed Strategy for Agroforestry Modelling

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Keywords: spatial and temporal heterogeneity/interaction modelling/upscaling/hierarchical approach/sensitivity study/modelling strategy

Introduction: Large variability and interactions within agroforestry systems: a challenge for modellers?

According to their inherent heterogeneous structure, agroforestry systems appear to be, by nature, more difficult to model. In agroforestry objects, one should thus consider:

- their vertical variability: according to the different layers aboveground (overstories, understories) and also below-ground (root distribution),
- their horizontal variability: aboveground, one should consider the distribution and size of gaps in the canopy, the patches of vegetation, the micro (between interception elements) and macro clumping (between plants); below-ground, row structure, patches of coarse debris (litter) create preferential directions for root growth,
- their temporal variability: according to their own phenology, the various strata of agroforestry systems create seasonal flexibility in

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the functioning of the whole system, especially if some strata are being managed (e.g., by pruning).

This complex vertical and horizontal structure results in very imprecise definition of the *elementary plot* (the minimal object to be handled by modelling), a huge variability between elementary plots, and a very flexible behaviour of the agroforest with time.

The agroforestry system is thus a highly intangible object, and one could wonder if, realistically, it remains accessible to modelling.

As a consequence of the vertical structure, a recurrent question in agroforestry modelling is the *partitioning* of fluxes (light, energy, H_2O, CO_2, N, etc.) between layers. Flux partitioning is very rarely assessed, and it remains very relevant to assess if simple rules of thumb are realistic, for example to partition the available light for upper and understorey according to the canopy projection fraction of the upper layer (Roupsard et al., 2006).

Another consequence of multiple species coexisting in agroforestry systems is the enhancement of *interactions*. For monospecific systems, it is usually referred to competition solely (e.g., "dominance, co-dominance, suppressing" in tree plantations), whereas for multiple associations, positive interactions and facilitations mechanisms also occur. We could list examples of such interactions as below:

ß Interactions between plants and with soil for radiation: incident light is first intercepted, then partially absorbed or reemitted (transmitted, reflected, scattered), then eventually, re-intercepted by new plants or soil units in the ecosystem, up to the final extinction after a series of exchanges. During this process, the amount and the quality of radiation are altered and most of the incident radiative energy is finally dissipated as heat or latent evapotranspiration. Hence, it is much more challenging to design models of absorption (that do take re-emissions and re-interceptions into account) than simple interception models. Light absorption is of course very much affected by the respective time-course of leaf phenology of elementary plants of the agroforestry systems;

ß Interactions for acquisition of soil resources: rooting depths of the multiple species is frequently used as an *indicator* for their respective access to soil water or nutrient resources. However, interactions were proved to occur also between root systems (e.g., toxicity, competition, hydraulic lift (Richards and Caldwell, 1987; Caldwell and Richards, 1989; Burgess et al., 1998)) that may considerably change the amount of available space or resource for one given plant. Again, this below-ground interaction may vary with time, for instance according to the leaf phenology (e.g., relationship between evapotranspiration and hydraulic lift);

ß Interactions for soil organic matter (SOM) provision and use: the partitioning of net primary productivity (NPP) into growth, litter production (mortality) and exports can be extremely variable between species (Roupsard et al., 2008c), thus affecting the amount of litter, and its further incorporation into SOM. According to its quality and its horizontal distribution, this litter can be available or not for the species of the agroforestry system (or even be toxic in some occasions);

ß Interactions during management: the management of litter (mulching, exports, fires, windrowing) may have a drastic influence on its final availability and for ecosystem nutrient budget and cycling. The management of forage (mulching) is also expected to benefit much to the nonfixing species.

How do models cope with the vertical + horizontal (V+H) variability?

According to specific goals, several modelling options coexist in the literature:

ß Some canopy models simply ignore the V+H variability (e.g., big-leaf such as Penman-Monteith, (Allen et al., 1998)). Even for simple one-layer ecosystems, big-leaf models generally require empirical tuning in order to match the reality of measured fluxes. Although they require a little amount of parameters and can give rapid estimates of fluxes in any kind of ecosystem, it is unlikely that they would be accurate enough for multilayer systems.

ß Some models ignore the V variability and average the H variability. These canopy models were designed to partition the water fluxes between the cover crop and the bare soil (Shuttleworth and Wallace, 1985). In this case, the H variability is ignored, and only spatial averages are considered. The fraction of flux that comes from the soil can further be adjusted into a flux coming from the understorey.

ß Some models deal with the V variability only: the horizontal variability is here averaged, but the vertical variability is considered layer by layer—multilayered models, such as Canoak (Baldocchi, 1997)—or in two layers (sun-shade models), one of sunlit and one of shaded leaves (de Pury and Farquhar, 1997; Roupsard et al., 2008a). Sun-shade models proved to combine the advantages of simplicity and accuracy of big-leaf and multilayer models respectively, after comparing the simulations of wheat photosynthesis displaying uniform (spherical) leaf-angle distribution and homogeneous (intercepting elements distributed randomly) canopy. Other authors confirmed the validation of canopy photosynthesis and of the terms of energy balance for wheat after comparing their own sun-shade and multilayer models (Wang and Leuning, 1998) or using field eddy-covariance measurements (Leuning et al., 1998). Hence, sun-shade models come out as simple and reliable approaches on low and dense canopies. We consider that they would deserve further developments over a range of canopies, such as tall, open, nonuniform (nonspherical leaf angle distribution) and nonhomogeneous (nonrandomly distributed elements), i.e., nonideal canopies. The advantage of sun-shade models is that they require a limited number of parameters while maintaining a high level of accuracy. Some agroforestry models separate horizontally between shaded and full-sun areas, according to the fraction of soil covered, respectively, e.g., CAF (Van Oijen et al., 2008).

ß Some models deal with the V+H variability, to incorporate explicitly the H variability and allow to represent the simulated scene tree by tree: Maestra (Medlyn, 1996), HiSafe (Werf et al., 2007), WaNulCas (Van Noordwijk and Lusiana, 1998).

ß Some models portray the V+H variability, using computations on plants elements of a few cm^2 only, based on detailed architectural 3-D representations (Dauzat et al., 2001).

As a result of this model offer, it remains of high relevance to appropriately choose a model, according to a specific objective.

How do models cope with interactions?

Some agroforestry models are inclined to ignore the interactions: for instance in CAF (Van Oijen et al., 2008) one given modelled stand is composed of two sizable subplots, one for full sun (no shading trees over coffee crop) and one shaded subplot that behave independently. In other agroforestry models, interactions are specifically assigned: e.g., WaNulCas, HiSafe (Werf et al., 2007). Obviously, parameterizing interactions makes sense only if when experimental evidences and quantification of interactions are available.

Prefer simple or complex reference models?

Simple models (less parameters) would likely be more compliant with the *upscaling* exercise (E. Dufrêne, M. van Oijen, pers. comm.): the main reason is that complex models frequently require more parameters, which would vary unpredictably on a large scale.

On the contrary, "reference" models (i.e., models with detailed and mechanistic parameterization) are expected to be more satisfactory for research applications on limited scales, although one can find many counterexamples in the literature: for example, a simple Priestley-Taylor model of evapotranspiration, corrected by a NDVI approach (Fisher et al., 2008). For this model, only five inputs are required: net radiation (R_n), normalized difference vegetation index (NDVI), soil adjusted vegetation index (SAVI), maximum air temperature (T_{max}), and water vapor pressure (e_a). Their model requires no calibration, tuning or spin ups and occurred to be more accurate on tropical forests than the "reference" Penman-Monteith approach. The reason was that the Penman-Monteith model required detailed parameterization of stomatal conductance, which was not available at that scale and led to erroneous results.

We argue here that every *hierarchical approach* (i.e., comparing reference and simple models), thus checking for accuracy of simple models allows to build-up confidence for both research and scaling-up applications.

Alternatively, the *sensitivity study approach*, described further below, may allow the use reference models, even in complex situations, such as agroforestry systems.

To scale-up agroforestry models: an example of coconut plantation

Once a model has been calibrated locally, it is tempting to scale it up to watershed, landscape or region. Net Primary Productivity (NPP) for instance is a key driver of ecosystem C balance, and its scaling-up to larger areas requires indirect methods: (i) e.g., epsilon models based on light-use efficiency (LUE = NPP/APAR, where APAR is the absorbed photosynthetically active radiation by green elements of canopy), or else models based on water-use-efficiency (WUE = NPP/E, where E = evapotranspiration); (ii) remote sensing tools to estimate the fraction of APAR (fAPAR) from vegetation indices, or to estimate E. However, LUE and WUE are suspected to vary in space (soil and climate conditions, planting density) and time (seasonality, age), which needs to be documented before scaling up. Moreover, the application of this scaling approach to agroforestry systems with a stratified canopy may be difficult, since each layer contributes to the overall ecosystem light- and water-use efficiencies. Applications of remote sensing for agroforestry systems even suffer from supplementary impediments: first, it is suspected that distinct contribution of the layers for the reflected signal can be detrimental for classification, although recent development of light detection and ranging (LIDAR) might help documenting spatially their complex vertical structure (Hilker et al., 2008; Sherril et al., 2008); second, NPP, C balance, remote sensing and parametric models remain scarce for agroforestry systems (Mattamachado and Jordan, 1995; Binkley and Ryan, 1998; Mobbs et al., 1998; Sundarapandian et al., 1999; McGrath et al., 2000; Das and Chaturvedi, 2005); finally, field data for calibration of simulated fluxes should be partitioned ideally between the upper and the understorey, which is extremely rare.

Roupsard et al. (2008b) described LUE and WUE, their seasonal variations and their partitioning for a very simple bi-layer system, composed by a coconut upperstorey and an herbaceous understorey. This study was proposed in order to facilitate spatial and temporal scaling up of NPP in similar coconut groves and to provide a simple example of scaling up of NPP for other agroforestry systems. Some major prospect of calibrating remote-sensing tools in coconut groves would be to map fAPAR or APAR directly and to verify how they vary among plots differing by age, density (given by land registers), cultivars, fertilisation, drought, etc.. The monitoring of APAR can be agronomically meaningful for studying modifications of APAR after foliar attacks, hurricanes or drought events (e.g., El Niño). Also, it must be stressed that about 46% of coconut NPP is for fruits, and this compartment is very flexible compared to vegetative compartments (Navarro et al., 2008), suggesting that a monitoring of NPP through remote-sensing tools might find applications in the prediction of yield on large scales.

Choosing a model: a recommended strategy

Below, we propose a general strategy that we believe could be helpful before choosing any model in order to optimize the allocation of labour and resources during the experiment and its interpretation or modelling. This strategy is especially oriented toward the simplification of pre-existing complex models for its application on a specific scale (for instance upscaling).

- To identify and delineate the question and the scales (space and time): is the model required for local research or for scaling up or for both?
- To start with the more mechanistical model from the selected category, trying to avoid empirical models that will generally allow little *genericity* (i.e., locally valid but not scalable).
- To short-list the site-dependent parameters required by the model: all other parameters that are not site dependent can reasonably be set to an average value, taken for granted in the literature, and local confirmation is not absolutely necessary: e.g., of site-dependent parameter, LAI.
- Among the site-dependent parameters, to list the ones for which the model is sensitive: e.g., specific leaf area (SLA). If the model is not or is little sensitive to the parameter, then it is not necessary to survey the variability of that parameter during the experimentation. Note that this sensitivity study should be performed before the experiment.
- Among the sensitive parameters, to separate those that do vary spatially or temporally in the experiment, and those that do not vary (for which an average can be used): e.g., leaf N content.
- To model the spatial variability of every model-sensitive parameter: for instance correlate the sensitive/spatially variable parameters to any variable that can be assessed spatially: e.g., LAI with NDVI, SLA with leaf position.

ß To check before the experimentation if all those selected parameters can be actually documented or else change the model, for instance, choose a simpler model with fewer parameters to document.

This strategy can be used efficiently for model upscaling (le Maire et al., 2005). Indeed, at the end, only the parameters for which the chosen model is sensitive and that are spatially variable need to be documented spatially. All other parameters are fixed to average values, either measured or taken from literature. This process is similar to a basic model simplification. It has the advantage to be very adaptive: the "simplified version" of the model will be different in function of the question, scales and local conditions.

How to assign parameter confidence intervals

Models simulate an average result, but preferably with a confidence interval for the prediction. It is recommended to start from the survey of the variability of the parameters in the literature, to describe the variability of parameters locally, to run the model for every combination and then yield model prediction with confidence intervals. The combinations can be simulated systematically (e.g., Monte Carlo) or according to probabilities (e.g., Bayesian approach).

The calibration of the parameters can be done *using* the probability description.

Conclusions

Multilayer and agroforestry systems generally use models similar to those for monocrops. Several layers are dealt with, aboveground and below-ground. Interactions are new and difficult tasks, making those models unique but even more complex to build, to calibrate and to validate. We argue here that *interactions* should be considered as being a specific field for investigation on multilayer and agroforestry systems. More experimentation is required in order to help conceptualizing these forms of interactions, which will lead to new generations of models. Also experimentation is required to validate model simulations. Very generally, constant feedback between experimentation and modelling is recommended.

Perspectives and strategies

Model choice, parameter short-listing and parameter-sensitivity study should ideally be achieved before experimentation in order to design the experimental display specifically for addressing the issues of variable + sensitive parameters. Model specialists should not only rely on past experimental information but also prepare future investigation, in tight conjunction with experimentalists.

Multilayer and agroforestry systems are attractive in this sense because they are more complex, less studied than monocrop models: we argue there is an open field for investigation, which could be called *interaction modelling*.

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Modelling Coffee Rust (*Hemileia vastatrix*)

Jacques AVELINO[1,2]

Abstract

Plant disease epidemiologists have built models in order to describe, explain or predict development of epidemics, taking into account the multiple factors that can affect a disease. Indeed, the existence and severity of a disease are determined by the effects of a host, a pathogen, an environment, a cropping system and their interactions. The host component concerns types of resistance, complete or partial. It also involves physiological, morphological or even architectural aspects. The parasite component concerns the biology of the organism and genetic aspects like virulence and aggressiveness. The environmental component concerns the climate (primarily wetness, temperature, radiation, wind) as well as soil, topography, landscape structure and the biological environment. The crop management component brings into play all the agricultural practices that can affect the disease, directly or indirectly.

For coffee diseases, only statistical models have been developed. Some of them are very simple. They explain a characteristic of the disease (for example, the latent period[3]) or of the epidemic[4]

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3 The latent period is the time elapsed between the spore germination and the production of new infectious entities.

4 An epidemic can be considered as the result of the interaction between a hosts population and a parasites population.

(the percentage of diseased leaves for example) by only a few climatic or host characteristics predictors. Others are much more complicated. They integrate a great number of predictors and sometimes make a hierarchy between them by order of influence on the response. All of these models have been very useful for the understanding of the conditions that are propitious to the development of an epidemic. However, further understanding of the mechanisms that govern coffee-disease epidemics requires different approach, including the development of mechanistic models, which permit analysing in a quantitative manner the way a system is functioning. It has been widely used for modelling plants diseases, as it allows quantitative integration of the individual effects, and interactions, of various factors on complex biological processes.

Resumen en español

Modelaci n de las enfermedades del cafeto

Los epidemiólogos de las enfermedades de las plantas han construido modelos con el objeto de descibir, explicar y predecir los desarrollos epidémicos, tomando en cuenta los múltiples factores que pueden afectar una enfermedad. En efecto, la existencia y severidad de una enfermedad están determinadas por el efecto de un hospedero, de un ambiente, de un sistema de cultivo, y de sus interacciones. El componente del hospedero se refiere a los tipos de resistencia, completa o incompleta. Este también involucra aspectos biológicos, morfológicos e incluso arquitecturales. El componente del parásito se refiere a la biología del organismo y aspectos genéticos como la virulencia o agresividad. El componente ambiental se refiere al clima (principalmente la humedad, la temperatura, la radiación, el viento), como también al suelo, la la topografía, la estructura del paisaje y el ambiente biológico. El manejo del cultivo concierne todas aquellas practicas culturales que pueden afectar la enfermedad, directa o indirectamente.

Sólo modelos estadísticos han sido elaborados sobre las enfermedades del café. Estos explican una característica de la enfermedad (el periodo de latencia[5] por ejemplo) o de la epidemia[6] (el porcentaje de hojas enfermas por ejemplo) a través de unos cuantos predictores climáticos o características del hospedero. Otros son mucho más complicados. Integran a un gran número de predictores y a veces los jerarquizan por orden de influencia sobre la respuesta. Todos estos modelos han sido muy útiles para comprender las condiciones que son favorables al desarrollo de una epidemia. Sin embargo, para mejorar el entendimiento de los mecanismos que gobiernan las epidemias de las enfermedades del café, es necesario otro enfoque, que incluye el desarrollo de modelos mecanistas, los cuales permiten analizar cuantitativamente como un sistema funciona. Se ha utilizado ampliamente para modelizar las enfermedades de las plantas ya que permite la integración cuantitativa de efectos individuales, e interacciones, de varios factores sobre procesos biológicos complejos.

Introduction

The existence and severity of a disease are determined by the interactions between a host, a pathogen and an environment. Disease is diagrammatically represented as a triangle. In 1979, Zadoks and Schein proposed a modification to that representation by adding one component: the actions of the grower, i.e., the cropping system, which is able to affect the incidence and severity of diseases by its action on the host, the pathogen and the environment. The triangle became a tetrahedron following the inclusion of that fourth component (Figure 1).

[5] El periodo de latencia es el tiempo transcurrido entre la germinación de la espora y la producción de nuevas entidades infecciosas.

[6] Una epidemia puede considerarse como el resultado de una interacción entre una población de hospederos y una población de parásitos.

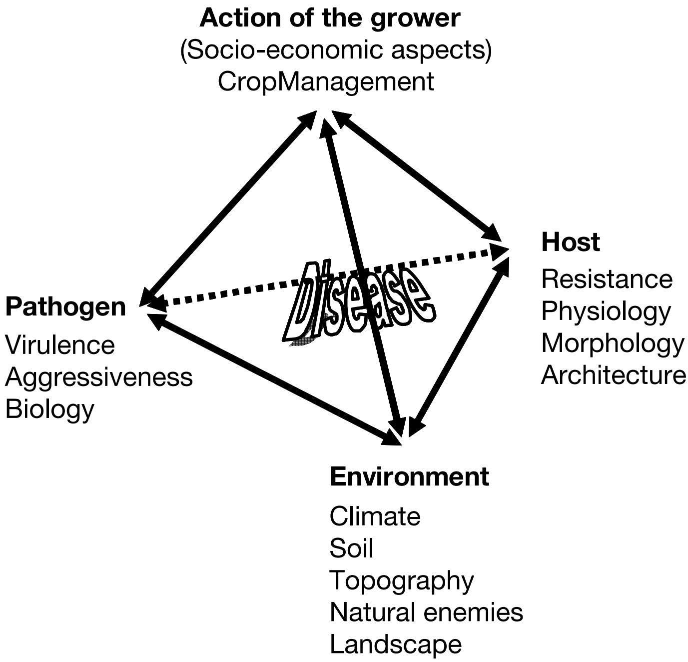

Figure 1. The disease tetrahedron and some of the main factors affecting disease development (modified from Zadoks and Schein, 1979).

A plant disease model is a simplified mathematical description of the tetrahedron. Kranz and Royle (1978) proposed to classify models into three types: descriptive, predictive and conceptual. Descriptive models describe epidemics and help to provide hypotheses on factors affecting their development, but they do not usually reflect the mechanisms that are the cause of that development. Some of these models can have predictive purposes, taking advantage of existing —probably empirical—relationships between variables. On the contrary, conceptual models are representations of the mechanisms that lead to the epidemic development. They allow the quantitative integration of individual effects, and interactions, of various factors on complex biological and ecological processes. Simulation models can be derived from these conceptual models.

Some coffee rust models

Only statistical descriptive and predictive models have been developed on coffee rust (Table 1). Some of them are very simple. They explain a characteristic of the disease (the latent period, for example) or of the epidemic (the percentage of diseased leaves, for example) by only a few climatic or host characteristics predictors. Others are much more complicated. The model built by Kushalappa et al., (1984) integrated a great number of predictors: rainfall, wind, leaf wetness, a quantification of the inoculum, the leaf area and yield. This model was proposed to determine the frequency of fungicides application in Brazil (Kushalappa et al., 1986).

Integrating crop management in coffee rust models

It seems there is only one attempt to include the action of the grower and especially shade management, the fourth component of the tetrahedron, in a coffee rust model (Avelino et al., 2004, 2006). In that attempt, coffee rust incidences, cropping practices and the other components of the tetrahedron were characterized through a three-year survey that involved 73 Honduran coffee plots. The plots that were observed over several years were considered as different individuals. Consequently, there were 133 plot-year individuals. The result was a regression tree (Figure 2) obtained by the automatic interaction detection method (AID; Morgan & Sonquist, 1963). This method can be used to relate a quantitative variable that has to be explained with qualitative predictors. It proceeds by dichotomies. At each level of the regression tree, data are divided into two groups by grouping the predictor modalities into two modalities, such that the two resulting groups are the most different with respect to the variable to be explained. As a consequence, AID regression classes the predictors by order of influence over the explained variable. In this study (Figure 2), the maximum annual incidence of coffee rust was first explained by the number of fruiting nodes per tree, i.e., the yield potential of the coffee tree. Then came fertilization, on the second level of the regression tree, altitude and shade percentage on the third level, soil pH and the number of young leaves per branch on the two following levels. It can be seen that local characteristics, specific to each plantation, and especially cropping practices like fertilization and shade, or yield, generally seemed to be more important than regional factors. For instance, altitude only came third in the regression tree, and annual rainfall did not appear.

Table 1. Some descriptive and predictive coffee rust models

Response	Predictors	Statistical method	Country and Reference
Latent period	Daily mean of minimum and maximum temperatures	Regression	Kenya; Rayner, 1961
Number of lesions per leaf	Daily mean of minimum and maximum temperatures; total rainfall	Regression	Brazil; Alfonsi et al., 1974
Proportion of leaf area rusted	Inoculum quantified as the proportion of leaf area with lesions and proportion of leaf area with spores; rainfall	Regression	Brazil; Kushalappa and Chaves, 1980
Epidemic growth rate	Inoculum quantified as proportion of leaf area with spores; proportion of new leaves; daily mean of minimum and maximum temperatures; rainfall	Regression	Brazil; Kushalappa, 1981
Epidemic growth rate	NSRMP (Net survival ratio for monocyclic process): parasite x host x environment	Regression	Brazil; Kushalappa et al., 1984
Incidence	Yield, fertilization, shade, altitude, soil pH, number of leaves	Regression tree	Honduras; Avelino et al., 2006

Shade effects on coffee rust: explaining controversial results

Figure 3 shows the maximum annual incidences of leaf rust recorded in four of the 73 plots surveyed. These four plots were located in two regions: Lake Yojoa and El Paraíso (Honduras). In each region, the two plots chosen were geographically very close and were therefore under the influence of the same climate. However, they differed in their cropping system. One was managed in what was close to an intensive system, with little shade. The other was managed in a more traditional system with high shade percentages. The incidences found in each region were very different. They could not be explained by climatic differences because the plots were under the same climate. The causes of the differences could only be sought in the specific characteristics of each plot, such as the cropping system, particularly shade. It can be seen that the effects of the cropping system on coffee rust were closely linked to their effects on yields represented by histograms. That was particularly true for the crops managed in the

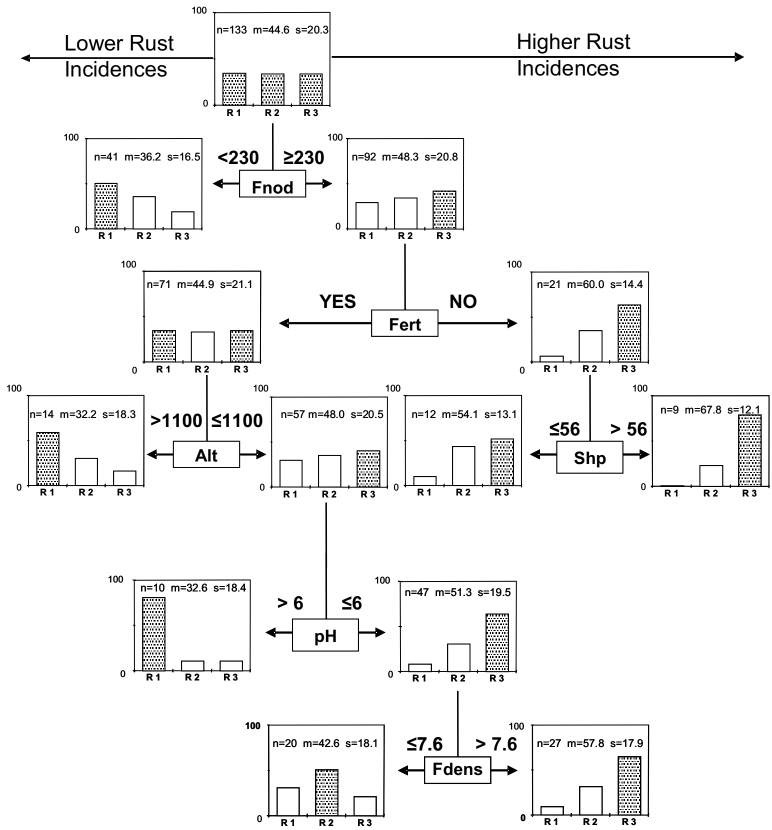

Figure 2. Regression tree explaining the maximum annual coffee rust incidence (R) from the following predictors: number of fruiting nodes per coffee tree (Fnod), annual number of fertilizations (Fert), altitude (Alt), shade percentage (Shp), soil pH (pH), number of young leaves per branch at the beginning of the rainy season (foliage density, Fdens). n: number of plot-year individuals, m: mean of R, s: standard deviation of R. For each predictor, the threshold value responsible for a dichotomy is mentioned above the arrows. All the dichotomies were significant according to the Student t test at 5%. As an illustration, for each of the groups formed, the histograms show the frequencies of the individuals in three categories of R, R1: 8.2%-32.0%, R2: 32.0%-53.4%, and R3: 53.4%-93.3%. The shaded columns correspond to the highest frequencies (for more details, see Avelino et al., 2006).

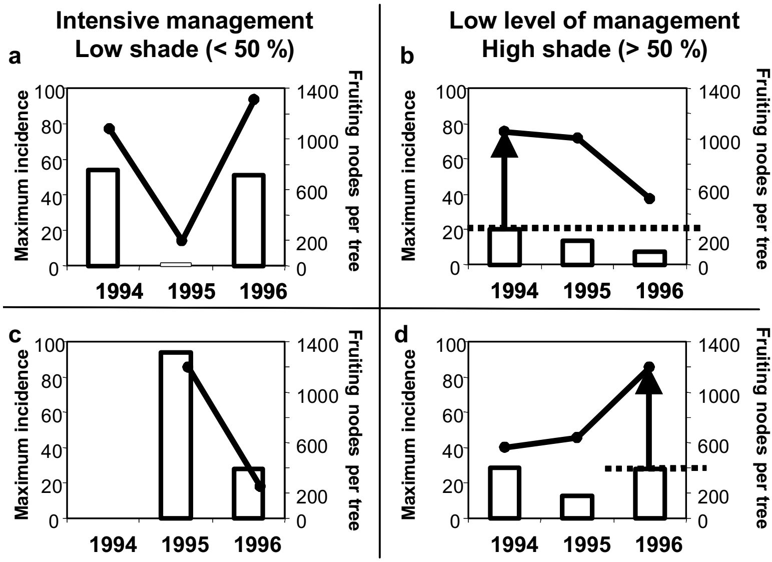

Figure 3. Trends in maximum annual incidences of coffee rust (continuous line) and number of fruiting nodes per coffee tree (histograms) in four plantations without chemical control from regions of Lake Yojoa (a,b) and El Paraíso (c,d) in Honduras (for more details, see Avelino et al., 2004).

intensive system with little shade. High yields went hand in hand with high incidences and low yields with low incidences. In plots with dense shade, as expected, yields did not reach very high levels. And, leaf rust incidence did not reach levels as high as in full sunlight, but it was never low either. It could even be very high when the trees had a fruit load of more than 200 fruiting nodes, which is very modest. These results suggest that shade has negative effects on leaf rust by keeping yields at low levels but favours leaf rust once production reaches a certain threshold, probably by favouring spore germination. This interpretation reconciles contrasting views on the effect of shade on coffee rust. Some authors have reported low attack intensities under shade (Soto-Pinto et al., 2002), while others have reported a high rust incidence (Machado and Matiello, 1983; Staver et al., 2001). These different results could be explained by coffee tree yield and its interaction with shade.

Modelling coffee rust epidemics

Modelling coffee rust epidemics probably requires different approaches from those developed until now. The development of mechanistic models, which allow analyzing in a quantitative manner the way a system is functioning, would be very useful. The effects of different factors influencing the dynamic of coffee rust epidemic could be considered at two levels. The first level would be the coffee tree, during one season. At this level, the system can be represented as a population of foliar sites at various stages (noninfected, latent, infectious, eliminated). The second level is the plantation in the course of successive production cycles. At this level, the system could be a population of leaves (healthy, infected and fallen) sorted by age classes. Those two levels, which differ by their physical size and time steps, would permit addressing different mechanisms and their interactions. The first level enables to focus on the direct intra-annual effects on the disease kinetic: for example, the effects of climate on the parasite life cycle. The second level enables addressing more complex, and often indirect, effects on epidemics—especially the effects of yield, which is known to follow a biennial rhythm. Moreover, coupling a coffee growth model with a coffee rust model could be necessary because of the narrow relationships between rust epidemics and coffee foliage and yield. To our knowledge, such a coffee rust model does not exist, but its development would trigger the mobilisation of current knowledge and new insight toward coffee rust management.

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Predicting the Effect of Climate Change on Perennial Crops: What Do We Know, What Factor Do We Need to Take into Account and Which Models Can We Use?

Nicolás FRANCK[1] and Carlo MONTES[1]

Abstract

Most research dealing with the agronomic impacts of climate change has focused on major annual crops, yet little is known about its impacts on perennial crops, which are less adaptable and could therefore be more susceptible to potential damage. Some of these perennial crops are of high socioeconomic and cultural importance (e.g., coffee and cocoa) and predicting the effects of climate change on their yield and quality will be needed to prioritize future adaptation strategies.

Our current knowledge of climate changes predicts increments in atmospheric CO_2 concentration (C_a), and variations in air temperature (T_a) and in the frequency and intensity of rainfall. All these environmental factors are directly involved in the agronomic outcome of perennial cropping systems by affecting their carbon assimilation, phenology and resulting yield. Moreover, all these environmental factors result in complex interactions at the crop level (e.g. C_a, T_a and water availability all differently affect photosynthesis) indicating that a modelling approach would be the best way of quantifying the effects of climate change on crop

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variables of economic interest. Different models can be used for this purpose, ranging from statistical models, based on observations gathered in different locations during the last decades, to mechanistic models, based on the study of crop physiological processes.

Here we summarize some crop models that take variations in either C_a, T_a water availability and combinations of these factors into account and could hence allow predicting the effects of climate change on different yield components of perennial crops. Aspects that need to be developed for simplifying, integrating and/or adapting these models in order to efficiently predict the effect of climate change on perennial crops are discussed. Finally, strategies for managing agroforestry systems for modifying the microenvironment in order to mitigate negative effects of climate change on perennial cropping systems are proposed.

Resumen en español

Predicci n del efecto del cambio clim tico sobre los cultivos perennes: Qu sabemos, qu factores debemos tomar en cuenta y qu modelos podemos usar?

La mayor parte de los estudios referentes a los impactos agronómicos del cambio climático se han centrado en los principales cultivos anuales, sin embargo poco se sabe sobre los impactos sobre los cultivos perennes, especies que son menos adaptables y podrían, por lo tanto, ser más susceptibles a potenciales daños. Algunos de estos cultivos perennes son de gran importancia socioeconómica y cultural (e.g., café y cacao) por lo que se hace necesario predecir los efectos del cambio climático sobre su rendimiento y calidad para poder priorizar futuras estrategias de adaptación.

Nuestro conocimiento actual del cambio climático predice incrementos en la concentración atmosférica de CO_2 (C_a) y variaciones en la temperatura del aire (T_a) y la frecuencia e intensidad de las lluvias. Todos estos factores ambientales están directamente involucrados en los resultados agronómicos de los sistemas de cultivo perennes, ya que afectan tanto su asimilación de carbono como su fenología y consiguiente rendimiento. Por lo demás, todos estos factores ambientales resultan en interacciones complejas a nivel de los cultivos (e.g., C_a, T_a y la disponibilidad de agua afectan la fotosíntesis diferencialmente), lo que indica que un enfoque de modelamiento sería la mejor manera de cuantificar los efectos del cambio climático sobre las variables de cultivo de interés económico. Para dicho propósito se pueden utilizar diferentes modelos que van desde modelos estadísticos, basados en la recolección de datos de distintas regiones a lo largo de las últimas décadas, hasta modelos mecanicistas, basados en el estudio de los procesos fisiológicos de los cultivos.

En el presente trabajo se resumen algunos de los modelos de cultivo que toman en cuenta los efectos de ya sea C_a, T_a, disponibilidad hídrica y combinaciones de dichos factores y podrían, por lo tanto, permitir la predicción de los efectos del cambio climático sobre diferentes componentes del rendimiento de los cultivos perennes. También se discuten algunos aspectos que se requeriría desarrollar para simplificar, integrar y/o adaptar estos modelos de modo de predecir eficientemente el efecto del cambio climático sobre los cultivos perennes. Finalmente, se proponen estrategias de gestión de los sistemas agroforestales para modificar el microambiente, de modo de mitigar los efectos negativos del cambio climático sobre los sistemas de cultivos perennes.

Climate Change: Its Impacts on Coffee Farming Households and the Role of Agroforestry

Jeremy HAGGAR[1]

Abstract

Climate variation and oscillating cycles between El Niño and La Niña have contributed to extreme variations in coffee production in Nicaragua, Central America. This has led to income of small farmers crashing from USD 2,300 one year to only USD 600 the next. Projections of the impact of climate change on coffee in Mexico and Sao Paulo Brazil indicate drastic changes in coffee production with change in climate likely to occur this century. Models to predict changes in coffee distribution, production and quality need to be developed for Central America and other regions. Adaptation strategies include better information management about short-term climate variation, development of varieties to adapted to new climatic conditions, shade management systems with greater resilience to climate variation, greater water efficiency in production and processing, insurance mechanisms to enable producers bridge years affected by climate extremes and last, but not least, marketing strategies to deal with variability in production. Nevertheless many options for adaptation both agronomic and economic remain to be validated; models are a powerful tool to explore the potential of different adaptation options and better understand their potential impacts.

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Resumen en español

Impactos del cambio clim tico sobre las familias productoras de caf y el papel de la agroforester a

Los resultados de investigación reciente sugieren que Centroamérica es una de las regiones más propensa a volverse más caliente y seca en el transcurso de este siglo. Evidencia obtenida en Centroamérica sugiere que esto ya está sucediendo. Estudios sobre el cambio climático en las últimas dos o tres décadas en zonas cafetaleras de México, Guatemala y Honduras indican que las temperaturas han aumentado entre 0.2°C y 1°C en este período de tiempo, y en algunos casos la precipitación ha declinado hasta un 15%. La extrapolación de estas tendencias indica un descenso significativo en la producción y aprovechamiento del café; por ejemplo, una reducción del 32% en Veracruz, México para el 2020. Las predicciones de cambio climático del Ministerio de Recursos Naturales y Ambiente en Nicaragua indican que dentro de este siglo las precipitaciones disminuirán en un promedio del 30%, y las temperaturas aumentarán de 1°C a 2°C. Estos cambios eliminarían efectivamente la producción de café en la vertiente alta del Pacífico Norte de Segovias, el café más solicitado y de mayor calidad en el país.

La variación climática parece estar teniendo un impacto significativo sobre la producción de café en Nicaragua. A lo largo de los últimos cuatro años, los ciclos climáticos de El Niño y La Niña han sido más frecuentes. Los ciclos han alternado de un año al otro; 2004 y 2006, años de El Niño, tuvieron precipitaciones bajas. El 2006 fue uno de los años con menos precipitación en la historia, mientras que el 2005 y 2007, años de La Niña, tuvieron precipitaciones muy altas. Estas fluctuaciones en la precipitación han coincidido con las fluctuaciones bianuales de la producción de café, conduciendo a altas y bajas extremas en dicha producción. En el 2004 y 2006 la producción de café fue de 1 millón de sacos de 46 kg, mientras que en el 2005 y 2007 la producción ha sido de aproximadamente 2 millones de sacos. Evidentemente esto tiene impactos significativos sobre la economía de las fincas y sobre el abastecimiento en café para los compradores. En las Segovias, Nicaragua, pequeños productores que produjeron 1.8 toneladas de café verde durante los años de La Niña, obteniendo un beneficio de USD 2,300, vieron declinar la producción a solo 0.7 toneladas de café durante los años de El Niño, obteniendo solamente USD 600. Producir la mitad del café repercute económicamente en tener solo un tercio de los beneficios. En realidad muchos agricultores no llegan a cubrir los costos de producción durante los años de El Niño y se mantienen en deuda, lo cual afecta su capacidad para manejar de su café y para cubrir las necesidades de sus familias en educación y salud.

¿Existe un papel potencial para la agroforestería en el amortiguamiento de estos cambios? Las áreas marginales cafetaleras en el sureste de Nicaragua a 450 m.s.n.m. con un promedio de 1.400 mm de precipitación presentan una situación de temperaturas altas y precipitación baja donde hemos estudiado los efectos de la sombra y manejo sobre la producción de café. Seis años de resultados demuestran que a pesar de las condiciones marginales, el café sin sombra ha sido igualmente o más productivo que el café de sombra. En el 2006 la precipitación cayó a solamente 1.000 mm, proveyendo condiciones similares a las que podemos esperar con el cambio climático. Las respuestas del café de sombra y sin sombra han sido muy diferentes bajo estas condiciones. Primeramente los niveles de sombra en la mayoría de los sistemas agroforestales bajó de 40–60% de cobertura a aproximadamente un 20%. La producción sin sombra se redujo entre el 25–65% de la producción promedio, mientras que la producción del café de sombra bajó entre el 6–75%. La variación en la respuesta pareció estar relacionada a la presencia de horizontes endurecidos en el perfil del suelo y al grado de quema en el florecimiento inicial. Sin embargo, hubo poca razón para pensar que el café de sombra tuvo más alta resiliencia a la sequía que el café sin sombra.

Estos resultados contradicen la sabiduría convencional que dice que entre más secas las condiciones, más sombra es necesaria. El modelaje puede proveer varios insumos:

1. ¿Cuál es el balance entre la mejora micro climática de la demanda de agua y la competición del suministro de agua entre café y árboles de sombra?
2. ¿Cuáles son los factores que determinan el inicio de la floración y el número de flores o aborto bajo condiciones de sombra o luz?
3. ¿Cómo afecta la variación de la precipitación y la temperatura a la maduración del fruto?
4. ¿Cuál es la base para desarrollar recomendaciones de manejo (regulaciones de sombra) para los años de precipitación alta o baja?
5. ¿Cuál es el potencial para mejorar la alta variación anual en la producción (y de este modo el ingreso de la finca)?
6. ¿Cuáles son las regiones (o condiciones) donde la producción de café puede adaptarse al cambio climático, y dónde desaparecerá?

Introduction

Results of recent research suggest that Central America is one of the regions most likely to get both hotter and drier during this century (IPCC 2007). Evidence from Central America suggests that this is already happening. Studies of climate change over the past two to three decades in coffee growing zones of Mexico, Guatemala and Honduras indicate that temperatures have risen by between 0.2°C and 1°C over this time period, and in some cases rainfall declined by up to 15% (Castellanos et al., 2003). Climate change predictions by the Ministry of National Resources and the Environment in Nicaragua indicate that within this century rainfall will decline by an average of 30%, and temperatures rise by 1°C to 2°C. These changes would effectively eliminate coffee production in the high northern Pacific-slope highlands of Segovias, the most in demand and highest quality coffee in the country.

How may climate change affect coffee production in Central America and Mexico?

Climate variation appears to be having significant impact on coffee production in Nicaragua. Over the past four years the El Niño/La

Niña climate cycles have increased in frequency. Cycles having alternated from one year to the next; 2004 and 2006 were low rainfall El Niño years, 2006 having historically low rainfall; while 2005 and 2007 were very high rainfall La Niña years. These fluctuations in rainfall have coincided with the normal biannual fluctuations in coffee production to create extreme highs and lows in coffee production, with 2004 and 2006 producing about 1 million 46-kg sacks of coffee, while in 2005 and 2007 production has been nearly 2 million sacks. Clearly this has significant impacts on farm economics and supplies of coffee to buyers.

In surveys with farmers in 2005 in northern Nicaragua and eastern Honduras, coffee production has varied from 540 kg to 930 kg per hectare green coffee over just the past three years, during which coffee prices have been relatively stable. Climate was the one of the three most important reason farmers gave for this variability (Table 1).

Subsequent monitoring of small coffee farmers in Segovias, Nicaragua, comparing 2005 and 2006, showed how variations in coffee production can affect farm economics. During the 2005 La Niña, they produced 1.8 tons of green coffee, making a profit of USD 2,300,

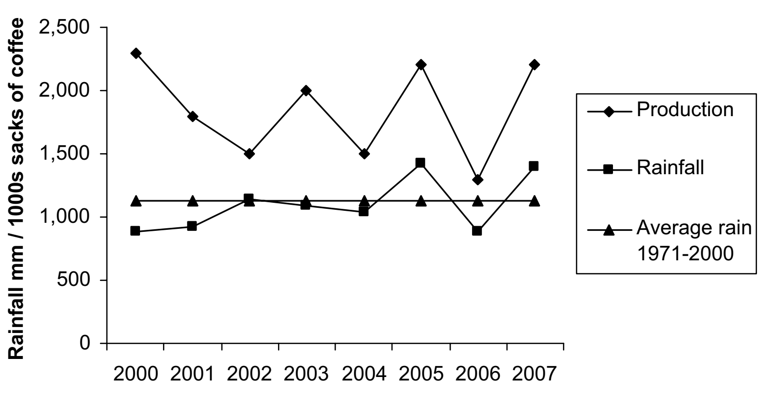

Figure 1. Variations in coffee production (thousands of 100 lb sacks) and annual rainfall (averaged from 6 sites near to coffee growing regions) in Nicaragua. Data from National Territorial Institute, Nicaraguan Central Bank and Ministry of Agriculture. Production for 2007 is an estimate.

which declined to only 0.7 tons of coffee in El Niño years, making only USD 600 (Table 2). Thus the economic impact of half the production is only a third of the profits. In reality many farmers do not meet their production costs in El Niño years and remain in debt, which affects their capacity to manage their coffee and meet their families needs for health and education.

The surprise in 2006 in Nicaragua was that not only was coffee production affected in the traditionally drier areas of Segovias but also in the normally wetter areas of Jinotega and Matagalpa. The technical managers of PRODECOOP and CECOCAFEN in Nicaragua have been stunned by a fall in coffee production of up to 50%. In one cooperative in San Juan de Rio Coco, coffee production per farmer has declined by 27%. They definitively attribute this decline in production to climate change and are anxious to develop strategies to confront it. At a national level the Ministry of Agriculture and National Coffee Commission estimate that the 2006–2007 harvest will be half that of the previous year, representing a loss of income of USD 100 million to the poorest country in Latin America.

The high rainfall from La Niña-induced hurricanes is not necessarily good news either. Coffee production and the families of producers in the Pacific of Guatemala were seriously affected by the floods and

Table 1. Farmer perceptions of the primary influences on yield variability in Nicaragua and Honduras.

	Lack of resources for management	Pests and Diseases	Climate extremes
% farmers who present this reason for variation in production	24-35%	0-43%	10-25%

Table 2. Comparative income of small coffee farmers in Segovias Nicaragua in El Niño and La Niña years.

	2005-06 ñ La Ni a	2006-07 ñ El Ni o
100 lb sacks green coffee	41	17.5
USD income	3310	1424
Production cost USD	930	771
Net income USD	2380	653

destruction from Hurricane Stan, which came just as the harvest was beginning at the start of October 2005. About 20% of the harvest was lost, and many coffee mills and access roads were damaged. The loss in coffee production from just the coffee cooperatives in Pacific Guatemala was estimated at USD 4 million.

Studies of the future impact of climate change on coffee-producing areas in Mexico by Gay et al., (2006) show that between 1969 and 1998 in Veracruz, rainfall decreased by 40 mm per year and temperatures increased by 0.02°C per year. Extrapolating these changes to 2020, they find that coffee production could decline by 34%, but most importantly, this decline in production takes producers from making net profits of on average about USD 440 per acre, to less than USD 40 per acre. Similarly dramatic changes in production and revenue have been predicted by Pinto et al. (2007) for Sao Paulo state in Brazil (Table 3).

Table 3. Change in coffee area, production and revenue from Sao Paulo Brazil with different temperature increments (Pinto et al., 2007).

Increase in temperature	Area Suitable for Coffee (km)	Production (tonnes)	Change in production (tonnes)	Change in revenue (USD)
+1°C	145,202	269,082	-80,829	-113,160,600
+3°C	75,455	139,614	-210,297	-294,415,800
+5.8°C	8,439	15,746	-334,165	-467,831,000

Recovery from the coffee crisis and adaptation to climate change

With the moderate recovery in coffee prices since 2003, Central American coffee producers have been attempting to reestablish their coffee plantations after their semi-abandonment between 2000 and 2003. For example, the major coffee cooperatives in Nicaragua (PRODECOOP, CECOCAFEN) and the Honduran Coffee Institute, among others, have initiated programs to plant millions of new coffee trees in 2006 and 2007. This is primarily to replenish old exhausted coffee plants, however the high variability in rainfall means this has become a risky investment. Unfortunately, after good rains in 2005, El Niño returned in mid-2006 and rainfall has been reduced; a long dry season is expected, which will probably lead to low survival of the new coffee plants.

During the previous El Niño cycle between 2000 and 2001 a group of farmers in Las Sabanas (a region that produced a top-10 Nicaraguan Cup of Excellence coffee in 2005) attempted to establish new coffee, but were only able to do so where evergreen shade trees were already established. Plantings of coffee with the temporary shade they normally employ had very low survival, leaving only 25–35% alive after one year. Coffee planted under established tree shade had adequate survival of 56–96%. Additionally, a year later only the coffee with evergreen shade trees had grown well, while 60–80% of the plants under deciduous shade were considered in poor condition. In contrast, in the higher rainfall region of Matagalpa, all coffee plantings had more than 80% survival and good growth irrespective of shade type. Permanent established shade conditions may prove essential to maintaining coffee production in these regions as they become hotter and drier.

The ECOM group in Nicaragua is so concerned by the effects of lack of rainfall that they have brought in drip-irrigation experts from India to help establish irrigation trials in the Segovias region. Obviously this represents a substantial investment as well as an added demand on declining water supplies. Other strategies include grafting Arabica buds onto more drought-resistant Robusta rootstocks. Technical staff from PRODECOOP have been adapting shade management strategies to maintain higher levels of shade during the dry season but then prune once the rains have started. Also in the region there are new coffee hybrids that appear to be less altitude (temperature) sensitive as to the quality they produce and with greater plant vigor and possibly greater resilience to drought.

Technical assistance providers have also been attempting to tailor their advice according to the short-term predictions of climate variation, especially the occurrence of El Niño and La Niña events. However, short-term predictions come in the form of probabilities of more, equal or less than normal rainfall that are not easy to interpret, let alone to develop management recommendations from them. Also, information may not reach the field in time as happened during the transition from El Niño to La Niña en early 2007: technical staff were recommending not pruning shade due to the El Niño of the past year, but weather conditions were rapidly changing to La Niña, which led to rains during the "dry season" in some coffee-growing areas. Another important weather change that affects producers is increased occurrence of cold fronts and rain during the harvest from November to February; in 2007-2008 many farmers reported that coffee ripening was at least a month behind due to these effects.

Is there a potential role for agroforestry in buffering these changes?

The marginal coffee growing areas in southern Nicaragua at 450 meters above sea level, with average 1,400 mm rainfall, present a situation of higher temperatures and low rainfall where we have studied the effects of shade and management on coffee production. Six years of results show that despite the marginal conditions, full-sun coffee has been equally or more productive than shaded coffee. In 2006 rainfall fell to just 1,000 mm, providing conditions similar to those we may expect with climate change. The response of shade and sun coffee has been quite variable under these conditions. First, shade levels in the *Inga* agroforestry systems fell from 40–60% cover to about 20% when the dry season extended into its seventh month. Production under full sun was reduced from 25% to 65% of average production, while shade coffee production fell from 6% to 75%. Those shaded (and sun) systems where production collapsed appeared to be related to the presence of a hard-pan in the soil profile, whose depth varies across the site. Nevertheless, there was very little reason to think the shaded coffee had more resilience to drought than full-sun coffee. These results are contrary to the conventional wisdom that under drier conditions more shade is needed.

Based on these experiences we can identify a number of tasks that may contribute to the development of a strategy for adaptation to climate change.

1. Monitoring and short-term predictions of climate in coffee zones
2. Model changes in climate of coffee regions
3. Estimate impacts on coffee distribution, production and quality
4. Evaluate new genetic materials for resilience to climate change
5. Use models and field trials of shade management to increase agro-ecosystem resilience
6. Increase water-use efficiency in processing

7. Create "insurance" measures to help producers bridge years affected by climate extremes
8. Develop marketing strategies to cope with variation in volume and quality of product
9. Identify policy instruments that facilitate adaptation

What do we need from modelling?

From modelling we need various inputs to improve our understanding of the potential impacts of climate change and to our options for adaptation:

1. Plant models of how climate affects initiation of flowering and fruit set, and fruit maturing
2. Plant-tree models of the balance between water competition and microclimate amelioration
3. Plant-disease models of how incidence and management may need to change under future climate scenarios.
4. Production system-climate models of productivity (and quality) under different climate scenarios
5. Farm models of management, productivity, costs and income as function of climate and other stresses
6. Business models for exporters of how to manage high annual variation in volume and quality of product
7. Landscape models of how coffee production and distribution (of coffee and other land-uses) is affected under different climate scenarios
8. Country models of how national production and income will be affected by climate variation and change under different policy scenarios.

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SESSION 2

Socioeconomic Modelling

Chairman: Jeremy Haggar (CATIE)

Economic Perspectives for Central America after CAFTA: A GTAP-Based Analysis[1]

Joseph F. FRANCOIS,[2] Luis RIVERA[3] and Hugo ROJAS-ROMAGOSA[4]

Abstract

The United States (U.S.) and the five Central American countries—Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua—concluded negotiations on the U.S.-Central American Free Trade Agreement (CAFTA) in January 2004. Under the Caribbean Basin Initiative (CBI), many Central American exports already enter the U.S. without duties. CAFTA will consolidate those benefits and make them permanent, so nearly 100% of all consumer and industrial products made in Central America will enter the U.S. market duty-free immediately on ratification of the agreement.

Our analysis uses the Global Trade Analysis Project (GTAP) database and standard static model with different shocks to evaluate the alternative scenarios. For the five Central American economies, CAFTA represents a series of opportunities that can be exploited, but also a series of critical challenges. Given the importance of U.S. trade and investment in the region, in addition

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to the huge size differences between both regions, the agreement produces significant sector and economywide effects. From a Central American perspective, our simulations find a noteworthy welfare increase from CAFTA. However, the agreement also induces a larger export specialization in the already significant maquila-based sectors (i.e., textiles and apparel). This effect increases the region's trade and growth dependence on a single sector, and it draws resources from other industries and the agricultural sector. The short-term political and social consequences of this specialization can be costly.

The most welfare-improving mechanism in CAFTA is the increase in Foreign Direct Investment and the capital stock of the region. This emphasizes the importance of exploiting the investment opportunities associated with permanent market access to the U.S. Without complementary economic policies, the trade agreement can be considered mainly as a balancing force to counteract the negative impact that the implementation of the Agreement on Textiles and Clothing protocol has for the regional economy with the increased competition of Chinese textiles and apparel goods. On the other hand, the U.S. economy is barely affected.

Resumen en español

Perspectivas econ micas para Centroam rica despu s de CAFTA: Un an lisis basado en el modelo GTAP

Los Estados Unidos de América y los cinco países centroamericanos—Costa Rica, El Salvador, Guatemala, Honduras y Nicaragua—concluyeron negociaciones sobre el Tratado de Libre Comercio para América Central (TLC o CAFTA por sus siglas en inglés) en enero de 2004. Bajo la Iniciativa de la Cuenca del Caribe (CBI), muchas de las exportaciones centroamericanas ya tienen entrada libre de impuesto en los EE.UU. CAFTA consolidará estos beneficios y los hará permanentes, así que aproximadamente el 100% de los productos industriales y de consumo producidos en Centroamérica entrarán al mercado estadounidense libres de impuestos inmediatamente después de la ratificación del acuerdo.

Nuestro análisis utiliza la base de datos GTAP y un modelo estático común con diferentes choques para evaluar los escenarios alternativos. Para las cinco economías centroamericanas, CAFTA representa una serie de oportunidades que pueden ser aprovechadas, pero también una serie de retos críticos. Dada la importancia del comercio e inversión estadounidense en la región, además de la enorme diferencia de tamaño entre ambas regiones, el acuerdo produce efectos significativos para a nivel de los sectores y de la economía. Desde la perspectiva centroamericana, nuestras simulaciones encuentran un incremento notable en la riqueza global por CAFTA. Sin embargo, el acuerdo también induce a una mayor especialización hacia la exportación en los importantes sectores de maquila (por ejemplo, textiles y prendas de vestir). Este efecto aumenta la dependencia del comercio y del crecimiento de la región sobre un único sector y quita recursos a otras industrias y al sector agrícola. Las consecuencias políticas y sociales a corto plazo de esta especialización pueden ser costosas.

El mecanismo que más incrementa el bienestar en CAFTA es el incremento de la IED (Inversión Extranjera Directa) y el stock de capital de la región. Esto enfatiza la importancia de aprovechar al máximo las oportunidades de inversión asociadas con el acceso permanente de mercado hacia los EE.UU. Sin políticas económicas complementarias, el acuerdo comercial puede considerarse principalmente como una fuerza de equilibrio para contrarrestar el impacto negativo que la implementación del protocolo del ATC (Acuerdo de Textiles y Prendas de Vestir) tiene en la economía regional con el incremento de la competencia de textiles chinos y artículos de vestir. Por otro lado, la economía estadounidense es apenas afectada.

Introduction

The United States (U.S.) and the five Central American countries —Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua— concluded negotiations on the U.S.-Central American Free Trade Agreement (CAFTA) in January 2004.[5] Computational General Equilibrium (CGE) applications have been used to evaluate its consequences for Central America.[6] In this case we use a standard GTAP application to evaluate the static effects of CAFTA for the region. In addition, we identify and evaluate potential effects associated with the complementary policies negotiated in the agreement.

Under the Caribbean Basin Initiative (CBI), many Central American exports already enter the U.S. without duties.[7] CAFTA will consolidate those benefits and make them permanent, so nearly 100% of all consumer and industrial products made in Central America will enter the U.S. market duty-free immediately on ratification of the agreement. The existence of an earlier trade-enhancing mechanism represented by the CBI introduces two important considerations. First, the CBI can be regarded as a halfway step in the trade liberalization process between both regions. As such, it would imply that CAFTA does not grant new market access for Central American products to the U.S., but it enhances the list of products that have had such trade preferences in the past.

Under these considerations, some sectors have already adjusted and taken advantage of export opportunities, and it is expected that CAFTA will expand the participation and trade volume of the remaining sectors.[8] This distinction is important because previous static CGE applications have been criticized for failing to fully account for the productive and export diversification driven by such trade agreements as NAFTA (Kehoe, 2003). The combined implementation

[5] The Dominican Republic was included in the agreement in August 2004, named afterward DR-CAFTA.

[6] The agreement has already been ratified by all signatory countries but Costa Rica (the Costa Rican ratification is expected in December 2008). Existing CGE applications include Brown et al. (2004), Hilaire and Yang (2004), USITC (2004), Sánchez and Vos (2007).

[7] The 1984 CBI benefits were enhanced by the Caribbean Basin Trade Partnership Act (CBTPA), enacted in May 2000 as part of the Trade and Development Act.

[8] Given the relatively small size of the Central American market for U.S. companies, the agreement can hardly create significant economywide effects for the U.S.

of the CBI and CAFTA with a relatively long intermediate period, assures that the productive adjustment process is gradual, and that we can be less concerned with this type of static CGE limitations.

Second, the agreement includes politically sensitive products not present in the CBI (e.g., sugar, textiles and apparel). Although the U.S. economy is barely affected, the trade agreement caused intense lobbying from interest groups in the U.S.

From a Central American perspective, our simulations find a noteworthy welfare increase from CAFTA. However, the agreement also induces a larger export specialization in the already significant *maquila*-based sectors (i.e., textiles and apparel). This effect increases the region's trade and growth dependence on a single sector, and it draws resources from other industries and the agricultural sector. The political and social consequences of this specialization could be costly.

However, the already implemented quota reduction of Chinese textile and apparel exports to the U.S. is currently creating intense competition pressures that will seriously affect the trade flows from Central America to the U.S. Our baseline estimations already capture the Chinese quota reduction. Thus, the lower-bound gains from CAFTA are expected to roughly compensate for Chinese competition in this sector. Taken into consideration the significant differences between the economies of both regions, CAFTA entails both significant opportunities and threats to Central America. Chinese competition highlights the importance of implementing policies aimed at diversifying exports and increasing agricultural competitiveness, which in turn can reduce the high unemployment and poverty rates of the region.

The main achievement of CAFTA is the formalization of market access concessions currently set by the U.S. on a unilateral basis under the CBI. In addition, an institutional and legal framework has been negotiated to ease FDI flows into the region. Thus, the potential increase in FDI is expected to incentive growth and employment opportunities. Moreover, an increase in trade facilitation mechanisms creates a positive and significant welfare effect.

On the other hand, the welfare implications of the agreement are positive for the U.S. Without CAFTA the reduction of the textile and apparel (T&A) Chinese quotas negatively affects this sector in the U.S. With CAFTA, the T&A sector in the U.S. increases output to supply the Central American *maquilas*. In addition, the bilateral trade balance is improved, while no specific sectors are hurt. Under the negotiated conditions, the sugar industry remains highly protected from Central American competition.

The Model

Our analysis is based on the GTAP 6.0 prerelease 3.10 database and we use a standard GTAP static model with different shocks to evaluate the alternative scenarios. A limitation of the database is that it groups together all Central American countries (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama and Belize), of which only the first five are included in CAFTA.[9] A recent study by the United States International Trade Commission (USITC, 2004) broadly adjusts the data to account only for the five countries and includes the Dominican Republic, which joined the agreement in August 2004.[10] We do not find significant differences with the USITC's broad estimations and thus leave the data unaltered. However, this highlights the need to include the countries separately in the future. This distinction is especially necessary for evaluating the effects of CAFTA for Costa Rica, which has a different productive structure and export platform than the rest of the region.

Table 1 summarizes the main results for all the scenarios. From the point of view of the U.S., CAFTA represents insignificant overall changes in its main macroeconomic indicators. From the different scenarios, some sectors benefit from the agreement, mainly rice and the T&A sector, which is expected to provide intermediate inputs to the T&A *maquilas* of Central America.[11] Moreover, bilateral trade volumes are significantly boosted, from values between 25% and 60% for the different scenarios.

[9] Panama is currently negotiating an FTA with the U.S. The new GTAP 7 data base has disaggregated data for four Central American countries.

[10] We do not include this country in our exercise because of data limitations; instead, we want to focus exclusively on Central America.

[11] Although we do not explicitly create any restrictions to account for rules of origin, in all our simulations CAFTA produces an increase of T&A imports from the U.S. to Central America, with a decrease of imports from the other two regions.

Table 1. CAFTA: Summary results for all scenarios.

	Welfare Gains (Mill. USD)		Welfare net Gains /1* (Mill. USD)		GDP (% change)		Household Income (% change)		Terms of Trade (% change)		Bilateral Trade Volume (% change)	
SCENARIO	USA	CA	USA	CA	USA	CA	USA	CA	USA	CA	USA	CA
Initial Values (Mill. USD)	-	-	-	-	10,082,153	70,149	-	-	-	-	23,169	23,044
ATC Protocol	6,293	-541	6,293	-541	0	-0.2	-0.1	-2.3	0.3	-1.3	-8	-7.4
CAFTA: Baseline	116	1,028	6,408	487	0	0.3	0	4.1	0	2.6	26.7	27.4
Full sugar liberalization	55	1,149	6,348	608	0 0.3	0 4.6	0	2.9	27.8	28.6		
CA food protection	81	1,065	6,373	524	0	0.2	0	4.4	0	2.7	25.4	26.3
Trade facilitation	395	1,756	6,688	1,216	0 0.8	0 6.4	0	3.6	36.3	37.2		
Fixed unskiled labor wages	270	671	6,563	130	0	2.2	0	2.1	0	1.4	30.5	31.1
Endogogenous capital accumulation	247	2,845	6,540	2,305	0 4.1	0 6.3	0	1.8	31.8	32.5		
CAFTA: Optimistic	1,006	4,471	7,299	3,931	0	12.3	0	6.8	0.1	0	55.5	56

Notes: (*) After excluding the effects of the ATC protocol scenario. Source: GTAP database 6.0 pre-release 3.11 and own estimations.

Conclusion

For the five Central American economies, CAFTA represents a series of opportunities that can be exploited as well as a series of critical challenges. Given the importance of U.S. trade and investment in the region, in addition to the huge size differences between both regions, the agreement produces significant sectoral and economywide effects.

It is clear from Table 1 that the most welfare-improving mechanism in CAFTA is the increase in FDI and the capital stock of the region. This observation points to the importance of exploiting the investment opportunities associated with a bilaterally determined and permanently privileged market access to the U.S. If CAFTA can improve the investment climate in the region and this is complemented with economic policies that improve infrastructure and increase competitiveness, then the region can achieve a path of sustainable growth.

The key factor for Central America will be the scope and depth of the complementary policies associated with CAFTA. After analyzing the Mexican experience with NAFTA, Lederman et al. (2004) conclude that FTAs with the U.S. offer great opportunities for Latin American countries, but without these complementary policies, there is no guarantee that the agreement can increase growth. In relation to CAFTA, the same conclusions are reached by the World Bank (2005). In addition, they analyze and report the specific complementary policies most needed in each Central American country.

Therefore, without complementary economic policies, CAFTA can be considered mainly as a balancing force to counteract the negative impact of the implementation of the ATC protocol. Given the great of importance of T&A commerce with the U.S., the Central American economy without CAFTA will be hurt by the increased competition of Chinese textiles and apparel goods. Even when our baseline scenario produces modest but positive welfare gains and the improvement of labor market outcomes, CAFTA also incentives a higher concentration in the already significant *maquila*-based T&A sector of the region. This specialization is so important that roughly two-thirds of exports will be supplied from these two sectors alone.

In turn, to generate this sectoral concentration, resources must be taken from the rest of the economy. The agricultural sector is significantly affected by this process, which is complemented by the reduction of import protection negotiated in the trade agreement. When we assess a medium-term simulation of the agreement by not liberalizing the agricultural sector in Central America, this situation is partially reverted. This highlights the importance of complementary policies in the agricultural sector that can mitigate or reverse these negative effects, while the phase-out of import protection is not fully implemented.

One significant drawback from CAFTA is that U.S. sugar protection is mainly unaffected, in clear contrast to the recent rhetoric of this influential industry in the U.S. With the liberalization of the sugar sector, the problematic imbalances created between the rural and urban sectors in Central America could have been averted, with additional welfare improvements for the region.

If the region can effectively implement the complementary economic policies that are expected, then we could reach the significantly positive outcomes estimated in our upper-bound scenario. In any case, the favorable impact in the labor market outcomes, if it is assessed as an increase in wages or a reduction in unemployment, generate key welfare gains that can be shared by the workers of the region and create a positive income increase for poor families. If in addition, labor-market legal conditions are also improved with the implementation of CAFTA, these positive outcomes could be even higher.

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Rural Producers' Organizations' Participation in Policy-Making Processes: Explaining Dynamics Through a Comprehensive Modelling of Strategic Behaviours

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Abstract

This paper contributes to the debate on the role of rural producers' organizations in the context of liberalization processes. It aims to explain the observed diversity in the implementation of liberalized economic policies that occurred in four farm sectors (coffee, milk, beans and pineapple). We use Partial Least Square (PLS) modelling in a comprehensive way to explain organizations' strategic behaviours and results in term of policy design influence. We relate organizations' results to (1) their human, technical and financial resources; (2) their mental models and (3) their trajectories. Our results indicate that organizations can efficiently contribute to integrate farmers into dynamic markets through their participation in policy-making processes, but nevertheless that their success is function of a path-dependent logic and depends notably on cognitive considerations. Finally, we draw some implications of these results on the way to enhance organizations' capabilities to influence policy-making processes.

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We discuss the possible application of this methodology to better understand the role of actors in the evolution of environmental service-provision incentives mechanisms.

Resumen en español

La participaci n de las organizaciones de productores en los procesos de dise o de pol ticas: Explicando las din micas a trav s de un modelaje comprensivos de sus comportamientos estrat gicos

Esta presentación contribuye al debate sobre el papel de las organizaciones de productores en el contexto de los procesos de liberalización. Intenta explicar la diversidad observada de los procesos de liberalización que ocurren en cuatro sectores (café, leche, frijoles y piña).

Un modelaje según los menores cuadrados parciales (PLS) se uso en forma comprensiva para explicar mejor los comportamientos estratégicos y los resultados de las organizaciones en términos de influencia sobre el diseño de políticas. Permite relacionar los resultados de las organizaciones con (1) sus recursos humanos, técnicos y financieros; (2) sus modelos mentales y (3) sus trayectorias.

Mostramos que las organizaciones pueden contribuir eficazmente a ayudar a los productores integrar mercados dinámicos a través de su participación en los procesos de concepción de políticas, pero que, sin embargo, su éxito responde a una lógica dependiente de la vía y depende notablemente de consideraciones cognitivas. Finalmente, sacamos algunas implicaciones de estos resultados sobre las maneras de mejorar las capacidades de las organizaciones de influenciar los procesos de diseño de políticas y discutimos de las aplicaciones posibles de esta metodología para entender mejor el papel de los actores en la evolución de los mecanismos de incentivos para la provisión de servicios.

Introduction

The implementation of liberalized economic policies has been characterized by state withdrawal of the marketing function and the opening of the national market (especially through reduction of tariff barriers). In the agricultural sector, which is, in most of the cases, the most important sector in countries with low development, liberalization processes had led to important changes in the agricultural sector and had challenged the small-scale farmers' situation.

Both empirical and theoretical literature insist upon the importance of an enabling institutional environment for the development of small farmers' agriculture (World Bank, 2008). We can observe a raising interest of the empirical literature on rural producers' organizations (RPOs). Authors put emphasis on the role of RPOs in different domains, notably in economic, social and environmental ones, (Rondot et al., 2001; Bosc et al., 2002). RPOs act through three types of specific functions: (1) they deliver technical and economic services to their members, (2) they are part of local development dynamics and natural resources management, and (3) they advocate for farmers' interests (Pesche et al., 2005).

In Costa Rica, the agricultural sector has experienced tremendous change during the past 20 years. The contribution of the agricultural sector to the Costa Rican economy dropped to a mere 8% of the gross domestic product (GDP). Export-oriented farm sectors experienced a strong development, while family agriculture has decreased and the entrepreneurial production system has increased. Costa Rica is characterized by a rapid process of liberalization and a democratic state, a consequent structured farmers' organizations movement at local and national levels, and a high level of farm sectors' organization. The analysis of the evolution of the public policies related to the agricultural sector showed a time lag between the global institutional environment and the different farm sectors institutional environments, as it is represented in Figure 1. Indeed, at global level, the liberalization process began in 1983 with the approval of the first Structural Adjustment Plan and the beginning of the withdrawal of the state from trading functions. The liberalization process was reinforced in 1994 with the adhesion of Costa Rica to the World Trade Organization and the reduction of the tariffs barrier (opening to international markets). However, at the farm sector level, the liberalization process followed a different pattern. For products oriented to domestic consumption, the pace and intensity of the liberalization process had been variable, from rapid and drastic in the case of the bean sector to smoother and more gradual in the case of the milk sector. Furthermore, the traditional export sectors, such as the coffee sector, and the newly formed export sectors, such as pineapple, did not follow the same pattern of liberalization, since the coffee sector still benefits from a state market regulation instrument and the pineapple sector had benefited from state support policies while the products oriented to domestic consumption experienced state withdrawal.

The article explores the reasons for such a difference between the global liberalization process and sector-specific liberalization processes. It addresses the following question: in the context of liberalization, can the RPOs contribute to secure or develop market access for farmers through the shaping of favourable institutional

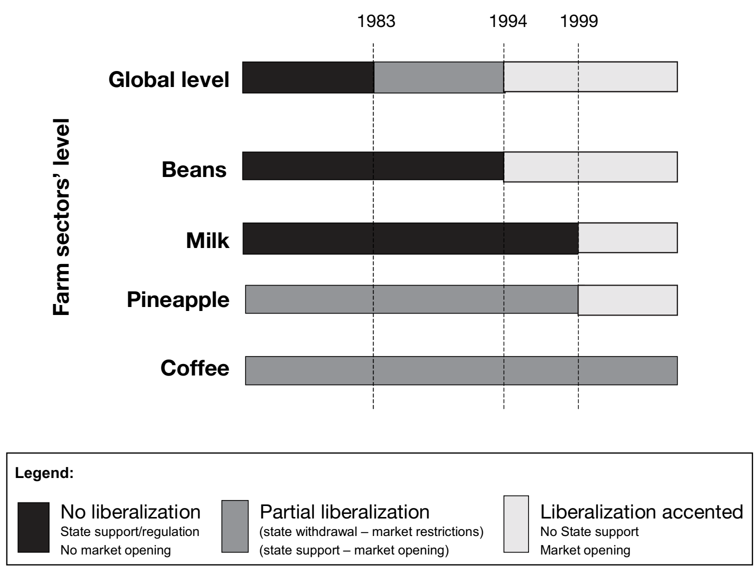

Figure 1. Liberalization processes at global and sector specific levels in Costa Rica (from Maître D'Hôtel, 2007).

environments? To answer this question, we test empirically the theoretical propositions made by leading authors of the new institutional economics (North, 1990; Denzau and North, 1994).

First, we introduce the theoretical background of the research and present the methodology we developed. In the second part, we present our results.

Theoretical background and methodology

To give insight on this differential evolution of the institutional environment, we adopt the approach of the institutional change proposed by Douglass North (1990), who put the interaction between organization and the institutions as central to understanding the evolution of institutions. We thus define institutions as the "rules of the game" and the organizations as "the players" (North, 1990). The approach of institutional change is both evolutionary and cognitive:

ß Evolutionary because institutional change is defined as an incremental phenomenon that follows a *path of dependence*
ß Cognitive because *mental models*, wich "internal representation that the cognitive system creates to interpret the environment" (Denzau and North, 1994), shape institutional changes. Mental models guide strategic choices of the agents and shape existing institutions.

Those theoretical propositions to explain institutional changes are merely validated by empirical analysis. We test empirically those theoretical propositions and identify two main hypothesis:

ß (H1) Mental models of RPOs' representatives influence RPOs' results
ß (H2) RPOs' trajectories influence RPOs' results.

To test these hypotheses, we build a comprehensive model of RPOs' behaviours. This model has been built on the evaluation of the results of the strategic choices of the RPOs and the identification of the strategic determinant of their choices. To identify those determinants, we rely on the organizational learning literature (Argyris and Schön, 1978; March and Olsen, 1976) and on the resources mobilization literature (Penrose, 1959; Wernerfelt, 1984; Barney, 1997). The structure of the comprehensive model we developed is presented in Figure 2.

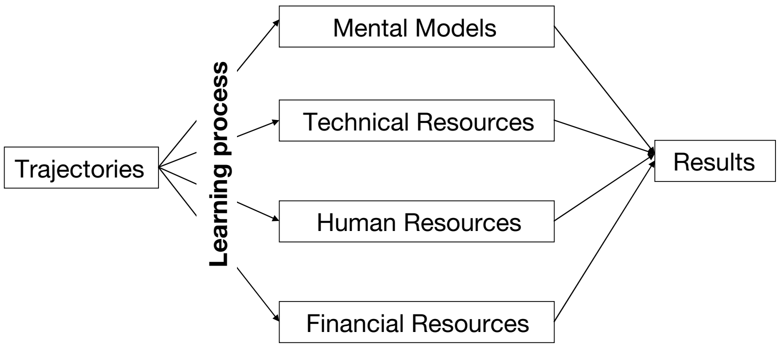

Figure 2. Comprehensive modelling of RPOs' behaviours.

Three sources of information have been combined, combining quantitative and qualitative methods:

ß To inform trajectories, results and technical, human and financial resources, we led 11 cases studies on organizations that do participate in policy-making processes.

ß To inform mental model, we used textual statistics to analyse discoursed of RPOS' representatives.

ß To integrate the different variables of the model, we used the Partial Least Square method, which allows us to test a hypothesis with few observations and numerous collinear variables (Lohmöller, 1989).

Results

The RPOs case studies show empirically the importance of organizations' trajectories. For instance, in the bean sector, organizations that negotiated the liberalization process with government representatives in the early 1990s were more disperse and lacked experience; the negotiation failed to implement a tariff that would protect bean domestic production from imports (the tariff was established then at a mere 1% rate). In the milk sector, the organization had a wider experience of negotiation (since the 1960s) and the process of negotiation was more structured. Plus, the cases reveal the importance of the learning process: for instance, in the bean sector, negotiation conducted in the late 1990s led to a reevaluation of the tariff barriers (to a level of 35% during national harvest period). Thus, trajectories and abilities to participate to policy-making processes appear empirically important to explain the results in term of negotiation outputs.

The textual statistical analysis applied to discourses of RPOs representatives identified different lexical classes. The analysis of these classes led us to distinguish two opposed mental models, according to whether policy negotiation is perceived as a constraint or as a real opportunity to defend ones interests (Table 1).

Table 1. Mental models of RPOs representatives (from Maître D'Hôtel, 2007) The figures into brackets correspond to the chi-squared associated.

	Representative words	Farm sectorsí variables
Mental model 1: policy negotiation as a constraint	Problem (27), conflict (11), to try (11)	Bean (41)
Mental model 2: policy negotiation as an opportunity	Interest (76), relation (50), advantages (36), to convince, to defend (33), to represent (11)	Pineapple (9) Milk (10) Coffee (70)

In the bean-sector case, the representative words used by RPOs representatives reveal a mental model where the policy process is considered as a constraint. In the other sectors' cases, the representatives' words indicate a mental model where the policy process is seen as an opportunity to defend their interests and get a better situation.

Finally, we use the Partial Least Square method to test the strengths of the relationships between the elements of the comprehensive model. The results are represented in Figure 3. Mental models do influence significatively RPOs' results. Moreover, these elements have a higher influence on RPOs' results than resources endowment (since the coefficient value of mental models is, in absolute value, 0.48 higher than the one of human, technical and financial resources; respectively compared with 0.25, 0.23 and 0.17). It's worth noticing that the financial resources tend to have the lowest influence on results. Furthermore, the coefficients show that trajectories have a stronger influence on mental models than on human and technical resources, but no significant influence on financial ones.

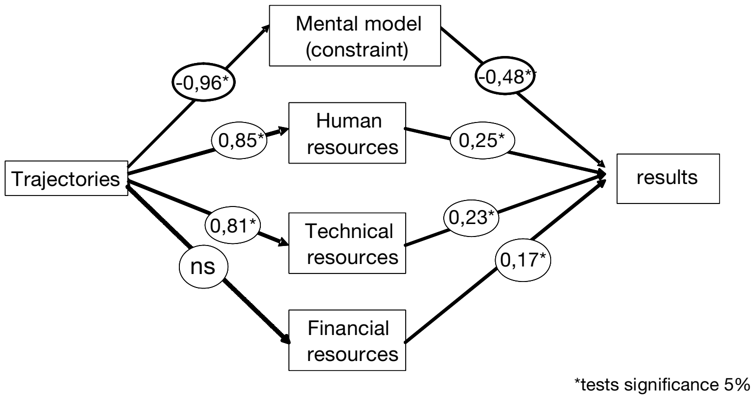

Figure 3. Structural relations between elements of the comprehensive model.

Conclusion

The use of Partial Least Square method demonstrates the importance of path dependency (through highlighting the influence of trajectories) and of mental models. These results correspond to newly developed theoretical propositions that had received poor empirically demonstrated attention. The importance of mental models on RPOs' results appeals for a strengthening of capacity-building programs and invites more careful study of learning process that are quite complex.

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Economic Analysis of Converting an Agroforestry System (AFS) with a Service Forest Component into a Joint Production AFS of an Agricultural Crop and a Forestry Crop (Timber): Case Study of Converting a Cacao-*Inga* sp AFS into a Cacao-*Cordia alliodora* AFS

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Abstract

The current research presents the theoretical framework for implementing a methodology for economic analysis of the conversion of an agroforestry system (AFS) with a forest-service component into a joint production AFS that will produce an agricultural crop together with a forestry crop, such as high-value commercial timber. To explain this methodology, a case study is presented that starts with a seven-year-old cacao AFS with *Inga sp* shade (AFS_1), then the alternative of converting this AFS_1 into a joint cacao-timber production with *Cordia alliodora* shade that will be managed in the future in a sustainable way as a uneven-aged AFS_2. That means that when trees reach their optimum rotation age, they will not be clear-cut but harvested and regenerated in a regular way to maintain a constant flow of timber together with the cacao production, which will also be renovated partially every year in areas where the harvesting of the trees would allow.

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With these two alternatives to evaluate, the land expectation value (LEV) was estimated for AFS_1, as the opportunity cost for evaluating the implementation of AFS_2. Moreover, the AFS_1 economic maturity and subsequently the AFS_1 holding value (AFS_1-HVv) at current age was calculated (seven years old). Then, the AFS_2-HVv for the AFS_2 has to be calculated in order to evaluate the implementation of the new system (AFS_2) from the present one (AFS_1). This second AFS2-HVv takes into account, as a first process, the net present value of the associated cash flow of the AFS_2 conversion (*Inga* elimination and *Cordia alliodora* replacement and maintenance process), and as a second process, the LEV of the AFS_2 when it reaches the optimum uneven-age state is calculated and brought to the present by the investor discount rate, considered through the conversion period. The calculation of the conversion period is equal to the optimal production cycle age of the crop with the longer period, in this case the optimal rotation age of *Cordia alliodora* trees computed at the age of 15 years, which determines the AFS_2 conversion period length.

The AFS_1-HV_7 reached a value of USD1,290/mz,[2] while the AFS2-HV7 was calculated in USD1,691/mz. Since the AFS_2-HV_7 is higher than the AFS_1-HV_7, it can be concluded that converting the AFS_1 into the AFS_2 is a profitable investment, even considering the 15-year conversion cash flow and the capital costs over this period. The conversion costs from AFS with a forest-service component into a joint production AFS that will produce joint production cacao-timber AFS with *Cordia alliodora* shade that will be managed sustainably in the future as a uneven-age AFS is economically acceptable, as it promises a higher net rent to the land asset in the proposed investment.

[2] Mz (Block) stands for the area unit that equals 0.7ha.

Resumen en español

La presente investigación presenta las bases teóricas de una metodología novedosa de análisis económico de la conversión de un sistema agroforestal (SAF) con componente forestal de servicio a un SAF con componente forestal de alto valor comercial. Para ilustrar la metodología, se toma un estudio de caso de un SAF de cacao en una situación actual bajo sombra de servicio de *Inga* sp con siete años de establecido (SAF_1). Luego se calcula el costo de oportunidad de convertirlo a un SAF con sombra de laurel (*Cordia alliodora*) bajo un concepto de producción conjunta cacao-madera de forma sostenible en el tiempo (SAF_2), sin considerar la corta del total de los árboles a la edad de rotación óptima.

Se calculó el valor esperado por la tierra (VET) para el SAF_1 y con base en él, se calculó el valor inmaduro del cultivo a la edad actual (VICy). Luego se calculó el VICy del SAF_2 que toma en cuenta los costos asociados a la conversión del sistema (eliminación de la *Inga* y proceso de sustitución por laurel), los ingresos netos durante el período de conversión y el tiempo en llegar a la condición deseable, o SAF_2. Para determinar la duración del período de conversión, se calculó el VET máximo de los árboles de laurel que se alcanzó a los 15 años. Esa edad de rotación (ER) óptima es la que determina la duración del período de conversión del SAF_2.

El VIC_y en la condición actual alcanzó un valor de USD1.290/mz, mientras que el valor inmaduro de la condición deseada (VIC_d) o SAF_2 es de USD1.691/mz. Debido a que el VIC_y de es mayor que al de la situación actual, se concluye que la conversión del SAF_1 al SAF_2 es rentable aún considerando el período de conversión de 15 años y el costo de oportunidad de la tierra. La inversión en la conversión de SAF con componente forestal de servicio a SAF con componentes forestal comercial es económicamente aceptada porque promete un mayor ingreso actual neto y revaloriza más el activo tierra.

Introduction

For many years, agroforestry systems (AFS) have been the subject of studies on diverse topics such as ecological interactions, biological diversity and ecological functions, nutrient flow and environmental services, etc. (Guiracocha et al, 2001; Suatunce, 2003; Duque, 1998; Avila 2001; Beer et al, 2001). Furthermore, many studies have been conducted on the socioeconomic implications of such systems (Segura et al, 2000; Avila, 1980; Avalapati, 2004; Guevara, 1998). In essence, agroforestry research efforts have been oriented to biologically identify, characterize and evaluate current AFS (Reiche, 1989).

On the other hand, much of the economic analysis that has been conducted has employed economic efficiency criteria such as net present value (NPV), internal rate of return (IRR), income/cost ratio (I/C), and labour remuneration (LR) (Segura, et al, 2000; Reiche, 1989; Arnold, 1983; Serrano, 1989; Hernandez and Von Platen, 1995; Juarez and McKenzie, 1991; Reiche, 1983; Avila, 1980; Juárez, 1999; Von Platen and Köpseel, 1998).

When implementing the economic analysis with this criteria, most of these authors implicitly or explicitly take into consideration clear-cutting the AFS tree component at the time that was defined as the maturity age, threatening the stability or sustainability of the AFS that was created. In other types of economic analysis, sometimes the capital costs are not taken into consideration; in others, the land opportunity cost is not considered in the authors' calculations. Only Segura, et al (2000) used in their research the land expectation value (LEV) as an additional economic indicator to the NCV, IRR and B/C, although it is clear that these indicators receive highest importance.

There are economic studies on timber trees as an alternative for shade trees in cacao plantations, such as the one by Hernandez and Von Platen (1995), where they estimate the cash flow from timber harvesting at the age of 15 years. They calculated the I/C ratio and LR for this conversion investment, which resulted in a profitable alternative action. However, the methodological conceptualization assumes that all trees will be clear-felled at the end of the production cycle without considering the renovation of the tree component, thus destroying the AFS.

The present study suggests an AFS economic analysis methodology where optimum rotation age (ORA) of the trees is calculated but clear-cutting is not considered. Implementing a constant annual selective utilization of a portion of the trees planted at the beginning is suggested, which is calculated by dividing the total number of trees by the ORA. It is assumed that trees selectively cut each year are replaced by direct planting or by natural regeneration management to keep a constant number of trees in the AFS. When the last of the initial trees is cut, those planted to replace the first harvested trees will be reaching the ORA, thus completing the cycle and starting another one, to continue in perpetuity.

The introduction of valuable timber species is an alternative compatible with cacao production that could allow AFS land value to increase (Somarriba and Calvo, 1998). *Cordia alliodora,* as a timber producer tree, is a key component in the AFS to reduce economic risks of producing only one crop (Ludewigs, Somarriba and Ramírez, 1998). Production and/or income stability have been used in intercropping systems as criteria to compare them with monocultures and justify its adoption (Eberhart and Russell, 1996; Marten, 1998, cited by Ludewigs, et al, 1998). *Cordia alliodora* is an ideal species because its crowns are more open, producing mild shade that allows more light to go through than other species studied in the Central American region (Somarriba and Calvo, 1998).

Conceptual Framework

Economic assessment of agroforestry production systems
Land expectation value (LEV)
The LEV is an economic criteria that measures the economic efficiency of a particular land use based on a projected cash flow. It is a discounted value formula that calculates a net land rent using a present value perpetual series adapted to estimate the LEV, known as the Faustmann formula (FF). With this formula, it is possible to calculate how efficient and acceptable a land-based investment is by comparing the LEV of a land-based production system against the land market price; for this study, land price was set in USD312/mz (the land price includes the price of the bare land + basic infrastructure + crop). The LEV formula can also be interpreted as the maximum willingness

an investor could offer for payment for land to be devoted to the assessed production system and earn at least the return on capital invested at a minimum acceptable discount rate (MAR) that reflects the investor's unique preferences. Using this approach, alternative production systems capable of being implemented on the same piece of land can be evaluated to determine which of the land uses will give the highest value to the land asset. The acceptance criteria for the investment analysis is that the estimated LEV must be higher or equal to the land price (LP).

What the LEV (formula) does is to discount the cash flow, usually projected at constant prices of a reference year using a real discount rate corrected for inflation, applied to a particular technology on a particular land-use productive cycle. These cycle profiles can go from a few months to several years, as is the case of cacao and timber trees considered in this study. It is very simple to explain to a producer how the asset value is estimated as a net current value because the investment can be modelled and evaluated into production systems in terms of the effect that they cause on the value of the land asset. That is to say, this value estimates whether the investment valuates or devaluates the land using as a reference the price the land,which is well-known by the producer. The formula (1) is known as the LEV formula.

$$LEV = \frac{D_{H_T} - C_{r_T} + \sum_{t=1}^{T-1} D_{M_t} (1+i)^{T-t}}{(1+i)^T - 1} - \sum_{y=1}^{Y} \frac{C_E}{(1+i)^y} \qquad (1)$$

The LEV depends on the net revenue (DHT-CrT) that comes from liquidating the net production system from the final harvest or management costs. For agricultural crops, this can be a rescue income, such as selling firewood from cutting cacao plantations when the production system is renovated. In some cases, this net revenue is the main income of the production system, for example when timber from a forest stand is harvested at the optimal rotation age (ORA). In addition, the sum of annual and periodic net revenues from other activities coming from annual crop (cacao) harvests is included—in the case of forest systems, from thinnings; this section also includes costs coming from maintenance, management, pest and disease control, and harvesting costs implemented in any t-year of the production cycle (DMt). All this cash flow between year 1 and year T-1 is capitalized to the end of the production cycle, when the crop system is to be renovated or the trees reach the optimal rotation age (T), by using the investor capitalization factor (1+*i*), where *i* is the investor's MAR. After that, the estimated future value, considered as the future net rent of the production system, is then discounted to the present using the investor discount factor minus 1 ((1+*i*)-1) to obtain the present value of a production system net rent, which includes all future production cycles as a way to consider the opportunity cost of the land asset used in the investment in order to comply with the definition of asset value. This is the net present value of the cash flow projected into the future. Therefore, the minus 1 deducted from the discount factor represents the land value of the production system in relative terms. When it is necessary to estimate the value of the bare land, then the costs of the crop establishment, improvements costs like roads and fences, and building infrastructure (CE) must be deducted from the net profit calculated from the production system.

The LEV can be used also to define an optimum economic production cycle for any crop or the optimal rotation age. This can be done by evaluating all possible extensions of a crop's production cycles, and in the case of forest systems, all options for final cutting ages of trees. The optimum LEV for a crop or a forest component is defined as that production cycle year or rotation age that calculates the highest LEV taking into account the investor MAR. The LEV is calculated by unit of area (mz (block) = 1.43115 hectares) for each or a combination of a production system. That is to say, the LEV of an AFS is the sum of the LEV of the agricultural crop plus the LEV of the tree component, and so on for as many components as the AFS has.

For this study, the LEV of cacao and timber trees is estimated to determine the efficiency of the conversion period between AFS_1 and AFS_2 and to determine whether the desired AFS_2 condition is better even considering the conversion costs

Agroforestry System Holding Value considering a conversion period
The problem of applying the LEV method is that it assumes the evaluation moment to be at the beginning of the production cycle or rotation. However, in most cases these production systems are

evaluated at some age or advanced year within the production cycle. For the case study to be developed further in this paper, it will consider an already established AFS_1 (cacao with service shade, *Inga sp*) that will be evaluated for the convertion to an AFS_2 (cacao with shade from commercial timber trees, *Cordia alliodora*). Because of that, it is necessary to estimate not the LEV but the holding value of the actual AFS_1 at the age of seven years (AFS_1- HV_y), for comparing it with the AFS_2 holding value at the desired state (AFS_2-HV_y), taking into account the AFS_2 conversion costs. If the AFS_2- HV_7 is higher than the AFS_1- HV_7, then the investment for conversion of the AFS_2 is more efficient.

In the application of the AFS holding value, two things are considered. First, the holding value, as in the LEV, is estimated from the producer's point of view, using as reference the market price of the land plus the crop's maximum expected value based on the cash flow projected from the present age up to its renovation or final harvest. The holding value establishes a selling price for this land-use asset in an immature state, or it also can at least determine if the immature value of the production system holds the competitive value in relation to the projected market value at the completion of the productive cycle, considering all inputs and output on the remaining period plus the capital and land rent costs. Second, in order to evaluate the performance and economic efficiency of immature production systems, a decision must be made on whether the immature production systems are to be held and continued or liquidated (terminated).

Formula 2 represents the AFS_2-HV_y, which is equal to (1) the net present value (NPV_{cp}) of the cash flow projected over the conversion period (cp) between the evaluation age (y) and the end of conversion period—the optimal rotation age (T) (cp=T-y); and (2) the net present value of the LEV of the desired AFS (LEV_{AFS2}), which represents the value of all future production cycles from a point in time that starts at the end of the conversion period. The LEV_{AFS2} is discounted to the present over the conversion period (cp) by the discount factor ($1+i$). For this reason, it is necessary to have a previous estimation of the AFS_2's LEV.

$$\mathrm{AFS}_2 - \mathrm{HV}_y = NPV_{cp} + \frac{LEV_{AFS_2}}{(1+i)^{cp}} \tag{2}$$

The AFS holding value (AFS-HV_y) is evaluated against the AFS liquidation value (AFS-LiqV_y), which is the land and immature crop market price that the producer can receive for selling the land and the immature crop at the evaluation age. If the AFS-HV_y is higher than the AFS-LiqV_y, then the AFS is considered to be economically immature and the decision is to keep the crop; however, if the AFS-HVy is the same as the AFS-LiqV_y, then the crop is considered economically mature and it would be the optimum time to harvest the crop and also would be the age that would be the optimum period for conversion of the system. But, if the AFS- HV_y is lower than the AFS-LiqV_y, then the system must be liquidated, as it would be considered economically overmature and not profitable to hold the productive system any longer; in this case, it would be best to convert the stand, change its use and eventually even sell the land.

For the economic analysis, the AFS-HV_y of the AFS_1 is compared to the AFS-HV_y of the desired situation or AFS_2 to determine both investments' net rents; in the case of the AFS_2-HV_y, it considers the conversion efforts. This economic analysis is relevant when working with perennial or forestry crops that require many years for the conversion process; high conversion costs can make the desired AFS not very appealing in cases where conversion costs are higher than the benefits of the desired AFS, which can be a compromise in terms of the capital cost and land rent.

Figure 1 is a graphic representation of the AFS conversion concept. It can be observed that from the moment when the optimal rotation age (Tmax) of the forest component is reached, a constant annual joint production begins for both the agricultural crop and forest systems. The time that these trees take to reach maturity is considered as the conversion period of the AFS.

This figure shows a cacao agroforestry system that starts a tree service component, where the AFS functions with a forest component to provide shade and nutrients to the cacao. At age *d*, it has been decided to change the shade function, and timber trees are planted, whose growth curve is represented by the blue dotted line. From point *d* to point *u*, trees grow and reach economic maturity. From that point, instead of thinking about total tree utilization, the concept is to utilize a constant number of trees annually, represented by .....*u*. At that time, the desired joint production state of cacao and timber is reached.

Case study

General description

To give an example of the methodological approach explained above, a study case of a small farmer from Rancho Grande, Matagalpa, Nicaragua, is presented. The farm's economy was based on a coffee plantation in association with other crops (*Musa,* fruits and cacao), cattle and basic grains.

Within the framework of a competitive restructuring project of Nicaraguan's coffee farming financed by FAO's Technical Cooperation Program, crop diversification options were analyzed, among them cacao and timber trees of high commercial value, such as *Cordia alliodora***.**

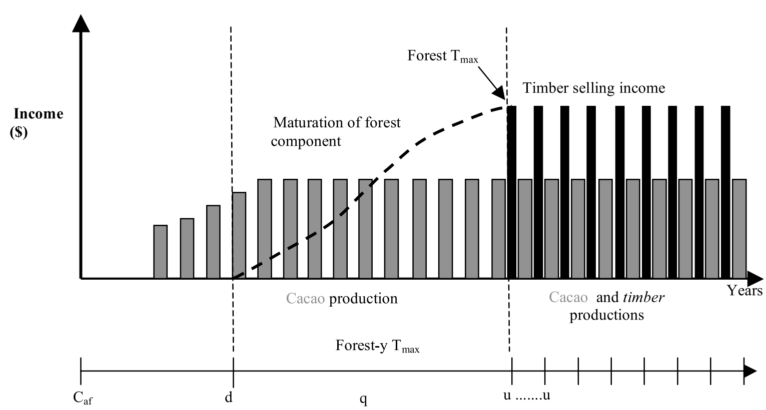

Figure 1. Graphic representation for the conversion of a traditional AFS to the establishment of a joint production AFS of cacao with a commercial timber production.

In this study a seven-year-old cacao-*Inga* sp AFS is analyzed, where *Inga* is the permanent shade-tree component. Since this shade type does not generate any important cash income, it was proposed to change it to high-commercial-value trees widely accepted in the local timber market as *Cordia alliodora* (AFS_2), as indicated in Table 1.

Table 1. AFS_1 current state and AFS_2 desired state after the conversion period.

Crop technology	Crops	Density (N/mz)	Age (years)	Observations
AFS_1 (with *Inga* sp shade)	Cacao	438	7	Current AFS state
	Inga sp	194		
AFS_2 (with *Cordia alliodora* shade)	Cacao	438	0	Elimination of *Inga* shade and plantain crop as temporary shade and *Cordia alliodora* as permanent shade Evaluation ex-ante of the conversion system
	Plantain	438		
	Cordia alliodora	70		

Field data collection

Field data was collected in August 2004 using an interview and a field visit to the farmer's holding. During the interview, data was obtained in relation to crop management technology, expected yields, production costs and product selling prices in local markets. This information was complemented with official bulletins of products and prices of inputs.

Cacao, plantain and *Cordia alliodora* production models

The time production function for cacao is taken from recurrent production measurements during 20 years (Haggar, 2004). The analysis is conducted taking into account organic management of cacao. For *Cordia alliodora,* equations were used to predict height (Somarriba and Beer, 1987), diameter and volume (Vallejo, 2004).

Minimum discount rate

The choice of a minimum acceptable discount rate (MAR) is a key element for an economic investment analysis. The MAR should be related to the farmer investment characteristics related to their liquidity, which represents the opportunity cost of the forgone investment.

The MAR employed for this study is real as it is corrected for inflation. To calculate it, a nominal rate of 25% was taken as reference and an interannual inflation (2003–2004) of 8.76%. The MAR was 15.36%.

Product prices and utilization costs
In August 2004, the price of 100 lb (qq) of dry cacao was USD36, while the selling price of *Cordia alliodora* wood was USD125/m^3 in the towns where it was traded. For cacao the harvest and drying cost was estimated at USD8.1/qq and the timber transportation and utilization cost was calculated at USD35/m^3.

Results

Land expectation value of the individual crops
Cacao cultivation is an activity economically profitable from the investment point of view. The LEV obtained for AFS_1 was USD564/mz, which is higher than the land price (USD312/mz). For the purpose of this study and according to Haggar's (2004) observations, 20 years was considered as the production cycle. It is important to consider that the cacao plantation has seven years, this means that 14 years are needed to reach the renovation age.

In the case of *Cordia alliodora* stands, it was possible to calculate the rotation age that yielded the maximum LEV. This value was USD257/mz; it was reached at 15 years of age and it is lower than the bare land value. This result is not a cause of concern because trees are not the main crop of the system. From these results, the one of interest is the tree ORA, which defines the AFS_2 conversion period. At this point, *Cordia alliodora* LEV does not interest us because the value is the result for clear-cutting all trees at the ORA. We have to keep in mind that we will assume an uneven-aged harvest-regeneration system that would allow cutting a certain number of trees per year, as proposed by this study's methodology.

Immature value of the AFS_1
The AFS-HVy of the AFS_1 at age 7 is USD1,240/mz, while the AFS_1-Liq_V at that same time reaches USD726/mz. Since the AFS- HV_y is higher than the Liq_V, it is found that the AFS_1 is immature and thus it is better to continue with the crop than to liquidate it.

Conversion cost from a AFS_1 to a AFS_2

The period needed to obtain a cacao-*Cordia alliodora timber* AFS_2 as a joint production in a sustained yield for both crops is reached at year 15 because it is the time required for reaching timber maturity. On the other hand, cacao reaches a fully regulated production at the age of nine years.

According to formula 2, the conversion cost depends on the NPV of all income obtained between year seven and the end of the CP, which is 15 years. The $AFS\text{-}HV_7$ is the NPV_{CP} plus the sum of the regulated system LEV_{AFS2} discounted by discount factor over the conversion period.

For this example, the NPV_{pc} is represented by all cacao net revenues, the cost of eliminating the *Inga* shade, the cost of establishing the temporary plantain shade, and its net revenues as well as by the cost of planting the permanent timber shade. Table 2 shows the NPV_{pc} and LEV_{AFS2} values discounted for each crop and the tree component.

The opportunity cost of converting AFS_1 to AFS_2 that takes into account a conversion period considers the NPV of the conversion period that includes cost of eliminating *Inga* shade, costs and revenues of cacao and plantain as temporary shade, and establishment of *Cordia alliodora* as permanent shade. In addition the LEV of the joint production AFS_2 cacao-*Cordia alliodora* under a uneven-aged management regulated state is also considered but discounted over

Table 2. Holding value of the AFS_2 (cacao-*Cordia alliodora*) considering a conversion period for a small farmer in Rancho Grande at a 15.26% discount rate, Matagalpa, Nicaragua. 2004.

Component	NPV of the conversion period (USD/mz)	LEV_{AFS2} discounted by the CP (USD/mz)	Holding Value for the proposed AFS_2 considering a conversion period (USD/mz)
Shade elimination	-58	0	-58
Plantain crop as temporary shade	377	0	377
Cacao	1,120	164	1,285
Cordia alliodora	-31	117	87
Total	1,410	282	1,691

the conversion period, which this discounted AFS_2 LEV is also part of this conversion cost. The result of this sum totals USD1,691/mz AFS_2-HV7, which is higher than the AFS_1-HV_7 (USD1,240/mz). Figure 2 shows graphically a diagram of this conversion process.

It can be observed in the figure that from year 0 to year 7 there is a cacao-*Inga* AFS_1 (period of foregone revenues and costs that are not considered in the analysis). Year 7, is a point of economic decision making where there is the possibility to continue with the initial AFS_1 or to convert it to a cacao-*Cordia alliodora* timber AFS_2. The initial investment analysis determined the conversion period should be 15 years because it is the time for the *Cordia alliodora* to achieve economic maturity, therefore, year 22 (actual age 7 plus 15 years of conversion) would be the cacao age when the AFS begins a joint production of cacao-*Cordia alliodora* timber. It is important to note that there is not a terminating point to the AFS_2, because from that moment on an annual percentage of cacao is renovated and another percentage of *Cordial alliodora* is harvested-regenerated in projected into the future in a sustainable level.

Discussion

Through this study it was possible to determine the cost of converting an AFS that was under low economic efficiency (profitability)

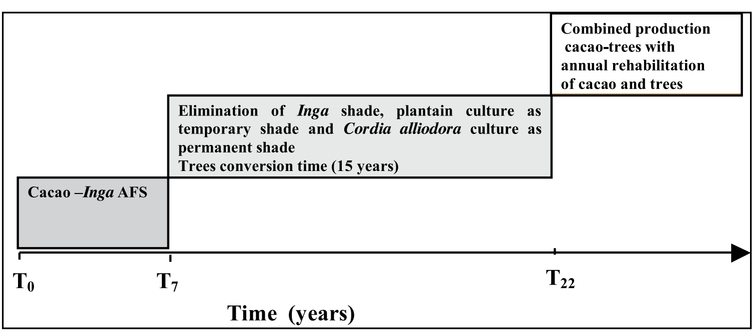

Figure 2. Graphic representation of the conversion period required to reach a joint production AFS_2 cacao-*Cordia alliodora* for a small farmer in Rancho Grande, Matagalpa, Nicaragua. 2004.

into another AFS with higher economic efficiency but evaluating also whether the conversion costs would not compromise the profitability of the proposed AFS. When considering conversion cost, it was established that despite the 15-year waiting period to attain the desired AFS, which would punish the proposed investment with heavy capital costs, the AFS_2 would still profitable and promises a higher income than the current AFS.

When estimating the optimum number of trees per unit of area for cacao shade, some authors such Somarriba and Calvo (1998) took into account the amount of trees desired for the final harvest. In this study, the optimum amount of shade that cacao tolerates without disturbing its production was 100 trees per hectare. The conceptual difference lies in that this example does not consider clear-felling all trees once they reach economic or technical maturity. This is a common problem found in the economic analysis of AFS—researchers implicitly assume harvesting of all trees at the rotation age presenting a highly profitable AFS due to liquidation of the tree component; however, this suggests the destruction of the AFS at the end of the production cycle because felling of all trees would affect the microclimate conditions created over the years.

The land expectation value (LEV) is a more adequate indicator for long-term investment analysis that involves the land as main investment asset (Samuelson, 1976). According to this economic criteria, the investment is accepted if the LEV is higher than the land market price. This means that if an investor decides to invest on a specific land use, such activity should have to produce a rent that at least pays the opportunity cost of the market land rent. Based on the LEV, it is possible to estimate the crop holding value at any age (HV_y) and decide whether at its current state an established crop, it is worth holding it and bringing it to its economic maturity.

Economic studies on the incorporation of timber trees as permanent shade to agricultural crops in AFS do not take into account the capital cost of the maturation of a timber production component. The purpose of this study is to provide an economic decision criteria for evaluating the adoption of AFS. When a farmer decides to invest on a timber-tree component for the AFS, the net rent expectation for the timber-producing component should be higher than the cost of their establishment and the capital cost for waiting for that timber component to start producing as part of an AFS.

The AFS economy should be treated as a joint production system where trees provide not only shade, temperature and humidity regulation services to the main crop but also also become an important part of the farmer's AFS land rent.

In this exercise, cacao is the main crop, which has a more intensive maintenance in respect to weeds and disease control, pruning, harvesting, etc. It is considered that tree component maintenance costs are negligible and therefore are considered within the cacao cost structure. The fact that there is no maintenance cost associated to trees planting during their maturation period makes the tree-component investment even more profitable and a good contribution to the farmer's economy.

The culture of having high commercial-value trees inside the AFS increases the value of the land asset for the farmer, and when both components are managed for a steady production of two main market products (cacao and timber), it will allow the farmer to obtain a higher annual net revenue. Investment profitability of AFS when the tree component does not have a high market value on its own is much lower than the AFS with timber-tree components of high commercial value. This simple fact justifies the adoption of timber trees in joint production with cacao production.

The utilization of a defined number of trees per year, once the tree component is well-structured, has a very positive effect on the farmer's cash flow, especially in a year when the main agricultural crop produced has low prices. The possibility of obtaining additional income by selling timber is an obvious advantage of cultivating high commercial-value trees as cacao shade.

Conclusions

The current research presented a theoretical framework for implementing a methodology for the economic analysis for analyzing the conversion of an agroforestry system (AFS) with a forest service component into a joint production AFS that will produce an agricultural crop together with a forestry crop such timber with high commercial value. This study has demonstrated that despite having to wait a long period to obtain economic benefits from timber trees, the investment is profitable even assuming the capital cost and the land opportunity cost.

Using the NPV, IRR, I/C and LR as investment criteria on AFS are not suitable for these kinds of economic studies because they do not take into account the opportunity cost of the land rent.

In this study case, the purpose was to simplify the analysis by taking into account a forest species of high commercial value that has been widely studied both under pure plantation and AFS conditions.

It is incorrect to assume the possibility of clear-cutting the entire AFS forest component at the age of economic or technical maturity. This would cause serious consequences; it will show false profitability indicators by liquidating the AFS, damage the cacao plantation due to mechanical damages to plants, and destroy the microclimate and nutrient relations that both cacao and timber trees have reached as an AFS through time.

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Methodologies for Land-Use Analysis and the Assessment of Institutional Changes Between Stakeholders: The Case of Pepper Producers in Costa Rica

Fernando SAENZ[1]

Abstract

Exploratory and predictive methodologies for land-use analysis have been developed to operate at a regional level, aimed to help planners, policy makers and regulatory agencies take actions on a specific problem. These models usually incorporate farm-level operations since most of the regional issues are affected by conditions and decisions taken at the farm level. The farm level also includes the institutional arrangements farmers implement to adjust strategies according to different market conditions. The exploratory analysis of changing institutional arrangements can help us to identify conditions where farmers gain higher competitive advantage and better bargaining power. We developed a nonlinear integer simulation model to predict the price level and the institutional arrangement (individual or group contract) adopted by pepper producers in Costa Rica, given a certain monopsonistic market condition, with one unique firm holding all bargaining power. The model maximises the income of the firm and farmers under three conditions, namely, monopsony (firm holds all bargaining power), monopoly (producers hold all

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bargaining power in a group contract) and joint profit maximization (firm and producers have equal bargaining power in the group contract). Our results show that in all scenarios a group contract is chosen for the high supply season, whereas individual contracts are chosen only in the low supply season assuming joint profit maximization. The major outcome of this study is that when transaction costs are taken into account, and under high frequency of transaction, the firm would benefit from bulking the contracts and procurement of inputs even when this would decrease its bargaining power.

Resumen en español

El uso de un modelo de maximizaci n para simular los beneficios de acciones colectivas: El caso de los productores de pimienta en Costa Rica

Se han desarrollado metodologías de exploración y predicción para el análisis del uso de la tierra a nivel regional con el fin de ayudar a los planificadores, legisladores y agencias reguladoras a tomar acciones sobre un problema específico. Estos modelos generalmente incorporan operaciones a nivel de finca, ya que la mayoría de los temas regionales son afectados por las condiciones y decisiones tomadas a nivel de finca. El nivel de finca además incluye los arreglos institucionales implementados por los agricultores para ajustar las estrategias determinadas por diferentes condiciones de mercado. El análisis exploratorio de los cambios de arreglos institucionales puede ayudar a identificar condiciones donde los agricultores obtienen una mayor ventaja competitiva y mejor capacidad de negociación. Hemos desarrollado un modelo de simulación integral no lineal para predecir el nivel del precio y los arreglos institucionales (individual o grupal) adoptados por los productores de pimienta en Costa Rica, determinado por cierta condición de mercado monopsonístico, con una única firma manteniendo toda la capacidad de negociación. El modelo maximiza el ingreso de la firma y de los

agricultores bajo tres condiciones: monopsonio (una firma tiene toda la capacidad de negociación); monopolio (los productores mantienen toda la capacidad de negociación en un contrato grupal); y maximización de beneficios conjuntos (la firma y los productores tienen la misma capacidad de negociación en el contrato grupal). Nuestros resultados demuestran que en todos los escenarios el contrato grupal es seleccionado en la época de abastecimiento alto, mientras los contratos individuales se seleccionan solamente en la época de abastecimiento bajo asumiendo la maximización de beneficios conjuntos. El resultado más importante de este estudio es que cuando los costos de transacción son tomados en cuenta, y bajo una frecuencia de transacción alta, la firma se beneficiaría del agrupamiento de los contratos y adquisición de insumos aun cuando esto disminuiría su capacidad adquisitiva.

Introduction

Methodologies for land-use analysis have been developed for the Atlantic zone of Costa Rica by the Research Program on Sustainability in Agriculture (REPOSA, DLV Program, Wageningen University) and the project Agrarian Policies for Sustainable Land Use and Food Security (UNA-DLV, CINPE-Wageningen University). Both research initiatives ended in 1999 after 12 years of research and yielded the book *Tools for Land Use Analysis on Different Scales: With Case Studies for Costa Rica (Bouman* et al.*, 2000)*. These methodologies addressed the problems associated to the land use since several perspectives, such as biophysical and socioeconomic conditions for a certain zone, the type of stakeholders involved, the time scale and the geographical scale of analysis. The Atlantic zone was chosen as a research area because it is a zone of relatively recent colonization, with diverse conflicts among local producers and among objectives of producers, governmental policy and environmental concerns.

Methodology

The methodologies for land-use analysis have an interdisciplinary character since they incorporate different dimensions in terms of soil science, agronomy, animal husbandry, economics, marketing and physical geography. They show certain complementarity, but different goals, methods, terminology, output, scale levels and aggregation issues (Table 1). They have been developed to operate at a regional level, aimed to help planners, policy makers and regulatory agencies take actions on a specific problem. These models usually incorporate the farm-level operations since most of the regional issues are affected by conditions and decisions taken at the farm level. The farm level also includes the institutional arrangements implemented by farmers to adjust strategies according to different market conditions. The exploratory analysis of changing institutional arrangements can help us identify conditions where farmers gain higher competitive advantage and better bargaining power.

The developed model

We developed a nonliner integer simulation model to predict the price level and the institutional arrangement (individual or group contract) adopted by pepper producers in Costa Rica given a certain monopsonistic market condition, with one unique firm holding all bargaining power (developed in Sáenz-Segura, F. 2006. Contract Farming in Costa Rica: Opportunities for Smallholders? Ph.D. thesis, Chapter 5. Wageningen University). The model maximizes the income of the firm and farmers under three conditions: monopsony (firm holds all bargaining power), monopoly (producers hold all bargaining power in a group contract) and joint profit maximization (firm and producers have equal bargaining power in the group contract). Our results show that in all scenarios a group contract is chosen for the high supply season, whereas individual contracts are chosen only in the low supply season assuming joint profit maximization. The major outcome of this study is that when transaction costs are taken into account, and under high frequency of transaction, the firm would benefit from bulking the contracts and procurement of inputs even when this would decrease its bargaining power.

Table 1. Tools for Land-Use Analysis.

Nature of methodology (nickname)	Scale	Characterization & Methods	Key Outputs	Goal	Information Generated
Projective (CLUE)	National & Regional	Statistical (regression, GIS)	Likely future developments in land use	Projection of likely future trends in agricultural land use	Likely future land-use changes (what, where & when)
Exploratory	Regional	Bioeconomic (LP, GIS)	Technological options + trade-off analysis + aggregate policy effects	Medium-term exploration of the effects of bio-physical and socioeconomic constraints	Quantification of trade-offs between policy goals (policy space)
Predictive (UNA-DLV)	Regional	Bioeconomic (expert systems, LP, econometrics, GIS)	Technological options + farmers' reactions + policy effectiveness	Short-term prediction of policy effects on farmers' land use decisions	Effectiveness of policy measures to induce adoption of desired land use systems
Predictive (SEM)	National	SEM (LP, econometrics)	Quantification of trade flows + policy effectiveness	Short-term prediction of policy effects on land use, associated trade flows and welfare	Quantification of policy effects on level and distribution of societal welfare
Proto-typing (BANMAN)	Farm	Precision farming (GIS + field experiments)	Adjustments in farm management	Complementarity between economic and bio-physical sustainability	Input-output relations of precision agriculture
Generation of land use systems (TCGs)	Field	Expert systems (process-based and expert knowledge, literature, field experiments)	quantification of input-output relationships	Provide building blocks for agricultural land use models	Quantification of input-output relationships for large number of land use systems

Conclusion

Some final remarks and recommendations can be drawn, as follows:

ß Models are useful tools for planners and policy makers to help make decisions.
ß They require a large amount of data (sometimes not available) and the organization of databases.
ß Training is important: the operational level is still constraining.
ß Models are not perfect and they required continuous research for a better approach to real problems.
ß The agenda is still open.

Policy Process and Empowerment of Farmer Organizations: How Models Can Help

Jean François LE COQ[1,2] and Fernando SAENZ[2]

Abstract

The participation of stakeholders in the design of common rules is a condition for their acceptance. The main questions addressed in this communication are as follows. What are the main issues regarding the successful inclusion of stakeholders in negotiations for policies design? What sort of models could be used and how can they be used to facilitate the negotiation processes?

This presentation proposes a review of the main issues related to policy design and strengthening of farmer organizations (FOs). Then it proposes a preliminary comparative review of some models and tools used in socioeconomics studies at different scales and their application to facilitate multistakeholder's decisions and negotiation processes. Finally it draws some recommendations and remarks on the use of models to help stakeholders in decision making.

We show that (1) the process of model construction is as important as the output of the model from the perspective of FOs empowerment (learning process, reduction of asymmetries,

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identification of preferences, etc.); (2) the modelling tools are not neutral in a negotiation perspective but a strategic negotiation resource for actors from the perspective of the policy design process—their legitimacy is a key factor.

We conclude that models can be helpful to facilitate multistakeholders' negotiations and capacity-building processes for both researchers and actors (policy makers, organizations) in a cross-learning process.

Resumen en español

Las negociaciones entre actores y el empoderamiento de las organizaciones de campesinos en la regulaci n de las cadenas de valores y en el dise o y la implementaci n de pol ticas agr -colas y ambientales: Qu tanto pueden aportar los modelos?

La participación de los actores en el diseño de reglas comunes es una condición para su aceptación. Las preguntas principales consideradas en esta presentación son las siguientes: ¿cuáles son los elementos claves para la inclusión de los actores en las negociaciones para el diseño de políticas? ¿Qué tipo de modelos se pueden usar y como usarlos para facilitar los procesos de negociación?

Esta presentación hace una revisión de los elementos claves relacionados con el diseño de políticas y la consolidación de las organizaciones de productores (OPs). Se propone luego una revisión comparativa preliminar de algunos modelos y herramientas usadas en estudios socioeconómicos a diferentes escalas y su aplicación para facilitar las decisiones de actores múltiples y procesos de negociación. Finalmente, propone algunas recomendaciones y anotaciones sobre el uso de modelos para ayudar a la toma de decisiones de los actores.

Mostramos que (1) el proceso de construcción de un modelo es tan importante como los resultados del modelo en una perspectiva de apoderamiento de los OPs (proceso de aprendizaje, reducción de las asimetrías, identificación de las preferencias, etc.); (2) las herramientas de modelación no son neutrales en una perspectiva de negociación, sino un recurso estratégico de negociación para actores en un proceso de diseño de políticas—su legitimidad es un factor clave.

Concluimos que los modelos pueden ser útiles para facilitar los procesos de negociaciones entres actores múltiples y de capacitación, tanto para los investigadores que los actores (tomadores de decisiones, organizaciones) en un proceso de aprendizaje cruzado.

Introduction

Policy building is complex process due to the number of stakeholders involved in the whole decision and implementation process. Some authors argue that a better decision process should involved stakeholders, nevertheless participation of all stakeholders in the policy process remains difficult. Farmers' Organizations as representatives of final beneficiaries or targets of agricultural policies particularly are not always part of the process.

On the other hand, scholars of diverse disciplines have developed modelling activities and models as a simplification of the current reality (as interpretation tools) to better understand its functioning (analytical purpose) and/or to predict future situations (simulating purpose). Under the framework of the Mesoamerican PCP, scientists are to develop a huge diversity of models, from biophysical to socioeconomic ones.

Based on a review of literature on the policy process and some existing socioeconomic methods developed by CIRAD using modelling activities to facilitate policy design, this communication proposes a reflection on the uses and interest of models and modelling activities in policy process and FOs empowerment.

Thus, in the first part, we explore the possible role of modelling activities according to different policy process approaches to conclude the main interests that are expected from modelling activities and outputs according to stakeholders (including researcher). In the second part, we explore the interests of modelling processes for the stakeholders and policy process.

Policy process and modelling activities

Policy process approaches

Different approaches have been developed to describe and understand policy process. Those different trends could be classified in two major approaches to understand the policy process: the "stage" approach and the "cognitive" approach (Bousaguet et al., 2006).

According to the stage approach, the policy process could be described as "cycle": the policy cycle that consists in a succession of phases and feedback. Basically, this model, developed in the 1970s, describes the policy process in different stages: issue emergence, agenda setting, alternative selection, enactment, implementation, evaluation and feedback (Birkland, 2005). This stage approach is often linked with a restrictive vision of the main actors participating in the policy process. Following Adams (1981) and his concept of "Iron Triangle," the policy process could be interpreted as the result of interactions between three types of actors: legislative part (Congress), the government agency (administration) and interest groups. Thus, in this strand, the policy process is mainly considered as a top-down process where the policy is the result of a rational choice of policy makers between different possible options.

In the 1990s, to overcome the heuristic limits of the stage approach and better take into account the evolution of the policy making context (such as the increasing number of actors involved in the policy process, the decentralization process, etc.), new trends of policy process analysis were developed (Sabatier, 2007). Those new strands of approaches put more emphasis on the ideas and the interaction between a larger set of actors than the previous strands. Thus, the importance of the ideas in the policy process has been emphasizing in the "Three I approach" (Heclo, 1994; Hall, 1997; Surel, 1998) and in political sociology with the concept of "referential" developed by Muller (Muller, 1990; Muller & Surel, 1998). In this strand, the policies are considered as the results of the dynamics creation, diffusion and competence of ideas inside different forums: forum of political communication, professional forum, forum of the community of public policy community—policy makers—(Jobert, 1994; Fouilleux, 2000). To understand and explain the policy process, Sabatier & Jenkins-Smith (1993) developed an analytical framework, the Advocacy Coalition Framework, that analyses the policy changes as the results of interaction between different coalition of actors (including not only the traditional government officers, politicians, etc., but also journalist, experts, researchers, etc.). These approaches put emphases on researchers' and experts' roles in policy processes to generate policy ideas.

The uses and utility of models from a policy cycle perspective

Modelling activities outputs could be used at different steps of the policy cycle (Figure 1):

ß At the issue-emergence step and agenda-setting stage, the modelling activities and outputs could be used to simulate/forecast current trends to raise awareness of policy makers on a specific problem and push them to tackle it. A current example is the use of simulation and forecasting of global climate change at the international level and the setting of an international political agenda and agreement to reduce emission of greenhouse gases.

ß At the formulation/alternative selection stage, the modelling activities and output could be used to provide ex ante evaluation of a set of policy options and test the possible impacts of those decisions in order to facilitate the selection of some policy options and tools. Many models application had been developed for this purpose at different level. For example, especially for liberalization and trade policy issues, we can mention different models used to simulate ex-ante possible impacts of liberalization and test mitigation practices (such as Global Equilibrium Models application with GTAP Model and its application to the Central American liberalization process; the Multilevel Analysis Tool for Agriculture (MATA Model) and its application to liberalization of commodity chains in Indonesia (Gérard, 1997), etc.

ß At the decision/enactment stage, the main use of modelling activities and outputs are analytical and comprehensive models that attempt to explain the final decision. The existing models to explain the final political decision are based on different approaches and rely on different hypothesis on actors' rationality. As illustration, we can mention both the simulating-oriented models, such as the decision models used in public choice theory based on the hypothesis of rational decision of the agent, and the game theory application to policy choices (Ordeshook, 1986; Morrow, 1994; McCarty & Meirowitz, 2007) as well as the heuristic no-simulating models of the "new "policy process analysis frameworks and models based on different assumptions of actors bounded rationality (Schlager, 2007).

ß At the termination-evaluation stages, the main uses of modelling activities and results are principally for ex-post evaluation of policies or programs. The aims of the model are heuristics. They tend to explain the impact/effect of policies and especially the difference between expected and observed outcomes.

For the first part of the cycle (Figure 1), from issue emergence to enactment, the simulation predictive models are more used since

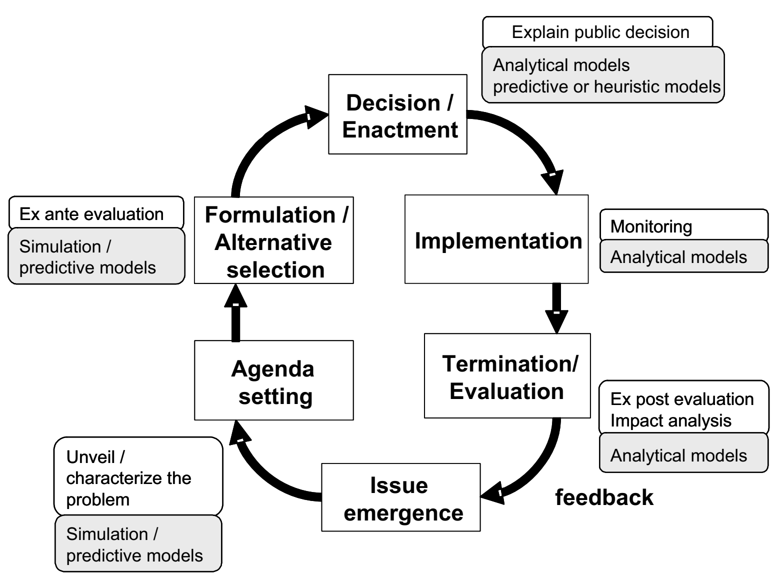

Figure 1. Modelling activities and results uses and types of models according to policy cycle stages. Source: policy cycle stages derived from Birkland, 2005.

policy makers tend to explore the future situation and measure possible impacts of policies. The models are then mainly considered as a way to optimize the policy makers' decision take the "better" decision.

For the second part of the cycle from enactment to feedback, the analytical models are more used since policy makers and scholars tend to understand the effect of policies and explain the difference between the expected and current results.

It is worth noticing that the models could be used by policy makers as a legitimization of the public decision.

The interest of modelling activities from a policy cognitive-approach perspective

From a cognitive-approach perspective, the models could then have different functions. From an advocacy-coalition-framework perspective, models (especially simulation models) can be considered as a negotiation resource for a coalition of interest. For example, the models of predictions on climate change developed by the scientists of the Global Change Committee are a negotiation resource for the coalition of those that are for the reduction of the fossil energy consumption. The GTAP model has been used to justify or to fine-tune and calibrate the liberalization process; it has been used by actors of the "liberation coalition" to support trade liberalization facilitation.

In a referential perspective, models (especially analytical models) could be used to support the constitution of a global or sectoral referential. In the different forums that are mobilized in the policy process, debate often takes place around the legitimacy of explicative models, the uses and the adoption of one model (as well as hypothesis of those models) in a forum (especially in the scientific forum) can be a stake that affect the middle- or long-term policy process outcomes.

Thus, in a cognitive perspective, even if models are used to facilitate public decision, the models are never neutral, as the models vector a vision—referential perspective—they are stakes in the forum and are a resource for a coalition—ACF perspective.

Possible uses from a stakeholder perspective
Table 1 proposes a synthesis of the main expected functions played by modelling activities according to major stakeholders involved directly or indirectly in policy processes.

The stakeholders' expectations about models could be of different types. Basically, we can consider that all stakeholders directly involved in policy processes (such as policy makers and farmers' organizations) have expectations from model outputs to reveal possible future states and shape accurate strategies and activities. The model outputs could be also considered by those stakeholders as arguments to be used in negotiation process.

Specifically, for policy makers (including both administration and elected bodies), the expectation toward models is to support public decision (counselling to better define the policy instruments to reach expected objectives) and to legitimize public decision (argumentation of the final decision).

For the farmers' organizations (as groups of interests), the model could be considered useful to understand their own situation, their

Table 1. Roles of modelling activities according to stakeholders.

<table>
<tr><th colspan="2">Researchers</th><th colspan="2">Stakeholders</th></tr>
<tr><th>Research oriented ↔</th><th>Action oriented</th><th>Policy makers</th><th>Farmer Organizations</th></tr>
<tr><th colspan="2">Generate knowledge</th><th colspan="2">Argumentation of their positions or convictions</th></tr>
<tr><td>Analytic (understand / explain facts, behaviors, choices)
Reproduce the functioning of observed reality</td><td>Support / facilitating decision making process
Influence decision</td><td rowspan="2">Facilitate public decision
By
Optimize decision (instrument choice)
And/or
legitimate decision process (modality of choice)</td><td rowspan="2">Understand their own situation, environment and possible evolution
To
Define strategy of actions to represent Farmers' interests (negotiation)</td></tr>
<tr><td colspan="2">Simulate or explore changes or future situations</td></tr>
</table>

environment and their possible evolution in order to facilitate the definition of a sound short- and long-term strategy for actions to represent farmers' interests (negotiation).

For researchers, models are a way to better describe the functioning of a system and to create knowledge. Nevertheless we could consider that researcher approaches could be described as a continuum from research to action. In the first pole (science-oriented researcher), the interest of the model is a better understanding, explanation of facts, situation, evolution, behaviours, actors choices, etc… This understanding could be done through diverse analytical model types or to simulation or predictive models construction (test is then used to revise model hypothesis questioned and identify new factors that influence the object to understand). At the opposite pole, the action-oriented researcher considers models as a tool to facilitate or support the individual or collective decision-making process.

To conclude this first part, it appears that there is a diversity of models and possible uses according to the policy-process stage, that the researchers have also role in policy process and that models are not neutral since they can be used by coalition of interest as a negotiation resource and/or contribute the policy referential evolution.

Modelling process and stakeholdersí participation and capacity building

The literature about development approach puts emphasis on the sounded institutions (rules of the games) as a condition for a better development. The analysis of the unexpected results of top-down approaches shows the importance of the participation of stakeholders in policy design (Brinckerhoff, 1997). To cope with those problems, tools and methods have been proposed to better integrate stakeholders in the public-decision setting (Jesus and Bourgeois, 2005).

The participation of civil society and especially farmers' representatives in the agricultural policy sector is also seen as a key factor of efficiency. Nevertheless, beyond the principles, the effective participation of FOs leaders is still limited due to the lack of (1) information on their situation, their environment and possible alliance; (2) resources (technical, human, financial); (3) capacities such as technical capacity (analysis of situation, alternative proposition, argumentation, etc.) or strategic capacity (alliances building, strategic action design, etc.).

Modelling process as a cross learning process

The modelling process can be considered as a cross-learning process between farmers/stakeholders and between stakeholders and researchers. Figure 2 presents the possible interaction between actors and scientists that could be generated during the basic steps of a standard modelling process. The first phase of the modelling process, the objective and user definition phase of the model, could be considered as a collective problem definition. The interaction between the scientists (modellers) and the stakeholders of the system to be modelled enables the scientists to grasp the demand of stakeholders and the pertinence of the model; carried out as a learning process, this phase could contribute to reinforce the problem-formulation capacity of stakeholders.

The second phase that consists in model conception and testing is generally scientist-driven. The consultation of involved stakeholders

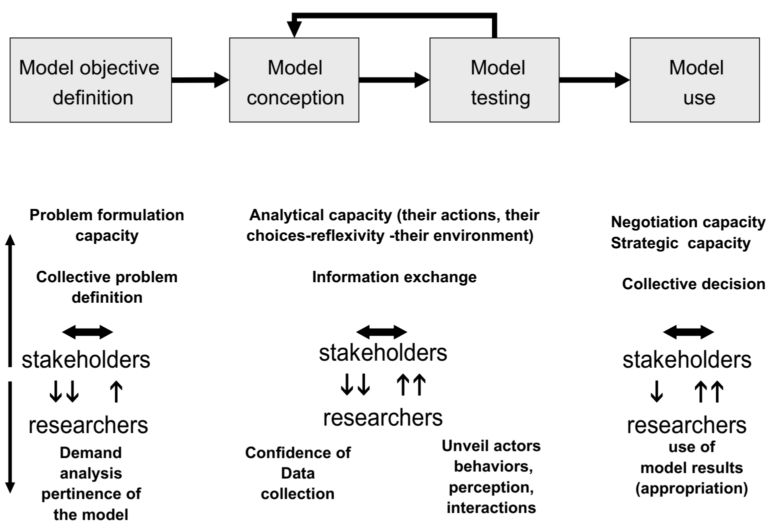

Figure 2. Modelling process and interactions between actors.

enables the scientists to have more accurate and reliable data and to unveil unexpected actor behaviours and perception. The participation of the stakeholders enables them to strengthen their analytical capacity, especially concerning their own strategy and context.

The third phase is the regular use of the validated model. The participation of stakeholders is to strengthen negotiation capacity and strategic capacities, to build collective decision. For the scientists, the participation of the stakeholders in the two earlier phases facilitate the appropriation of the model and its outputs and thus its utilities for the development purpose.

Possible outcomes of modelling on stakeholders
Modelling processes and model outputs (simulation) play both a role in the policy-making process and FOs capacity strengthening. Table 2 summarizes those different interests.

The participation of stakeholders in the modelling process contribute: (1) to the reduction of information asymmetries between stakeholders; (2) to increase the knowledge of stakeholders about their situation and their environment; (3) to a critical analysis of their own strategy—revealing others actors; strategies may foster the creation of new alliances and a better understanding of other stakeholders' rationales. Finally, a better understanding of the construction of the model may facilitate the appropriation of the model by the users and the legitimacy of the outputs (simulation).

Table 2. Interest of modelling in policy building and FOs strengthening.

Modeling process	Model outputs
Interest of stakeholdersí participation: - share information and **reduce asymmetries** - Contribute to increased knowledge of stakeholders about their situation and their environment - Foster new bridges between stakeholders (RPG–validation meeting) - Facilitate appropriation of the model and its output (model legitimizing)	**Interest** - Contribute to setting the agenda (raise actors' awareness) - Contribute to define political instrument (policy design, etc.) - Foster collective decision - Resources for the policy negotiation (argumentation, justification, etc.)

Nevertheless, it's worth noting that stakeholder participation in modelling activities leads to some difficulties, such as knowledge gaps, time constraints, etc.

The model outputs, especially through simulation, contribute to agenda setting, the definition of the policy instrument. It could contribute to motivate collective action among different stakeholders and/or elaborate individual or collective strategies. Finally, it may be used as a resource for a negotiation process.

Conclusion

Models can be helpful to facilitate multistakeholder negotiations and capacity-building processes for both researchers and actors (policy makers, organizations) in a cross learning process.

The process of model building is as important as the output of the model from a stakeholders and FOs empowerment perspective since it provides the opportunity for a learning process for both researcher and stakeholder. It contributes to the reduction of asymmetries of information between FOs and others stakeholders. In this perspective the modelling activities and outputs could be considered as intermediary objects[3] (Vinck, 1999) for construction of innovation between stakeholders and researchers.

The modelling tools and outputs are not neutral in a negotiation perspective; it is a strategic negotiation resource for actors in a policy design process. Its legitimacy is a key factor, thus it ask for a careful demand definition analysis.

The participation of actors in modelling processes has a high potential in term of capacity building of FOs leaders and cross learning. Nevertheless, the development of actors' participation in the modelling process is still a key issue. It asks for further research in order to develop accurate methodologies to cope with inherent difficulties such as knowledge gaps between actors and stakeholders, and

[3] As defined by Vinck (1999), an object (material o intellectual) around which actors in interaction reshape their relationships, stabilize their network and contribute to produce knowledge.

actors' time restrictions. It also asks for the development of a clear and negotiated interaction framework between stakeholders-users and researchers-modellers.

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SESSION 3

Models Adapated to Agroforestry Systems (AFS)

Chairman: Neil HUTH (CSIRO)

Simulating the Shading Pattern of Tree Shades Using ShadeMotion 2.0

Francisco QUESADA[1] and Eduardo SOMARRIBA[1]

Abstract

ShadeMotion is a software designed for modelling the position and movement of tree shades on the ground. The user can choose any spatial distribution of trees within a plot of up to 40,000 square units of length (meters, yards or any other unit of length), as well as the size, height and shape of each tree crown. The plot can be located anywhere on earth. The initial and final dates of the simulation period can also be arbitrarily selected by the user. ShadeMotion will output a graphical representation of the shades on the plot, showing how many hours of shade are accumulated in each cell of the grid. The user can also obtain an Excel file with all the information provided by the simulation. ShadeMotion also allows the user to visually compare the position, shape and size of shades as the sun changes its position during any particular day of the year. ShadeMotion is a stand-alone application that can be downloaded from Internet (http://www.catie.ac.cr), but it requires the previous installations of Windows Netframework in the user's computer. In this workshop we demonstrate the use of ShadeMotion and describe how shade patterns are calculated, both from the mathematical and computational standpoints.

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Resumen en español

ShadeMotion: patrones de sombra arb rea en el suelo

ShadeMotion es un programa de cómputo diseñado para modelar la posición y movimiento de las sombras de árboles sobre el suelo. El usuario puede escoger cualquier distribución espacial de árboles dentro de una parcela cuadrada, con un lado de hasta 40.000 unidades de longitud (metros, yardas o cualquier otra unidad de medida de longitud), tanto como el tamaño, altura y forma de la copa de cada árbol. La parcela puede localizarse en cualquier ubicación de la tierra. Las fechas iniciales y finales del período de simulación pueden ser arbitrariamente seleccionadas por el usuario. ShadeMotion producirá una representación gráfica de las sombras sobre la parcela, mostrando cuántas horas de sombra se han acumulado en cada celdilla de la cuadrícula. El usuario puede también obtener un archivo de Excel con toda la información provista por la simulación. ShadeMotion puede trazar la posición y movimiento de en la pantalla, de tal manera que el usuario puede visualizar los efectos de las formas de las copas y los tamaños, como también los cambios en la posición del sol a través del año y entre horas en un día dado.

ShadeMotion es una aplicación autónoma que puede bajarse desde Internet: http://www.catie.ac.cr, pero requiere de la instalación previa de Windows Netframework en la computadora del usuario. En este taller mostraremos el uso de ShadeMotion y describiremos cómo los patrones de sombra son calculados, tanto desde el punto de vista matemático como del informático.

Introduction

ShadeMotion 2.0 is a computer program that simulates the position and movement of tree shades on the ground while building a graphical and numerical representation of the shade distribution. The program is available in both Spanish and English languages and can be downloaded from the site: www.catie.ac.cr (once in the Web page, type ShadeMotion in the search box and then click on the appropriate selection to access the software). ShadeMotion version 2.0 deals only with the projection of shades on a flat horizontal plane. Future versions will include the projection of tree shades on tilted planes.

ShadeMotion was conceived as a research tool for agroforestry research and development. It is ideal for testing the shade patterns of different arrays of trees in agricultural fields (for instance, shaded cocoa or coffee plantations, and dispersed or planted trees in annual crop fields) or pastures.

Modeling options

The following list of parameters can be defined by the user when using ShadeMotion.

Tree parameters

1. Any number of trees can be placed in the plot and in any spatial planting arrangement.
2. Crown shapes are limited to five types: spherical, semi-spherical, ellipsoidal, semi-ellipsoidal and conic.
3. Each tree can have its own parameters: trunk height, crown shape, crown height, crown width. This is useful to depict many tree species.

Global parameters

1. Starting and ending dates of the simulation period.
2. Daily (hours) range of simulation (i.e., from 9 a.m. to 4 p.m. each day).
3. Geographical latitude of the plot.
4. Time step unit (how often the position of the sun is to change during the day).
5. Plot size.
6. Units of measure for length and area (meters, yards, etc.).
7. Y axis orientation of coordinate system.
8. Selecting "h" to obtain the shade distribution "h" units above the ground level. (h = 0 means shade distribution at ground level).

Simulation outputs

The program produces two outputs:

1. A graphical representation of the shade cast on the ground presented in the form of a contour map (Figure 1). Darker areas represent more time units of shade cast on the cell. By placing the pointer on any cell, the number of time units of shade accumulated in that cell is shown in the output bar at the lower edge of the ShadeMotion screen.

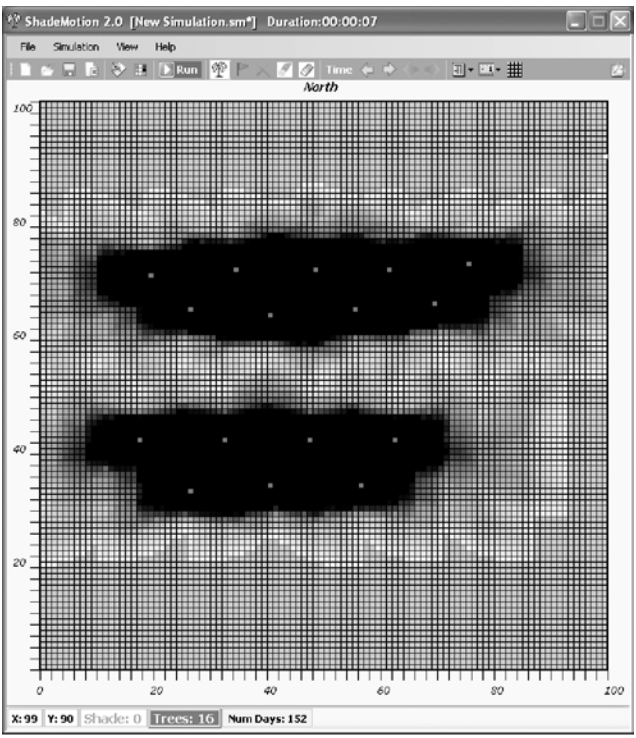

Figure 1. Shading pattern produced by 16 identical trees accumulated over a six-month period (01/01/2008 to 06/01/2008, each day from 7 a.m. to 5 p.m.), at latitude 0°.

2. An Excel file can be produced containing the coordinates of each cell in the grid and the amount of shade accumulated in each cell. This file also contains all the input data used in the simulation (both all tree and global parameters).

By simulating the shade cast by trees on one given day (as opposed to the accumulation of shade over a simulation period as in Figure 1), the user can change the position of the sun at the time interval he/she chooses using arrows provided in the Tools bar. By doing this, the user can track the movement of the shade on the ground and be able to explore the changes in shading patterns for different days in the year or for a given day in different latitudes (Figure 2).

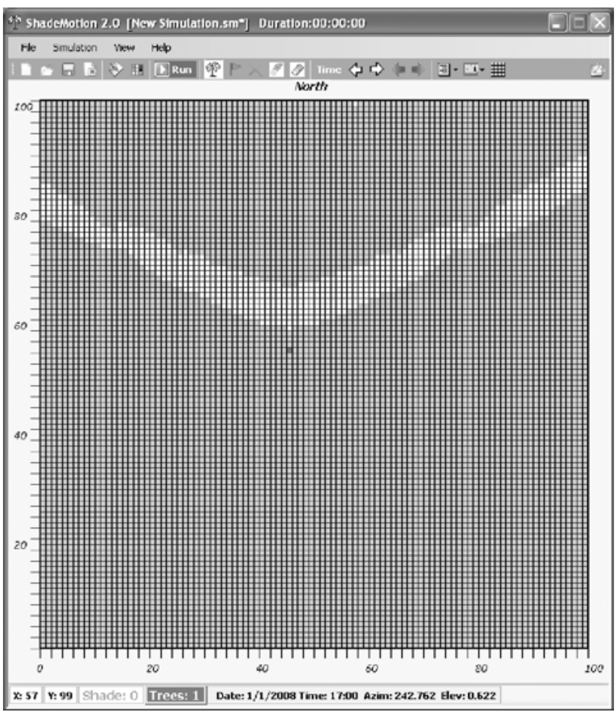

Figure 2. Area swept by the shade of one tree on January 1, from 7:30 a.m. to 4:30 p.m. at latitude 30°.

Basic underlying assumptions

ShadeMotion operates on the following list of basic assumptions:

1. Crown shapes are simple geometrical objects of three possible types: ellipsoidal, semi-ellipsoidal and conic (spheres and semi-spheres are special cases of ellipses and semi-ellipses).
2. Crowns are opaque objects.
3. The shade projected by the tree trunk is neglected.
4. The presence of clouds in the sky is not taken into account.
5. The refraction of solar rays when entering the atmosphere is neglected.

The mathematics behind ShadeMotion

ShadeMotion computes the exact location of the shades cast by the crown of each tree planted in the plot for each position of the sun, as determined by the latitude, day and hour ranges defined by the user. When computing shades, tree crowns, which are solid three dimensional objects, are replaced by flat surfaces (the crown's cross section) opposing the direct trajectory of sun rays (diffuse radiation is not taken into consideration in ShadeMotion). The shade cast by some crown shapes is modeled using two flat surfaces: for example, a conic crown is replaced by a vertical triangle and a horizontal disc, the latter representing the base of the cone.

The position of the sun is computed using horizontal coordinates: elevation and azimuth. The following standard formulas are employed for elevation (elev), azimuth (azim), declination (decl) and hour (hor) angles.

$hor = 15\ (hour - 12)$

$decl = 23.45\ sen\ (360/365)(d + 284)$

$elev = sen^{-1}[cos(lat)cos(decl)cos(hor) + sen(lat)sen(decl)]$

$azim = cos^{-1}\{[cos(lat)sen(decl) - sen(lat)cos(decl)cos(hor)]\ /\ldots$

$\ldots cos(elev)\}$

When the position of the sun is known, the exact position of a shade is determined on the ground. All shades are expressed with respect to a universal reference system SRU of rectangular Cartesian coordinates. Each cell of the grid (plot) is referenced by a pair of coordinate numbers (x, y) relative to SRU. Two auxiliary reference systems (also Cartesian) SRA and SRB are employed before translating the shade to SRU. Each tree has its own SRA an SRB systems. The origin of SRA is located at the center of the shade and the X and Y axis are parallel to the natural axis of the shade. SRB has the origin also in the center of the shade, but the X and Y axis are parallel to those of SRU. By default, the Y axis of SRU points toward the North. SRA is transformed into SRB by means of a rotation of coordinate axis. An additional translation is needed to go from SRB to SRU (Figure 3).

In order to determine if a cell (i, j) is under the shade of a tree, we must first define an equation that describes the contour of the shade in SRA, then express this equation with respect to the rotated SRB coordinate axis and finally translate the equation to the common system SRU. Let's illustrate this in the case of a tree with an ellipsoidal crown, located at coordinates (x_0, y_0). The contour of the shade projected by such a crown is an ellipse.

The inequality for the interior of such an ellipse in system SRA, is:

$$x^2/ a^2 + y^2 / [(b\cotan(elev))^2 + a^2] < 1$$

where a = crown width and b = crown height

When referring the latter expression to system SRU, the tree coordinates (x_0, y_0) and the azimuth angle must be included. A cell (i, j) is under the shade projected by this tree if the values x=i and y=j satisfy the following inequality:

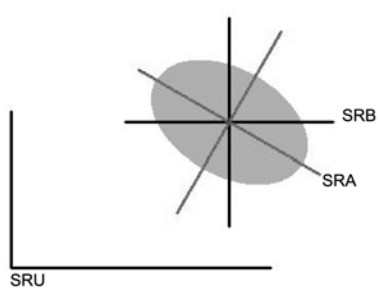

Figure 3. Cartesian coordinate systems used to determine the position of the shade on the ground.

$[(x-x_0)\cos(azim+180) - (y-y_0)\sin(azim+180)]^2 / a^2 + \ldots$

$\ldots[(x-x_0)\sin(azim+180) + (y-y_0)\cos(azim+180)]^2$
$/ \ldots \ldots[(b\cot an(elev))^2 + a^2] < 1$

Scanning the shades

The plot is internally represented by a square matrix M. The number of entries in M is the same as the number of cells in the plot. Entry n(i,j) of M is an integer which denotes the total amount of shade accumulated in cell (i, j), at any time during the scanning process. When the program scans the plot in search for shades, there are three questions that have to be answered. (1) What is the value of time (day and hour)? (2) Which tree is being processed? (3) Which cell is being scrutinized? The search for shades is performed following the order: cells-trees-time. This means that:

ß For a given tree, all cells in a selected region of the plot that contains the shade have to be scanned, before moving to the next tree.

ß All trees in the plot have to be scanned before moving to the next time unit.

Each time a cell (i, j), is shaded by a tree, then the corresponding entry n(i,j) of M is replaced by n(i,j) + 1.

When the scanning process comes to an end, entry n(i,j) of M contains an integer which denotes the total amount of time units of shade cast on cell (i,j), by all trees, over the entire simulation period.

Shading at a given height above ground

ShadeMotion provides a means to determine the shading pattern at a certain height above ground. For instance, if the user wants to determine the shade cast over the canopy of coffee plants 2 m in height, the user may set the height parameter at 2 m and ShadeMotion will calculate the shades at that height and not on the ground.

Simulating Agroforestry System at Plot Scale: APES-Agroforesty. Limitations and Advantages of Modularity

Eric CASELLAS[1]

Abstract

APES (Agricultural Production and Externalities Simulator www.apesimulator.org) is a cropping system biophysical model developed in the SEAMLESS European FP6 project (www.seamless-ip.org).

APES is targeted at estimating the biophysical behaviour of agricultural production systems in response to the interaction of weather and different options of agrotechnical management. It is a daily step, multiyear, multicrop, 1D field model that can simulate both monoculture (crop, grassland, tree) or intercropping (agroforestry, vineyard + grassland). It has modules for plant growth and phenology; water and nitrogen soil dynamic; water, nitrogen and light competition; root profile evolution; pesticide fate; and an agromanagement module that triggers events according to rules.

APES has a computer structure based on principles of modularity, genericity and reusability (Argent, 2004; Donatelli, 2004; Rizzolli, 2004). Modularity is a great advantage for coupling different models, these modules can also be used in a different context and facilitate its extensibility with new models (Athanasiadis,

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2006). This technical modularity can also be dangerous because it doesn't assure any consistency at all between the coupled models; this consistency has to be checked. APES includes also several applications and tools targeted either to APES use or to components development.

Resumen en español

Simulaci n de sistemas agroforestales a la escala de la parcela: APES-Agroforestry: Limitaciones y ventajas de la modularidad

APES (Agricultural Production and Externalities Simulator www.apesimulator.org/) es un modelo biofísico de sistemas de cultivo desarrollado en el proyecto europeo FP6 SEAMLESS (www.seamless-ip.org/).

APES está dirigido a estimar el comportamiento biofísico de los sistemas de producción agrícola en respuesta a la interacción del clima y las diferentes opciones de técnicas agrícolas. Es un modelo de campo, monodimensional, con paso de tiempo diario, con simulaciones plurianuales que pueden incluir uno o varios (cultivo, pasturas, árboles) cultivos o cultivos mixtos (agroforestería, viñedos + pasturas). Tiene módulos para crecimiento y fenología de la planta; suelo dynamico de agua y nitrógeno; competición de agua, nitrógeno y luz; evolución del perfil de raíces, destino de los pesticidas; y un módulo de manejo agrícola que desencadena eventos de acuerdo a las reglas. APES también tiene una estructura informática basada en módulos según reglas establecidas.

APES tiene una estructura informática basada en principios de modularidad, genericidad y re-utilisabilidad (Argent, 2004; Donatelli, 2004; Rizzolli, 2004). Esta modularidad es una gran ventaja para acoplar modelos diferentes que también pueden ser

usados en un contexto diferente y facilitar su extensibilidad con nuevos modelos (Athanasiadis, 2006). Esta tecnical modularidad también puede ser peligrosa porque no asegura del todo que el modelo completado sea consistente.

APES incluye varias aplicaciones y herramientas, dirigidas tanto al uso de APES como al desarrollo de nuevos componentes.

Introduction

Several simulation tools allow the study of the impact of agricultural management on production activities in specific environments. Such tools are specialized, to different extents, to one or more specific production activities: arable crops/cropping systems, grassland, orchards, agroforestry, livestock, etc. Also, their outputs include to varying degrees an estimate of system externalities that may have a negative environmental impact; they may include, for example, an estimate of nitrogen leaching or the fate of pesticides. Very often, the structure of such systems neither allows for an easy plug-in of models for new agricultural production activities nor the use of different approaches for the simulation of processes via alternate formulations (Argent ,2004; Donatelli, 2004). Furthermore, documentation of such tools may not be updated and may not follow a single standard, which makes it difficult to access information. Finally, when such systems are proprietary systems of either research groups or projects, it may not be possible for third parties to reuse the system for further development (Athanasiadis, 2006).

The SEAMLESS European Project

The EU 6th Framework Research Programme SEAMLESS project is developing a tool to integrate analyses of impacts on a wide range of aspects of sustainability and multifunctionality (van Ittersum, 2008). This requires the evaluation of the agricultural outputs and system externalities for a wide range of production systems and environments. Although some indicators of system performance can be provided using static models derived from existing databases, estimating system behaviour for novel techniques requires process-based simulation. Also, even for known systems, some of the externalities due to agricultural production are not available as observational data except for a very limited number of experimental sites. The analysis of the biophysical components of agricultural systems thus requires a simulation framework that can be extended and updated by research teams, which allows easy incorporation of research results into operational tools and which is transparent with respect to its contents and functionality (Cwalina, 2006; Donatelli, 2008; Rizzolli, 2004).

APES: Agricultural Production and Externalities Simulator

APES is a simulation model system for estimating the biophysical behaviour of agricultural production systems in response to the interaction of weather, soil and agrotechnical management (Figure 1).

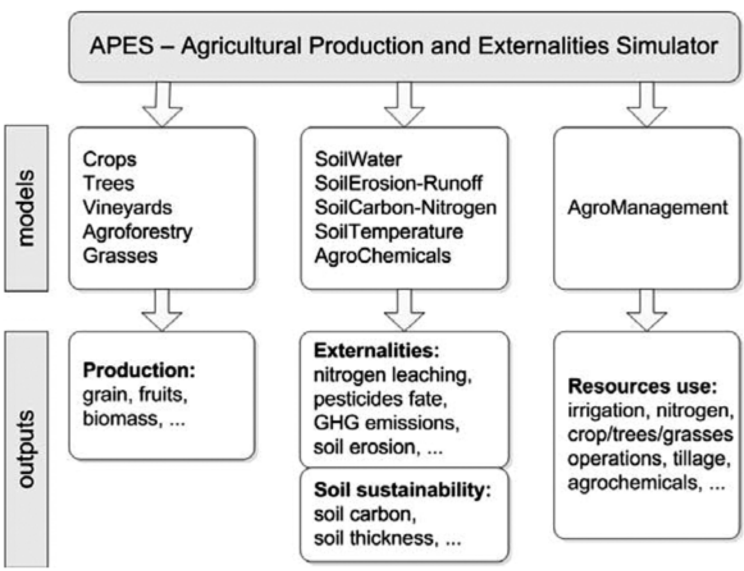

Figure 1. Schematic representation of APES model.

The system is being built to incorporate, at a later date, other modules that might be needed to simulate processes not included in the present version, such as plant diseases or grassland. All models use a daily time step for integration and communication across modules although, within a component, calculations can be carried out with a shorter time step. Each component contains one or more existing peer-reviewed models that simulate the constituent processes (Bishop, 2008; Jones, 2001; Mesketer, 2004). The relevant references are listed in the documentation of each component.

Biophysical processes are simulated in APES using deterministic approaches that are mostly based on mechanistic representations. The criteria for select modelling approaches were the need to

ß Account for specific processes to simulate soil-land use interactions.
ß Input data to run simulations (which may be a constraint at EU scale).
ß Simulate agricultural production activities of interest (e.g., crops, grasses, vineyards, agroforestry).
ß Simulate agromanagement implementations and their impact on the system.

Functional requirements of APES:

ß Estimation/generation of variables via different models.
ß Estimation of parameters from observational data.
ß Provision of data at run time, accessing either observational or generated data, and making available model outputs.
ß Provision of quality checks on imported data.
ß Provision of quality checks on outputs.
ß Robust behaviour of the component that degrades gracefully, raising appropriate exceptions.
ß Traceable component behaviour with traces that are scaleable (i.e., browsable at different debug levels).

Nonfunctional requirements of APES:

ß Ease of use: the components must be easily used by clients.
ß Extensibility: the capability of easily adding alternate processing capabilities to the ones of the component from the side of the component user.
ß Reusability: the practical possibility of using the component in different software systems.

- Replaceability: the capability for components to be replaced by a different component conforming to the same specification.
- Availability of fit-for-purpose documentation of models, software design, and code.
- Successful unit tests: unit tests for each public method, input-output tests should be reported in the documentation.

Component-based structure

Developing a simulation system based on the component-oriented paradigm (Argent, 2004; Donatelli, 2004; Donatelli, 2008; Jones, 2001) poses specific challenges, both in terms of biophysical model linkages and implementation architecture. Component-based architectures demand the definition and implementation of subsystems that minimize the need for links to other components and the need for repeated communication between different components. However, even when a system to be simulated is divided into subsystems with little need for communication between them, data exchange prior to integration within a time step is needed. Thus an articulated interface is needed that allows such calls (Cwalina, 2006).

Although being potentially prone to mix and match "everything," is often suggested as an intrinsic weakness of component-based systems, this problem can be overcome by shifting the focus to the components themselves using semantically rich interfaces that ensure that the linked variables are the correct ones (Athanasiadis, 2006). To illustrate the concept, if a component makes available a variable characterized by units, range of use, type and description and another component requires the same variable as an input, the link can be considered correct if a check of the variable attributes show that these are identical, whereas the correctness of the variable as an input must be investigated within the component producing the output. The principle of applying "parsimony" is of course still valid in model building. For instance, there is no point in coupling two components in which strong assumptions (and thus the limitations) of one impose an unnecessary burden on the modelling capabilities of the other. This, however, applies both to monolithic and component-based system development. As always, the choice of model should be conditioned by both the intended application of the model and a comprehensive system analysis, and this is totally independent of the type of implementation.

The problems and requirements outlined in the previous paragraph have formed the basis of the design of APES in terms of both flexibility in making available an open modelling environment and a set of software architecture choices. The emphasis in APES has consequently been to provide a transparent and flexible modelling platform that can be adapted to different modelling goals.

APES is composed of two main groups of software units: the simulation engine that uses the modelling framework MODCOM (Hillyer, 2003; van Evert, 2007), and the model components. Model components can be grouped into soil components, production enterprise components, weather and agricultural management.

There is no single solution to the problem of splitting complex systems into components. However, some divisions are more effective than others. The criteria used for doing this in APES were

- Consistency with knowledge about the organization of the real system.
- Consistency with the goal of encapsulating a useful/reusable set of modelling solutions relevant to the specific domain.
- Minimization of the need for communication between components within a time step.

This has led to components with different model granularities (from the whole system perspective) as one of the possible solutions to modularization of agricultural production systems. Targeting model component design to match a specific interface requested by a modelling framework decreases its reusability. A possible way to overcome this problem is to adopt a component design that targets intrinsic reusability and interchangeability of model components. Such components can be used in a specific modelling framework by encapsulating them using dedicated classes called "wrappers." The disadvantage of this solution is the creation of another "layer" in the implementation. However, if components are correctly designed, there is a negligible, penalty in performance, and the wrapper does not add complexity. They also allow modelling knowledge to be shared in a form that makes it easily reusable.

Model granularity in components: the strategy design pattern

One possible definition of a model, relevant to the work of developing components for biophysical simulation, is a conceptualization of a process. A model can be implemented in a class, providing the estimation or generation of a variable (or a set of interrelated variables), obtaining a fine level of granularity. There might be more than one way to do this. If two different models estimate variable A, those two models are alternatives for estimating variable A even if they have different input requirements and different parameters. As a consequence, the two models must be available as separate units, and their input, parameters and output must be defined. Such units are here called "strategies," from the related design pattern introduced below. A way to have all models available in a component, via the same call, including alternate approaches, is the implementation of the design pattern Strategy.

This offers the user of the component algorithms that are alternative options (strategies) for doing the same thing. When building a biophysical model component, this allows, in principle, alternative options to be offered for estimating a variable or, more generally, to model a process. This often-needed feature in the implementation of biophysical models, if implemented in this way, comes with two very welcome benefits from the software side:

- It allows easier maintenance of the component, by facilitating the addition of other algorithms.
- It allows the easy addition of further algorithms from the client side, without the need to recompile the component, while keeping the same interface and the same call.

The basic point here is that a strategy (a model class) encapsulates a model, the ontology of its parameters and the test of its pre- and post-conditions. It can be used either directly as a strategy (in this case we call it "simple strategy," where simple indicates that it does not use other strategies as part of its implementation), or it can be used as a unit of composition, as described below.

A composite strategy differs from a simple strategy because it needs other (simple) strategies to provide its outputs. A sequence of calls might be implemented inside a composite class. The list of inputs is given that includes all the inputs of all classes involved (except those that are matched internally). The list of outputs includes all outputs produced by each strategy and the ones specific to the composite class (if any). The list of parameters needed includes those of the classes associated with and the ones (if any) defined in the composite class. When the value of a parameter is set, if the parameter belongs to an associated class, it is set on that class. The test of pre/post conditions makes use of the methods available in each associated simple strategy class, plus the new tests specified in the composite class. If a violation of pre/post condition occurs in one of the associated classes, the message informs the user not only about the violation that has occurred, but also in what class it has occurred. Composite strategies do not differ in their use compared to simple strategies. The interface used for models is the same for all modelling solutions in the component, implementing the Façade pattern to hide the complexity of model solutions based on composite strategies (Bishop, 2008).

Intended use of APES

As the simulation tool has been developed with a focus on modularity, APES versions including different modelling engines will be made available as "closed" modelling solutions. A set of options may be made accessible, but APES users will not be able to access model composition in order to protect system integrity. However, an open system is being developed so that the same individual, with a different role, may access model building, in this case taking the responsibility for the choices made. This is the expected use beyond the end of the SEAMLESS project (March 2009).

The system allows plant growth (crop, tree), water, nitrogen and pesticide dynamics to be simulated at the field scale in response to agromanagement in the range of environments (soil-weather combinations) characteristic of the agricultural parts of Europe. The choice of spatial scale has been a direct consequence of the goals of the simulation: to estimate production and system externalities in response to detailed agricultural management applied in specific soil-weather combinations. Modelling approaches selected and implemented in APES were mostly developed at the field scale. Simulation outputs at this scale have been used in the literature to provide outputs at the regional scale by linking to Geographical Information Systems (GIS) holding information on the spatial distribution of soils and weather. In such cases the most frequent recommendation is to use simulation outputs to make relative comparisons between different agromanagement options. Other options are to use simulation outputs at the field scale as "cell" data to be integrated in spatially explicit models, as in some catchment models. In this case, the increased number of inputs needed generally limits the use of these models to case studies. All uses at scales other than the field scale involve additional assumptions that may be difficult to justify. Moving across scales is being addressed in SEAMLESS with specific actions, but it is outside the modelling domain of APES.

APES integration in broader modelling system

Given its component-based structure, APES can be run not only via a user interface but also using a command line procedure. This allows the model also to be called from applications developed using languages that have no binary compatibility with NET (e.g., Java) as far as such applications are run on a machine running Windows. A support to integration can also be provided if the application that acts like a client is a web application, if such application exposes web services and includes rich clients. APES tools for integration are hence presented both as command line applications and as graphical user interface tools.

APES integration, although technically possible even at tighter levels than the ones outlined above, should, however, be approached with caution, providing users means to access and verify results of any operation involving simulations, such as simulation per se or finalizing parameter calibration. This is not highlighted because of the unusual component base structure of APES, but rather because such models simulate complex systems via process-based models. Automated procedures in model chains may produce nonsense results, which may fit some optimization procedures but which would be meaningless in biophysical terms. Whether simulation anomalies due to either input data or even the misuse of the simulation model might be evident working with the biophysical system simulation alone, a misuse of APES (or of any other process based system) in model chains may be very difficult to spot, and it could have an unpredictable impact on final results of the analysis. Even if included in a model chain, it is advisable to link APES simulations to other models asynchronously, allowing for simulation results to be evaluated by an analyst prior to using APES outputs as inputs for further processing.

Conclusion

The strategy behind APES development was a shift of paradigm with respect to the past for two reasons. First, APES is not proposed as "the" model. Instead it is made available stressing the need for broadening modelling approaches and for comparing them at a finer granularity than for whole simulation systems. Secondly, even in comparison to the advent of modelling frameworks for overcoming the problems of monolithic models, APES is a shift of paradigm because it moves the focus onto components and their reusability outside APES itself, even as stand-alone entities. Developing model components, even with the requirements listed in the previous paragraphs, is a small challenge in terms of implementation, but it forces us to formalize modelling knowledge and the problem of model linkage and reuse (in modelling terms). Technology is expected to move more and more toward declarative modelling in an operational way, but the work done creating fine granularity, discrete model units, encapsulating a semantically rich description of interfaces—hence discussing and understanding many aspects about model assumptions and structures—will also be of great help in that direction. The work done so far in APES development has led to an increasing opportunity to concentrate on modelling options, while also making reuse of expertise in different domains. APES will be offered as a complete simulation tool but also, and of no lesser importance, as a loose collection of model objects that allow the modelling knowledge APES Teams have assembled to be shared in an operational way. Utilities and applications are also available as independent objects for reuse. A third party may want to use a single component or an extended set of them; in any case each of them will be easy to be used in custom-developed applications and they will be fully documented and extensible.

At the end of the third year of the SEAMLESS project, APES development follows five paths:

1. Developing new components and modelling options.
2. Testing the simulation model and the user interface.
3. Developing utility applications, e.g., for calibrating APES models and running sensitivity analyses.

4. Seeking cooperation to reuse APES components in other modelling frameworks.
5. Integrating APES within the larger SEAMLESS Framework (link with FSSIM farm model and survey databases).

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Loss of Functional Diversity with Agricultural Intensification: A New Model for Evaluating Loss of Biodiversity with Implications for Ecosystem Functioning

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Abstract

It is generally accepted that agricultural intensification and land-use conversion is one of the principal drivers of the loss of biodiversity, particularly native, forest-dependent species in the tropics. However, the implications of changes in species number and composition on the provisioning of ecosystem functions is poorly understood at best. Early ecological studied focused on the response of biodiversity to changes in environmental conditions, and regarded species as rather passive recipients of environmental change. Recent work, however, increasingly demonstrates that biodiversity, including species richness and composition, can be a driver of ecosystem processes. However, studies linking biodiversity and ecosystem function have struggled to identify the underlying mechanisms driving this relationship. Recently, the

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shift has changed from focusing on taxonomic classifications of compositions to functional classifications that focus on what a species does in a system rather than its taxonomic origin.

In meta-analysis, we used published data from both temperate and tropical human-dominated landscapes with published species lists of birds, mammals and plants in natural, semi-natural and agricultural land uses. Using a trait-based continuous classification of functional diversity, we find functional diversity is much more sensitive to agricultural intensification than either species richness or the Shannon-weiner index of diversity. Using null model simulations, we also find that, in most cases, the loss of functional diversity is greater than would be randomly expected. Finally, we investigate whether specific trait clusters are more prone to extinction and find no evidence for trait mediated extinctions. Loss of species occurred across traits. Rather, functional groups that had lower than average species per group were more likely to become extinct, providing support for the insurance hypothesis.

Our results beg the question: if functional diversity is being significantly lost, what are the implications for critical ecosystem functions, and can the concept of functional diversity be used as a means of restoring ecosystem function in agroforestry systems?

Resumen en español

P rdida de diversidad funcional por la intensificaci n agr cola: un nuevo modelo para evaluar la p rdida de la biodiversidad con implicaciones sobre el funcionamiento de ecosistemas

Está generalmente aceptado que la intensificación agrícola y el cambio de uso de la tierra sean las causas principales de la pérdida de biodiversidad, particularmente en lo que se refiere a las especies nativas dependientes del bosque tropical. Sin embargo, las implicaciones de cambios en el número y la composición de especies en el suministro de funciones ecosistémicas son, en el mejor de los casos, pobremente entendidos. Estudios ecológicos anteriores se enfocaron en la respuesta de la biodiversidad a los cambios de condiciones ambientales y consideraron a las especies como recipientes pasivos del cambio ambiental. Sin embargo, el trabajo realizado recientemente demuestra de forma creciente que la biodiversidad, incluyendo la riqueza y composición de las especies, puede ser un conductor de procesos ecosistémicos. Sin embargo, estudios que asocian la biodiversidad y la función ecosistémica han tenido dificultad para identificar los mecanismos fundamentales que conducen a esta relación. Recientemente, esto ha cambiado; en vez enfocar la clasificación taxonómica de las composiciones, se enfoca las clasificaciones funcionales que enfatizan la acción de las especies en un sistema y no en su origen taxonómico.

En el meta análisis, usamos datos publicados de paisajes intervenidos templados y tropicales con listas publicadas de especies de aves, mamíferos y plantas en usos de tierra naturales, semi naturales y agrícolas. Utilizando una clasificación continua basada en rasgos de diversidad funcional, encontramos que la diversidad funcional es mucho más sensible a la intensificación agrícola que cualquier riqueza de especies, o que el índice de diversidad Shannon-weiner. Usando simulaciones de modelo nulo, también encontramos que en la mayoría de los casos, la pérdida de diversidad funcional es mayor de lo que se hubiera esperado de una distribución aleatoria. Finalmente, investigamos si ciertos clusters de rasgos son más propensos a la extinción y no encontramos evidencia de ello. La pérdida de especies se distribuye entre los rasgos. En cambio, grupos funcionales con menos especies que el promedio de especies por grupo fueron más propensos a extinguirse proveyendo apoyo a la hipótesis de seguro.

Nuestros resultados llevan a la siguiente pregunta: si la diversidad funcional se está perdiendo significativamente, ¿cuáles son las implicaciones para funciones ecosistémicas críticas, y puede el concepto de diversidad funcional ser usado como medio de restauración de funciones ecosistémicas en sistemas agroforestales?

Plot-Scale Modelling of Coffee Agroforestry Systems in Central America

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Abstract

The productivity and environmental impact of coffee agroforestry systems depend on many factors: environment, management, coffee cultivar, tree species. We present a simple dynamic model of coffee agroforestry systems that can help analyse the impacts of the different factors (van Oijen et al., 2008). The model includes the physiology of coffee plants, and its response to different growing conditions. This is integrated into a plot-scale model of coffee and shade-tree growth that includes competition for light, water and nutrients. The model can simulate management treatments such as spacing, thinning, pruning and fertilising. Model outputs are the variables that we want the model to calculate, as a function of the inputs. The major outputs of the model are

- Productivity: coffee-bean yield, tree-stem volume
- Environmental impact: rate of N-leaching to groundwater and of N-emission to the atmosphere, rate of loss of organic carbon and nitrogen in surface runoff.

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We analysed to what extent the literature has sufficient information to allow parameterisation of the model for various coffee-tree combinations. Information on weather, coffee and trees is found to be limited, but soil information seems adequate. In particular, missing are multifactorial experiments to examine interactive effects of different environmental factors. Although model parameterisation thus remains uncertain, model behaviour seems consistent with observations. We show examples of how the model can be used to examine trade-offs between increasing coffee and tree productivity, and between maximising productivity and limiting the impact of the system on the environment.

Resumen en español

Modelaje de sistemas agroforestales a escala de parcela en Am rica Central

La productividad y el impacto ambiental de los sistemas agroforestales de café dependen de muchos factores: ambiente, manejo, plantación de café, especies arbóreas. Presentamos un modelo dinámico de sistema agroforestal de café que puede ayudar a analizar los impactos de los diferentes factores (van Oijen et al., 2008). El modelo incluye la fisiología de las plantas de café, y su respuesta a las condiciones de crecimiento diferentes. Esto es integrado dentro de un modelo de café y árboles de sombra a nivel de parcela el cual incluye la competición por luz, agua y nutrientes. El modelo puede simular tratamientos de manejo tales como espaciamiento, raleo, poda y fertilización. Los resultados del modelo son las variables que queremos que el modelo calcule, como una función de los insumos. Los resultados mayores del modelo son

- Productividad: producción del grano de café, volumen del tronco de los árboles
- Impacto ambiental: tasa de lixivación de N al agua subterránea y de emisión de N a la atmósfera, tasa de pérdida de carbono orgánico y nitrógeno en la escorrentía de la superficie

Analizamos hasta qué alcance la literatura tiene suficiente información para permitir la parametrización del modelo para varias combinaciones de café-árbol. La información sobre clima, café y árboles es limitada, pero la información sobre suelo parece ser adecuada. En particular hacen falta experimentos de factores múltiples para examinar los efectos interactivos de los diferentes factores ambientales. Aunque la parametrización del modelo permanece incierta, el comportamiento del modelo parece ser consistente con observaciones. Demostramos ejemplos de cómo el modelo puede ser usado para examinar ventajas y desventajas entre el incremento de las productividades de café y de los árboles, y entre la maximización de la productividad y la limitación del impacto del sistema sobre el ambiente.

Introduction

Coffee (*Coffea arabica*, L.) poses many demands to its growing environment (DaMatta et al., 2003). For example, coffee is intolerant to frost but also to overly high temperature. Protection against both temperature extremes can be afforded by the use of shade trees.

One way of integrating the scattered knowledge on coffee agroforestry systems is by trying to build a process-based model. Here, we describe such a model for coffee agroforestry systems that was developed in project CASCA (van Oijen et al., 2008). The purpose of the model is to explore the system's response to strategic management decisions (fertilisation level, shade-tree species and density, pruning and thinning regimes), regional differences in growing conditions (weather and soil) and environmental change (climate and atmospheric composition). To meet these goals, the model was built to simulate a full rotation of coffee growth, which takes typically 10–25 years in Central America.

Here, we take the view that model complexity should be commensurate with data availability. We therefore aim for a simple coffee agroforestry model, realising that ongoing research may justify adding complexity at a later stage. Thus far, no models have been developed specifically for the coffee agroforestry system.

A dynamic model for coffee agroforestry systems

The main components and interactions in coffee agroforestry systems that need to be modelled are shown in Figure 1. In the tree-covered part of the field there will be competition for resources between trees and coffee. The major resources required by both plant types are CO_2, light, water and nutrients.

When tree cover is less than 100%, part of the field is not shaded (left) and competition for resources only takes place in the shaded part (right). The shaded part expands because of tree growth and contracts because of tree management.

The competition for light is generally asymmetric, with tree canopies having first access to incident radiation and shade-coffee only intercepting light transmitted by the trees. There is full competition

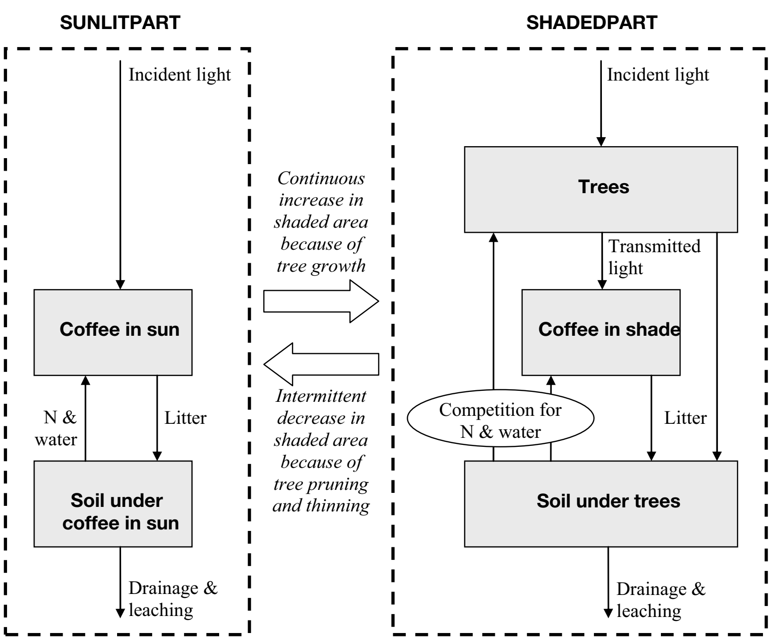

Figure 1. Resource fluxes in coffee agroforestry systems.

for soil resources because the root systems of the two plant types at least partly occupy the same soil volume. Tree cover is generally not 100%, so part of the field is unshaded. Our model represents both the shaded and unshaded parts of the field and how their relative areas change over time.

We focus on potential productivity, defined as growth unlimited by factors other than light, water, N and only constrained by local soil and weather conditions and by site management. We concentrate on coffee and tree genotypes used in Central American coffee-growing regions of various altitudes (which differ climatically mainly in temperature), with different levels of availability of water and nitrogen and different management regimes.

The inputs to the model are all the factors whose impact we want to know about:
ß Weather conditions: temperature, rain, light, humidity, wind
ß Soil conditions: initial organic matter and nitrogen content, water retention characteristics, slope
ß Coffee management: rotation length, N-fertilisation, pruning regime
ß Tree management: choice of species, density, thinning regime, pruning regime

For the modelling, we selected the following group of six shade-tree species that are commonly used and for which data are becoming available from various ongoing research programmes in the area: *Cordia alliodora*, *Erythrina poeppigiana, Eucalyptus deglupta, Gliricidia sepium, Inga densiflora, Terminalia ivorensis*. Besides providing shade, *E. poeppigiana*, *G. sepium* and *I. densiflora* fix nitrogen, while *Cordia alliodora*, *E. deglupta* and *T. ivorensis* provide timber.

Model outputs are the variables that we want the model to calculate, as a function of the inputs. The major outputs of the model are
ß Productivity: coffee-bean yield, tree-stem volume
ß Environmental impact: rate of N-leaching to groundwater and of N-emission to the atmosphere, rate of loss of organic carbon and nitrogen in surface runoff

The model operates on a daily time step and takes as input daily values of weather conditions: radiation, temperature, precipitation, humidity and wind speed. Shade trees reduce photoperiod temperature of the understorey more than they increase nighttime temperature (Barradas and Fanjul, 1986) which is modelled descriptively as a reduction of daily average temperature proportional to the fraction of radiation intercepted by the trees.

The model considers, for shaded and sunlit coffee plants separately, how carbon and nitrogen content, leaf area and phenology change over time. Seven state variables are distinguished: carbon in leaves, woody parts, roots and reproductive organs, nitrogen in leaves, LAI and phenological stage.

Light interception is modelled using Beer's law with a constant light extinction coefficient. Assimilate production is calculated by multiplying light interception with a light-use efficiency that decreases with light intensity.

The relative allocation of assimilates to different organs is constant with four exceptions: (1) after flowering, reproductive growth increases towards a maximum, returning to zero at bean maturation, (2) the maximum sink strength of reproductive growth is proportional to light intensity around flowering, (3) reproductive growth only starts in the third year after planting and is hampered for one year after pruning of the coffee plants, (4) allocation to roots follows a functional balance, increasing in case of drought and N-deficiency. The onset of flowering was modelled as the first day of the year exceeding a threshold amount of rain. Bean maturation follows a fixed number of degree days later. Leaf area increases as the product of leaf biomass growth rate and specific leaf area, the latter being reduced in case of drought. Senescence of all organs follows organ-specific time constants and leads to the addition of carbon and nitrogen to the soil.

The submodel for trees is based on the BASic FORest simulator (BASFOR), described in more detail elsewhere (Van Oijen et al., 2005). Six state variables are distinguished: carbon in leaves, branches, stems and roots, nitrogen in leaves and tree density. All morphological variables, i.e., projected crown area of individual trees, leaf area index (*LAIt*), wood volume and tree height, are calculated as allometric functions of the biomass variables.

The soil submodel is a simple one-layer model, of fixed depth, with eight state variables: carbon and nitrogen in litter, unstable and stable organic matter, mineral nitrogen and water. Two soil compartments of constant depth are distinguished, representing the shaded and unshaded parts of the field.

Potential rates of transpiration and evaporation are calculated by means of the Penman formula (Penman, 1948). Actual rates of transpiration depend on soil water content according to the site-specific soil water retention curve. Runoff is modelled as proportional to the daily rain not intercepted by the canopy, increasing from zero on flat soil to complete runoff on vertical soil.

Carbon cascades from litter to unstable organic matter to stable organic matter, with fixed time constants and efficiencies for each conversion step, following the simple soil model developed by Goudriaan (1990) and Goudriaan and Ketner (1984). Nitrogen follows the same cascade.

With respect to light, the model is kept simple, with tree crowns being assumed to be higher than the coffee plants, so trees have first access to light. In contrast, there is true competition for soil water and mineral N, and the distribution of these resources between the two species depends on their relative resource demands, the relative root system densities, and the specific uptake capacities of the root systems.

Literature review on coffee agroforestry systems

The model described above has about 60 parameters whose values need to be quantified. We searched the literature for quantitative information on the ecological and physiological processes that underlie coffee and tree productivity in coffee agroforestry systems. Literature search was conducted for the peer-reviewed literature using Web-of-Science and for the grey literature using Google Scholar and further Web search. Special attention was given to publications from Central America.

Simulations

The default system we simulated was a coffee agroforestry system growing under the measured Turrialba weather conditions, on soils with a slope of 5% and with initially 113 ton ha^{-1} carbon and 10 ton ha^{-1} nitrogen in the root zone, fertilised with 150 kg N ha^{-1} y^{-1}, and with 250 shade trees ha^{-1} (thinned to half that after 2.7 years, and annually pruned) of a generic N-fixing species with parameter values averaged over the leguminous trees in the literature review. Eight years of growth were simulated, from 1-6-1997 to 30-5-2005. We carried out four types of simulation with the model:

1. Simulations using the default system
2. Simulations using a system without shade trees (full sun)
3. Simulations using different species of shade trees
4. Simulations with one environmental factor modified

A summary of the predictions of the model for these various systems is shown in Table 1.

Discussion

Compared to crop modelling, agroforestry modelling is still in its infancy. The model presented in this paper is one of the first that simulates a tropical agroforestry system. The model simulates the mass balance of carbon, nitrogen and water fluxes through a coffee agroforestry system. The model is kept simple because, as the literature review showed, there is insufficient empirical information available for building a complex parameter-rich model. Furthermore, model simplicity enhances the chances that it will ultimately become useful in decision-making—and not remain purely a research tool, like most models developed for tropical systems (Matthews et al., 2000).

The model also has limitations in that it does not produce results for some important indicators of the success of coffee agroforestry systems, such as the quality of coffee beans and tree timber, and the impact of management decisions on biodiversity (Dix et al., 1999). However, the model is complex enough to permit preliminary assessment of the trade-offs between increasing coffee and tree productivity, and between maximising productivity and limiting the impact of the system on the environment.

Table 1. Simulations exploring the effects of single-factor changes in coffee agroforestry systems on annual average yield (Coffee bean production, Wood volume production) and environmental impact (C-sequestration on-site, Water drainage, N-leaching, Volatile N-emission and Soil C-loss in runoff). All changes are relative to a default system with coffee grown under 250 trees ha^{-1} of a generic N-fixing shade tree species in the climate and soil conditions of Turrialba, Costa Rica.

Variable	Coffee production	Wood production	C-sequestration	Water drainage	N-leaching	N-emission	Soil C loss
Default system	1.32 t DM ha^{-1} y^{-1}	6.37 m^3 ha^{-1} y^{-1}	3.81 t C ha^{-1} y^{-1}	5.28 mm d^{-1}	175.34 kg N ha^{-1} y^{-1}	8.02 kg N ha^{-1} y^{-1}	0.07 t C ha^{-1} y^{-1}
% change relative to Default system							
Full sun system (no shade trees)	29	-100	-54	0	28	27	16
Cordia alliodora	-6	5	0	-1	-18	-17	-2
Eucalyptus degluptans	-8	2	10	1	-15	-15	3
Erythrina poeppigiana	-16	112	15	1	-12	-12	-2
Gliricidia sepium	26	-70	-35	-2	16	17	5
Inga densiflora	-6	24	15	-1	0	0	-9
Terminalia ivorensis	-57	102	29	4	-16	-16	-6
Tree density x 2	-48	88	35	3	-15	-15	-11
Extra tree thinning	6	-25	-16	0	8	8	5
Tree pruning freq. x 2	13	-32	-19	1	7	7	8
Coffee pruning	-26	0	-22	1	13	12	57
No fertilisation	-22	-30	-46	1	-46	-49	53
Fertilisation x 2	1	10	13	-1	69	70	-13
Slope = 0%	0	0	1	1	1	0	-100
Slope = 50%	-1	2	-7	-7	-7	4	714
Rain x 0.5	-2	9	13	-78	-28	164	-62
Rain x 2	-28	-35	-70	162	50	-38	336
Temperature - 5°C	17	-5	-20	5	11	8	14
Temperature + 5°C	-19	-31	-10	14	7	-2	1
[CO_2] x 2	20	32	51	0	-30	-28	-10

At this stage in model development, a greater weakness than that of model simplicity probably is that of limited model testing against data. A rigorous test against detailed data has not been performed, nor has the uncertainty of model outputs been quantified. Based on our literature review on coffee, tree and soil parameters, we suggest that the following kinds of missing data may be needed in particular to allow model improvement:

1. More and longer time series of daily weather data in different coffee growing regions. The FAO dataset only has monthly data for a very small number of sites.
2. More long-term experiments that follow seasonal and interannual changes in coffee and trees, rather than one-off observations. Measurements over the whole rotation period, 10–25 years, would be valuable for analysing the lower yields in the first and last years. Such measurements may also help address the issue of biennial yield performance of coffee.
3. Soil measurements that extend to greater depths than the top 10 or 20 cm.
4. Closed-balance studies for carbon, nitrogen and water that allow quantification of the full flux-budgets without the need for guesses regarding missing fluxes.
5. Data from multifactorial experiments. Of particular value would be a systematic comparison of the same major shade-tree species, planted on a range of sites across Central America differing in soil and climate, with additional differences in management.
6. Measurements on the impact of pruning on tree morphology.

Conclusions

The literature study in this paper revealed substantial quantitative information about coffee agroforestry systems in Central America, but with many gaps and inconsistencies. This allowed only preliminary parameterisation of the model developed here, but model behaviour seemed qualitatively consistent with empirical knowledge. The main preliminary conclusions from model application were

1. Coffee in Central America is overfertilised at present: reduction in fertilization is generally possible without significant impact on yield.
2. The degree of N-leaching is very high in coffee agroforestry systems and this is difficult to change through any management activity other than reducing N-fertilization.

3. N-fertilization may be more beneficial to tree wood volume production than to coffee yield.
4. The expected future increase in atmospheric CO_2 concentration is likely to make N-fertilization slightly more effective.
5. Global warming, as calculated using the HadCM3 Global Climate Model, is expected to increase temperatures in Central America by 3.3–4.4 ºC in this century. This level of warming is expected to decrease coffee yields significantly.
6. Global warming is likely to hamper shade-tree growth.
7. Coffee yield tends to decrease with tree density, even if the trees are N-fixers. Tree pruning tends to benefit coffee productivity but with some decrease in tree productivity.
8. In a comparison of six tree species, the N-fixers *Erythrina poeppigiana*, *Gliricidia sepium* and *Inga densiflora*, and the non-N fixers *Cordia alliodora*, *Eucalyptus deglupta* and *Terminalia ivorensis*, the simulations identified *E. poeppigiana* and *T. ivorensis* as the species producing most wood (but note that the wood of *E. poeppigiana* is considered to be of little economic value), with only *T. ivorensis* significantly hampering the growth of the coffee plants.
9. The rate of N-fixation by leguminous trees is generally only a minor flux in the overall N-budget of the system, but large enough to maintain productivity.
10. The contribution of coffee agroforestry systems to greenhouse gas production in the form of gaseous N-emission is low, even at high levels of N-fertilization.
11. Carbon sequestration rates in coffee agroforestry systems are not very high and are relatively insensitive to management choices.
12. Drainage of water to the groundwater is very high in the systems, and only marginally smaller at sites with steep slopes—where runoff rates are higher than elsewhere;
13. Soil loss in Central America is less than in other tropical regions. High fertilization levels are of benefit in this respect as they guarantee large, protective ground cover. Tree pruning decreases ground cover and is likely to increase soil loss rates but not to very high levels.

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Olympe, a Multiscale Tool to Explore Management Options in Agroforestry Systems

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Abstract

Olympe is a software developed by INRA, IAMM and CIRAD to model and simulate the functioning of cropping and farming systems. As it is based on economic analysis that considers contextual components, it enables identification and modelling of one or several farmers' strategies and trajectories. Prospective analysis is also possible, including prices volatility or climatic events and their impacts. This tool was first developed in close cooperation with research institutions involved in tropical agriculture and tested in different case studies, including agroforestry systems, in North and West Africa, Southeast Asia and Latin America, leading to a wide variety of applications. Such variety displays the richness that can be expected from reliable and representative farming systems studies at various levels. These levels go from the simple comparison between two cropping systems, through farming system modelling and further monitoring or counselling, to the study of entire irrigated schemes at regional levels, prospective analysis and elaboration of potential scenarios and role games. Such diversity in uses can be addressed to an equal diversity of actors: farmers, project or community leaders, extension institutions, researchers and policy makers.

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Resumen en español

Olympe, una herramienta de escala m ltiple para explorar las opciones de manejo en SAF

Olympe es un programa de cómputo desarrollado por INRA, IAMM y CIRAD para modelar y simular el funcionamiento de sistemas de producción y de cultivo. Como está basado en análisis económicos que consideran los componentes contextuales, permite identificar y modelar una o varias estrategias y trayectorias de los agricultores. También se pueden realizar análisis potenciales incluyendo volatilidad de los precios o eventos climáticos y sus impactos. Esta herramienta fue primeramente desarrollada en cooperación cercana con instituciones de investigación involucradas en agricultura tropical y probada en diferentes estudios de caso, incluyendo sistemas agroforestales, en el norte y oeste de África, sudeste de Asia y América Latina, conduciendo a una variedad amplia de aplicaciones. Tal variedad de aplicaciones despliega la riqueza que se puede esperar de estudios de sistemas agrícolas fiables y representativos a varios niveles. Estos niveles van desde una comparación simple entre dos sistemas de cultivo a través del modelaje de sistemas agrícolas y luego un monitoreo o asesoramiento—hasta el estudio de esquemas completos de riego a nivel regional, análisis prospectivos y elaboración de escenarios potenciales y juegos de representación. Esta diversidad de usos puede dirigirse a la misma diversidad de actores: agricultores, líderes de proyectos o de comunidad, instituciones de extensión, investigadores y legisladores.

Introduction

As agriculture sustainability is becoming a major concern, the main questions concerning ecological sustainability are linked to the problem of degraded environment and fragile soils and thus fertility, biodiversity and protection of watersheds. Several cropping systems offer potential solutions to these problems: agroforestry systems, permanent cover cropping systems, etc. Crop diversification and rapid technical change characterise the evolution of existing farming systems. The history of these innovations and innovation processes are key elements to analyse and understand and thus be in a position to make viable recommendations for development.

The notion of economic sustainability places emphasis on the profitability of specific technical choices: (margins analysis, income generation, return on labour and capital as a function of a specific activity, analysis of constraints-opportunities, etc.) from the point of view of farming systems, at the regional level and the "community level" where there are serious constraints with respect to land availability, and to access to capital and information. Analysis of farming systems and knowledge about smallholders' strategies in the different contexts are thus key elements that should also be taken into account.

As sustainable development is on the way to becoming the new priority objective, the rehabilitation of previously intensively managed agricultural or degraded land also deserves consideration

Perennial crops in particular are subject to very marked and sometimes very rapid changes in plantation/replantation strategies in pioneer and postpioneer areas, and these changes currently characterise farmers' strategies in the mid tropical areas of the world.

The impact of these strategies on land control, land-use dynamics (agreement on the definition of new types of territories, or land uses), between stakeholders) and relations among stakeholders, including those not directly involved in agricultural production, should be major topics of research if we are to gain a better understanding of farmers' strategies in the present context of multiple crises. A constant factor that underlies such strategies is innovation: both the process of technical innovation (technical pathways) and of organisational innovation (farmers' organisation, access to credit, etc.) are key elements to understanding and qualifying change.

Most perennial crops (cocoa, rubber, coffee, etc.) are now facing a postboom crisis. Political changes have resulted in new decentralisation policies (indirectly linked with democratisation in some countries) that can/may introduce new ways of local governance. The major economic trend is toward globalisation accompanied by highly fluctuating prices for most agricultural commodities. Concurrently, most farmers enjoyed direct links to markets over a relatively long period of time, in particular in the case of cocoa, coffee, rubber, oil palm and coconut.

Therefore emphasis should also be placed on the history of innovation processes in the context of the change from pioneer fronts to increasingly stable postpioneer areas.

To ensure that the adoption and appropriation of technology by smallholders is efficient, further research is required on innovation processes and technical change in general, using socioeconomic tools. Negotiations among stakeholders and a better knowledge of the relations between the state and farmers are essential to improve the effectiveness of future projects and development actions.

The main objective of topic-oriented research centred on the analysis of decision-making processes at different levels (farms, community, projects, regional or national policies makers) would thus be to provide socioeconomic information to policy makers to improve the decision-making process in agricultural development. The process of innovation (for farmers) and of decision-making (both for farmers and developers) are key research topics in sustainable development. And the analysis of farming systems, the characterisation of agrarian systems and the identification of stakeholders' strategies are key components to a better understanding of these issues.

This type of approach is applicable at different scales, going from small areas to watershed or agrarian regions by taking into account the different levels of intervention (production systems, experimentation of farming systems and commodity systems, etc.). One expected output would be the clear identification of the conditions required to ensure that future projects are more viable at the decision-making level.

A further output would be to ensure the scientific valorisation of this collaborative work by

1. anticipating problems (e.g., recurring negative phases of booms, drops in fertility/productivity due to overexploitation, negative externalities, etc.)

2. offering alternatives (technical pathways or organisational innovations, etc.)
3. providing better support for technical choices made by decision makers regarding agricultural policy

The purpose of this paper is to show how the Olympe software could be a modelling tool for a possible global approach, including the identification of gaps and opportunities to promote actions and projects or the implementation of policies that answer the needs of sustainable development, as well as those of local stakeholders, developers and researchers.

Agronomists and economists working on cropping and farming systems always have to collect information in order to characterise them and identify typologies and potentially recommendations domains. CIRAD, INRA and IAMM have developed a software called Olympe that enables the modelling of cropping and farming systems at different scales, including modules for farms groups analysis, externalities, trends and scenarios integration for prospective analysis.

This software, associated with classical cropping or farming systems surveys, allows a wide range of opportunities:

ß testing the economic impact of a technical choice on a cropping or a farming system or between different systems
ß identifying farmers possibilities and potential strategies according to technical alternatives
ß calculating environmental positive or negative externalities
ß testing the robustness of a technical choice according to climatic or economical uncertainties (effect of a drought, an El Niño year, or price volatility, etc.)
ß assessing risks and helping farmers and donors make decisions

Data analysis can be discussed with farmers using a participatory approach or partnership with farmers through on-farm trials in order to validate scenarios and guarantee a high level of representativeness. A network of representative farms can be monitored for several years with two main objectives: first, to diagnose constraints and opportunities and, second, to measure impacts due to technical change (with or without project activities).

One of the main output of such approach is to assess impact of technical alternatives or choices at the farming systems level on the economic point of view as well as on the environmental point of view. Olympe is fed with data from adapted farming systems surveys and will provide key information in terms of diagnosis and, further on, in term of prospective analysis.

Methodological context for the use of Olympe

Tools for the comprehension of farming systems based on simulation and modelling such as the Olympe software allow a comprehensive understanding of how a given cropping or farming system functions, as well as provide a tool to model prospective technical choices, price scenarios and even ecological scenarios.

Such tools are based on the use of primary data (Figure 1) collected during surveys for the characterisation of farming systems and are essential to provide decision-making tools to key stakeholders in terms of development, adaptive research, project orientations and so on, all projects that require serious negotiations between partners. They can be used at different levels: local community, regional, national or international, depending on the stakeholders and on the commodities involved. Emphasis would be on the farmer and on the other people directly involved in the farmers' environments, including the government (development policies at the national level).

The Participatory and Action–Research approaches are a basic methodology commonly employed by Olympe users to collect data. In addition to the Participatory approach and on-farm experimentation, links with SIG and Multi-Agent System Modelling (SMA) allow possible answers to be identified to important agricultural questions. As contexts are important in the evolution of processes, the impact of globalisation on smallholders and commodity systems as well as on their internal growth (logical internal development within a specific context) and the effects of decentralisation policies can also be included in this analysis.

Knowledge on the local farming context (pioneer zones, rehabilitation areas or traditional rubber belts), capabilities and strategies will contribute to build alternatives, solutions and proposals to

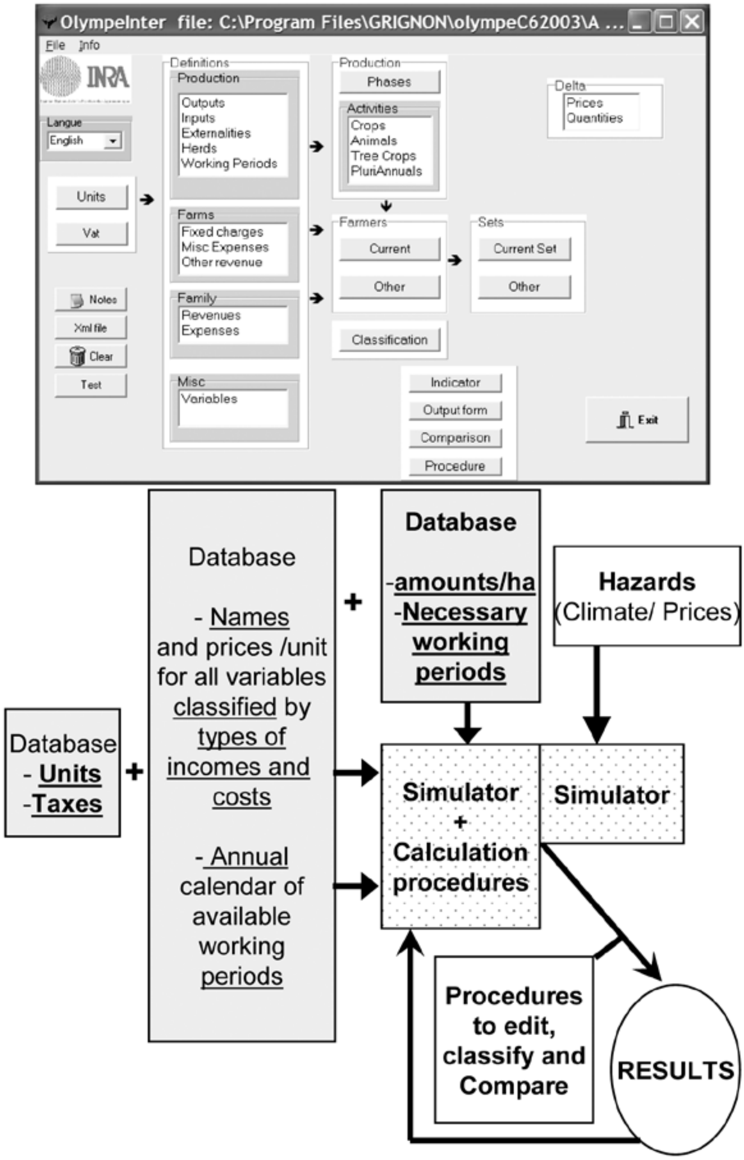

Figure 1. Olympe's first window (top) and corresponding conceptual model (bottom).

help farmers to make the right decision at the right time. The use of Olympe is aimed to improve farmers' understanding and provide orientations or policies for development institutions or donors.

The objectives of using the Olympe modelling tool can be the following:

- ß to identify smallholders' constraints and opportunities in a rapidly changing environment for the adoption of new cropping or farming systems
- ß to understand farmers' strategies and their capacity for innovation;
- ß to assess their ability to adapt to changing economy, prices crisis and technological change
- ß to provide tools to understand the farmers' decision making
- ß to replace cropping or farming systems information in its social and economical context, through a regional approach
- ß to undertake prospective analysis

Olympe is based on the systemic approach and is generally used in the form of an iterative analysis of a question (Figure 2). It has been validated by experiments and activities in the field led by a network of researchers that exists since 2001. All researchers, teachers and consultants involved in this network are also playing the role of β-testers for this free software in permanent evolution.

Data required for cropping and farming systems modelling using Olympe

Information that qualifies the structure and components of production factors of the crop or the farm are required (operational costs, inputs and outputs, yields, externalities, labour requirements). They are obtained through traditional survey. In addition, since Olympe is focused on the origin of the different sources of incomes and costs, all information should be collected in four domains in the case of farming system analysis:

1. The different cropping systems: crops are divided into annual crops, perennial crops (minimum five years) and multiannual crops (banana, pineapple or cassava, between one and five years' cycle).
2. Livestock-raising systems.
3. Activities systems, not directly linked with agricultural or livestock production and including transformation of primary products.

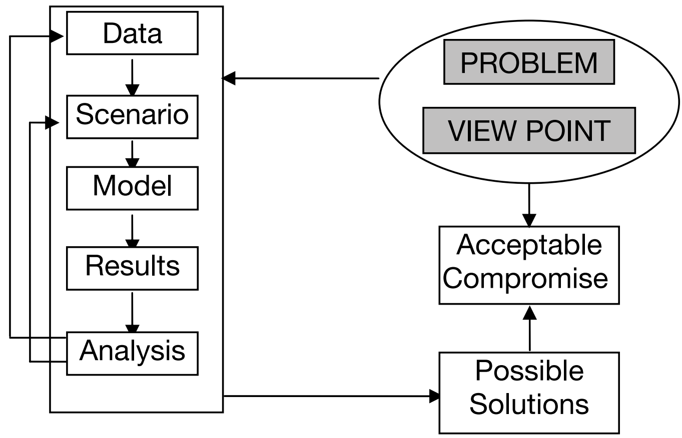

Figure 2. Iterative analysis using the Olympe software (From Penot et. al., 2004).

4. Farming systems: the farm level with a decision maker (the producer) and a strategy for the combination of production factors. All nonoperational costs (incomes, including off-farm, credits, loans and expenses) are integrated at that level. Family account and enterprise account can be separated but should be recorded.

Finally, commodity prices should be collected, in particular taking into account the local variations as well as international historical series of prices that will enable to build potential scenarios.

Olympe: methodological systemic approach for farming systems modelling

As an example, the methodology used in Olympe can be based on the following stages that create a framework for its implementation:

1. **Diagnosis:** a preliminary diagnosis based on the collection of all available information (bibliography, data collections, key-informants) and an exploratory survey of the characteristics of the farming system to understand the constraints, opportunities, income and labour productivity of each cropping system and farm

activities. The data analysis should provide an operational typology and a clear identification of constraints and opportunities.

2. **Identification of an on-farm experimentation programme.** The identification of a potential on-farm experimentation programme aimed at overcoming technical constraints (technical innovations) or social constraints (organisational innovations). On-farm trial protocols should be identified as a function of the typology. Experiments should be listed in order of priority.
3. **Implementation of on-farm experimentation.** Implementation of on-farm experimentation using a participatory approach in an on-farm trials network.
4. **Monitoring farming systems.** Implementation of a "farming systems monitoring reference network" in order to monitor technical changes and the adoption of innovations and to assess their impact and externalities at the farming system and regional scales.
5. **Analysis and reassessment of the research programme.** Feedback analysis with farmers, extension agents and research institutions and the reassessment of the on-farm trial in a constantly ongoing process of R&D.

   An agronomic approach including on-farm experimentations linked with a socioeconomic approach (farming systems analysis, typology, etc.) provides suitable technical pathways or improved cropping systems for farmers. It also ensures adequate conditions for the adoption and appropriation of innovations by farmers.
6. **The results and outputs are**
   ß Annual and perennial cropping patterns and technologies (technical pathways for monoculture, intercropping, agroforestry systems, etc.),
   ß An operational typology of situations and farmers leading to the identification of topics of recommendations
   ß A global overview of the possible adoption of technologies as a function of farmers' strategies and local conditions
   ß An ongoing and dynamic database on farming systems using Olympe software

Conclusion

Whether the Olympe user is a researcher, a developer, a producer or a decision maker, the flexibility and the diversity of uses already known and shared in the network makes it very attractive. After seven years of improvements, Olympe software shows an excellent ability to adapt to various questions and contexts (temperate/tropical; technical/multifunctional studies; Diagnosis/Prospective analysis; etc.) in the study of farmers' behaviours, activity impact, farm evolution and decision-making processes.

As Olympe provides three potential levels of analysis—crop, farm and groups of farms—its great flexibility allows it to adapt its level of detail and analysis according to the case study's requirement. Simulations of farming possibilities, risks factors and decisions on production factors' assignment (capital, work, land) in the mid- and long-term are a net advantage compared to other tools more focused initially on annual results.

Forecasting of incomes, monthly treasury and labour availability per activity allows a fine evaluation of viability of technical and organisational choices. This function helps to define technical thresholds and possible scenarios of evolution.

Good quality data and all information on origin and use of sources of income remain the determining elements to identify properly the evolution of farmers' strategies. When properly validated by actors, Olympe is an operational representation of decision-making process and its components. As farmers are in permanent interaction with rapidly changing climatic and economical risks, modelling and forecasting these risks is of high interest for them, especially if we can include all noneconomic factors inherent to the rural world and agricultural production. A large variety of goods and services such as biodiversity conservation, land sustainability, etc., that cover the multifunctional aspects of agricultural activities, have to be integrated into farmers management and strategies.

The use of Olympe, coupled to a real contextual socioeconomic analysis shows operationality in both research and development activities. It remains however an approach requiring rigour, a constant effort of validation and a clear definition of the initial problematic in order to avoid instrumentalisatio disconnected from reality.

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Modelling the Contribution of Silvopastoral Systems for Biodiversity Conservation: New Habitat and Increased Connectivity in the Copan River Watershed, Honduras

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Abstract

In tropical as in temperate regions, agriculture negatively affects natural ecosystems and its biodiversity by transforming land use from natural areas to those dominated by agriculture. Tropical regions are particularly vulnerable to the impact of human activities because of their high species richness, original forest cover, rapidly increasing development and expansion of the agricultural frontier. This combination and wide variety of threats make conservation in this region a global priority. Cattle production is one of the agricultural activities with the greatest impact on biodiversity in Central America and has been identified as one of the principal causes of deforestation in the region. Because of this, it is increasingly necessary to identify mechanisms that reduce the negative impacts of cattle production systems. The objective of this project is to characterize land use and landscape metrics of the 600 km^2 that encompass the Copan River watershed. We develop habitat quality and landscape connectivity models for three genera of avifauna—*Trogon*, *Icterus* and *Dendroica*—and we evaluate the contribution of current land use,

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particularly silvopastoral systems to habitat provision and landscape connectivity. We also model how landscape connectivity and conservation value change with the addition of silvopastoral systems and riparian forests. We developed a land-use cover map from a 2007 Ikonos image; the association between the existing land cover and habitat quality for each of the evaluated genera was obtained from a literature review. We derived permeability values from a database of pervious avian studies that evaluated richness and abundance of bird species in different Mesoamerican landscapes. We completed the GIS analysis for habitat quality and functional connectivity using FunConn for ArcGis 9.1. The Copan watershed is a highly fragmented landscape with less than 25% original forest remaining. Modeled habitat quality for *Icterus* and *Dendroica* is much larger than the habitat modeled for *Trogon,* which is much more dependant on forest habitats This forest habitat is highly dispersed in small patches throughout the landscape. Silvopastoral systems, particularly pastures with high tree density, are identified as critical managed land uses for maintaining and increasing connectivity of landscape networks for the three evaluated genera in the region. The model that introduced silvopastoral systems on steep slopes had significant impact on landscape connectivity as did the model including a 50-meter strip of riparian forest. Silvopastoral systems play an important role in providing habitat and functional connectivity in the Copan watershed landscape. More tolerant genera such as *Icterus* and *Dendroica* are capable of using these systems as habitat; less tolerant genera sharing the dispersal and habitat preferences of *Trogon* may use these systems as corridors to move throughout the landscape but will find them unsuitable as habitat. Landscape management initiatives should include strategies that promote more environmentally friendly production systems such as silvopastoral systems, combined with strategies that conserve and expand the natural areas within a landscape, particularly for less mobile species. Species-specific landscape models need to be validated in the field; however, when based on field data, they are an important tool for making landscape scale management decisions and for conservation planning in agricultural landscapes.

Resumen en español

Contribuci n de los sistemas silvopastoriles a la conservaci n de la biodiversidad por medio de la provisi n de h bitat y de conectividad en la cuenca del r o Cop n, Honduras

En regiones tropicales como en templadas, la agricultura afecta negativamente los ecosistemas naturales y su biodiversidad al transformar el uso de la tierra de áreas naturales en áreas dominadas por la agricultura. Las regiones tropicales son particularmente vulnerables al impacto de las actividades humanas a causa de su alta riqueza en especies, cobertura arbórea original, creciente desarrollo y expansión de la frontera agrícola. Esta combinación y amplia variedad de riesgos hace que la conservación en esta región sea una prioridad global. La producción ganadera es una de las actividades agrícolas con mayor impacto sobre la biodiversidad en Centroamérica y ha sido identificada como una de las causas principales de deforestación en la región. A razón de esto, cada vez más es necesario identificar mecanismos que reduzcan los impactos negativos de los sistemas de producción ganadera. El objetivo de este proyecto es caracterizar el uso de la tierra y los indicadores del paisaje de 600 km^2 que cubre la cuenca del río Copán. Desarrollamos modelos de calidad del hábitat y conectividad del paisaje para tres géneros de fauna avícola—*Trogon*, *Icterus* y *Dendroica*—y evaluamos la contribución del paisaje actual, particularmente sistemas silvopastoriles a la provisión de hábitat y conectividad del paisaje. También creamos modelos sobre cómo la conectividad del paisaje y el valor de la conservación cambia con la adición de los sistemas silvopastoriles y bosques riparios. Desarrollamos un mapa de usos de paisajes desde una imagen de Ikonos del 2007; por medio de la revisión de literatura se obtuvo la asociación entre la cobertura del suelo y la calidad de hábitat para cada género evaluado. Derivamos valores de permeabilidad de la base de datos de estudios avícolas previos que evaluaron riqueza y abundancia de especies de aves en diferentes paisajes mesoamericanos. Completamos análisis de SIG para la calidad del hábitat y conectividad funcional utilizando FunConn para

ArcGis 9.1. La cuenca de Copán es un paisaje altamente fragmentado con menos del 25% de bosque original permanente. La calidad de hábitat modelada para *Icterus* y *Dendroica* es mayor que la calidad de hábitat modelada para *Trogon,* el cual es mucho más dependiente de hábitats forestales. Este hábitat forestal está altamente disperso en pequeños parches a través del paisaje. Los sistemas silvopastoriles, particularmente pasturas con densidad arbórea alta, son identificados como usos de tierra de manejo crítico por mantener e incrementar la conectividad de las redes dentro del paisaje para los tres géneros evaluados en la región. El modelo que introdujo los sistemas silvopastoriles en pendientes altas tuvo un impacto significativo en la conectividad del paisaje, lo mismo que el modelo que incluyó una franja de 50 metros de bosque ripario. Los sistemas silvopastoriles juegan un papel importante en la provisión de hábitat y conectividad funcional en la paisaje de la cuenca de Copán. Los géneros más tolerantes como *Icterus* y *Dendroica* son capaces de utilizar estos sistemas como hábitat; géneros menos tolerantes que comparten la dispersión y las preferencias de hábitat del *Trogon* pueden utilizar estos sistemas como corredores para desplazarse a través del paisaje, pero no los encontrarán apropiados como hábitats. Las iniciativas de manejo de paisaje deben incluir estrategias que promuevan sistemas de producción amigables con el ambiente como los sistemas silvopastoriles, combinadas con estrategias que conserven y expandan las áreas naturales dentro del paisaje, particularmente para especies de menos movimiento. Los modelos de paisajes para especies específicas necesitan validarse en el campo; sin embargo, cuando están basados en datos de campos, pueden servir como una herramienta importante para tomar decisiones de manejo a escala de paisaje y para la planificación de la conservación en paisajes agrícolas.

Introduction

Cattle production is one of the principal agricultural activities with the greatest impact on biodiversity in Central America and has been identified as one of the main causes of deforestation in the region.

Conservation of biodiversity within cattle production landscape should encompass the preservation of natural habitat and modifications to the conventional production systems that allow for a more permeable matrix, promoting landscape connectivity. Modelling various scenarios of land-use change can be particularly useful to identify which land use strategies should be implemented and in which areas in order to improve landscape conservation capabilities. The objectives of this project were to characterize land use and landscape metrics for the 600 km^2 that encompass the Copan River watershed, evaluating the actual functional habitat and connectivity for three selected genera of avifauna: *Trogon, Icterus and Dendroica*. Also three different scenarios of land-use change were evaluated and their effects on the overall landscape functional habitat and connectivity described.

Modelling the avian diversity in silvopastoral systems

Definition of the habitat

We also developed habitat quality and landscape connectivity models for the genera *Trogon*, *Icterus* and *Dendroica,* and evaluated the contribution of current land use, particularly silvopastoral systems, to habitat provision and landscape connectivity. Analysis was performed using ArcGis v9.1, and the extension Fucconn (Theobald, 2006). We generated habitat quality values ranging from 0 to 100 for all the different land uses present in the landscape. This was accomplished by adapting the habitat reported by Stiles y Skutch (1989) and Howell y Webb (1995) to the land-use categories for the different species of each genus reported to be present in the landscape. Percentage of species reported in a particular habitat represented the habitat quality values to be used for a particular gender (Table 1). Functional habitat patches were selected based on home range requirements. Patches with a habitat quality greater than 66% were selected as functional habitats if they were located within the home range area perceived by each genera. This area of home range is based on an allometric relationship to body size (Harestad and Bunnell, 1979), where $I = 1.166M1.06,$ where M is body mass in kg and I is the surface in km^2. Next, we derived the radius required to fulfill the area requirement using $R = (I/3.1415)1/2$. The lowest value for each genus was selected to ensure the representation of all species evaluated for each genera.

The Mesoamerican database used

Permeability values were derived from databases of previous avian studies that evaluated richness and abundance of bird species in different Mesoamerican landscapes. In these studies bird species were recorded in different land uses similar to the ones present in the Copan River watershed, including pasture without trees and pasture with high and low tree density. Permeability values ranged from 0 to 1 and were obtained similarly to the habitat quality values representing the number of species accounted for in each land use category (Table 1).

Table 1. Values of habitat quality and permeability for avian species in the *Trogon*, *Icterus* and *Dendroica genera*.

Land use	Habitat quality			Permeability		
	Trogon	*Icterus*	*Dendroica*	*Trogon*	*Icterus*	*Dendroica*
Broadleaf forest	86	88	75	1	0,83	0,83
Pine forest	71	75	100	1	0,83	0,83
Oak forest	71	75	100	1	0,83	0,83
Mixed forest	100	75	83	1	0,83	0,83
Riparian forest	86	100	83	1	0,83	0,83
Natural regeneration	14	100	67	0,8	0,8	0,8
Shade coffee	29	100	75	0,4	0,66	0,83
No shade coffee	0	50	25	0	0,3	0,3
High density silvopastoral systems	0	63	33	0,4	0,5	0,33
Low density silvopastoral systems	0	63	33	0	0,5	0,33
Annual crops	0	0	17	0	0	0
Pasture without trees	0	0	25	0	0	0
Timber plantations	29	88	75	0	0,66	0,83
Live fences	0	13	25	0,6	0,5	1

Functional connectivity was modeled based on graph theory analysis (Urban and Keitt, 2001; Theobald, 2006), creating a network that represents connectivity within functional habitat patches. This was accomplished using functional habitat patches as source and land cover data with the respective permeability values for each land cover category. We also modeled how landscape connectivity and conservation value changes with the addition of silvopastoral systems and riparian forests.

Three different scenarios were modeled:

- Model 1: Inclusion of a 50-meter strip of riparian forest on each side of the existing rivers.
- Model 2: Inclusion of low density silvopastoral systems on slopes of 0–15%, high density silvopastoral systems on slopes of 16–40% and restored forest on slopes higher than 40%.
- Model 3: Inclusion of a 50-meter strip of riparian forest on each side of the existing rivers and the inclusion of low density silvopastoral systems on slopes of 0–15%, high density silvopastoral systems on slopes of 16–40% and restored forests in slopes higher than 40%.

GIS resolution

A land-use cover map was developed from a 2007 Ikonos image, positioning the Copan River watershed as a highly fragmented landscape with less than 25% original forest remaining. Modeled habitat quantity for *Icterus* and *Dendroica* is much larger than the habitat modeled for *Trogon,* which is much more dependent on forest habitats (Figure 1). This forest habitat is highly dispersed in small patches throughout the landscape, threatening the persistence of viable populations of forest-dependant species due to insufficient and fragmented habitat.

The number of functional patches was lower for the genus *Icterus,* followed by *Dendroica.* The *Trogon* genus presented the highest number of functional patches; this genus not only has the lower quantity of habitat but also has the highest number of patches representing a smaller patch size compared to *Icterus* and *Dendroica* genera (Figure 2).

Landscape connectivity varied for each genus in the different models (Figure 3). Connectivity for the *Trogon* genera was lower in the actual landscape and Model 1 in comparison to *Dendroica* and *Icterus*. In model 2 and 3, connectivity raises, being superior to *Icterus*

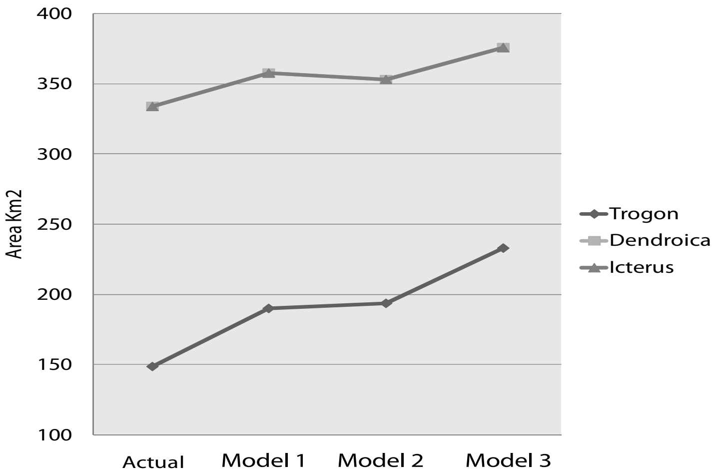

Figure 1. Functional habitat quantity for the evaluated genera on the actual landscape and on the different evaluated models. (*Dendroica* and *Icterus* obtain the same amount of functional habitat above the established threshold).

and *Dendroica* genera in this models. Connectivity for *Icterus* and *Dendroica* was similar across all different models, in some cases being slightly higher for *Icterus* and in others for *Dendroica* due to similar habitat and permeability perceived by this genera.

The reduction in the number of functional patches in Model 1 is due to the fact that structural connectivity increases throughout the landscape. Patches that are apart from each other in the actual landscape become a single patch when riparian forests are established between them, also producing an increase in the mean patch size. Fewer and bigger patches are beneficial for conservation, especially for forest-dependent species, providing more opportunities to support the local populations. The reduction in the connectivity index by this model in comparison to the local landscape is a consequence also of the increase in structural connectivity; patches that are apart in the actual landscape and need to be connected by a corridor become structurally connected, allowing for the movement between them without crossing different land uses.

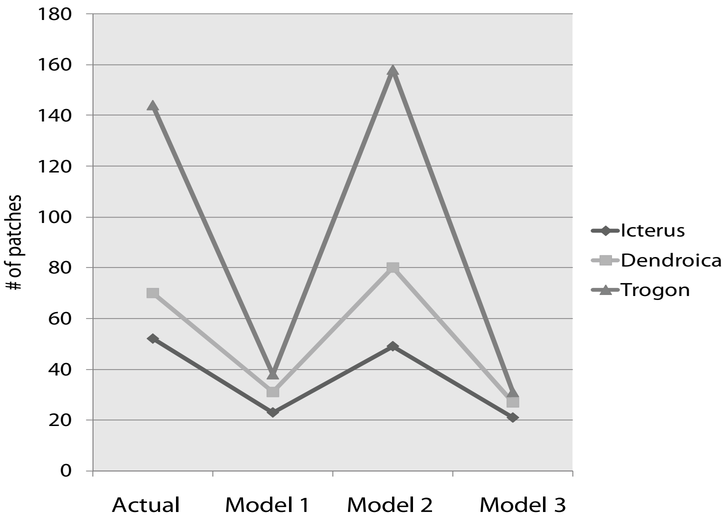

Figure 2. Number of functional patches modeled for the evaluated genera.

When modeling the inclusion of low-density silvopastoral systems of slopes of 0–15%, high density silvopastoral systems on slopes of 16–40% and restored forest on slopes higher than 40%, we observed a higher quantity of habitat for the three genera. The increase was higher for the genus *Trogon* since new forest patches were included in areas that before did not represent functional habitat for this genus but were part of the functional habitat in the actual landscape model for *Dendroica* and *Icterus*. For the genus *Icterus* and *Dendroica* a reduction in the number of functional patches is observed; this reduction is caused by the structural union of separated patches in the actual landscape. In the case of *Trogon,* a greater number of functional patches are a consequence of the new forest areas that appear in the landscape. Connectivity is also higher for *Trogon* in Model 2 because of more functional patches to be connected and the modifications of the productive systems that allow for more permeable corridors being established across the landscape.

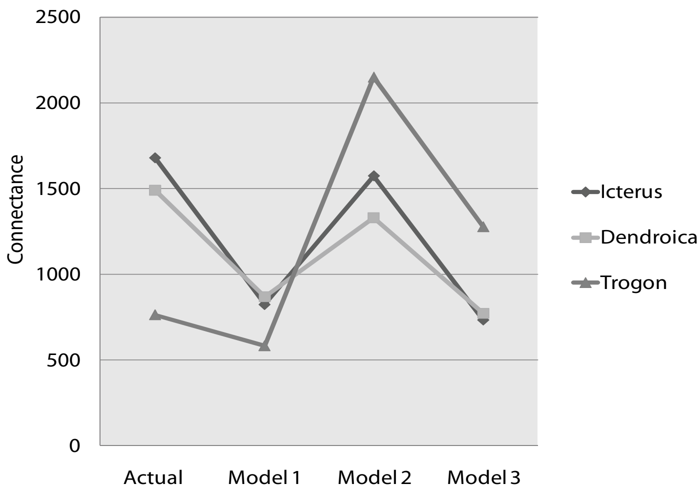

Figure 3. Connectance index (Urban and Keitt, 2001) for the evaluated genera in each model.

Model 3 showed the highest value for habitat quantity at the landscape level. Functional patches are fewer in this model compared to Model 2 and are higher for *Trogon* than in Model 1 and the actual landscape. Mean functional patch size is also higher in Model 3. Connectivity in Model 3 is higher than in Model 1 and the actual landscape; it is lower than in Model 2 because there is a lower number of functional patches to be connected in Model 3. For the genus *Trogon,* which as we had shown is the most threatened genus of the ones evaluated, Model 3 provides a higher number of functional patches with greater size and greater connectivity than the actual landscape. For this and other forest-dependent organisms, this would be the model that provides greater benefits for conservation within the fragmented landscape of the Copan River watershed. Silvopastoral systems, particularly pastures with high tree density, are identified as critical managed land uses for maintaining and increasing connectivity in landscape networks for the three evaluated genera in the region. The model that introduced silvopastoral systems on steep slopes had significant impact on landscape connectivity, as did the model including a 50-meter strip of riparian forest.

Conclusion

Silvopastoral systems play an important role in providing habitat and functional connectivity in the Copan River watershed landscape. More tolerant genera such as *Icterus* and *Dendroica* are capable of using these systems as habitat; less tolerant genera sharing the dispersal and habitat preferences of *Trogon* may use these systems as corridors to move throughout the landscape but will find them unsuitable as habitats. The modification of conventional cattle production systems combined with the restoration of forest patches on unsuitable land is the best combination to improve the landscape conservation capabilities and maintain cattle production for local communities. Landscape management initiatives should include strategies that promote more environmentally friendly production systems such as silvopastoral systems combined with strategies that conserve and expand the natural areas within a landscape particularly for less mobile species. Species-specific landscape models need to be validated in the field; however, when based on field data, they serve as an important tool for making landscape scale management decisions and for conservation planning in agricultural landscapes.

Acknowledgements

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Studying Cropping System Management by Simulation: The Record Platform Project

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Abstract

The pressing need to adapt and improve farming practices has motivated research efforts to extend the classical analyses of soil-crop-climate systems to considerations of their management at field, farm and regional scales. For the specific question of analysing and designing innovative cropping systems, INRA (French National Institute for Agricultural Research) has launched the development of a simulation modelling platform called RECORD. This modelling platform is intended to ease complex model development and to promote model reusability.

Analysing and designing cropping systems by modelling and simulation require consideration of the interactions between agronomical, environmental and socioeconomics components. A key feature of the project is to put the management of cropping system on an equal footing with biophysical aspects In order to open widely the platform to all the models. We chose to make no restrictions on the type of biophysical and decisional models that will be developed or plugged into our environment.

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The platform will also offer common methods for estimating model parameters, analysing simulation outputs and optimizing management policies.

The main contribution of the framework should be to encourage modellers to adopt a systemic approach. The object-oriented paradigm and the incorporated ideas of polymorphism, inheritance, interface-based communication are offering clean and efficient means in the modelling process. In other words, the objected-oriented representation should ideally be embedded with the systemic structuring approach.

The framework will support the co-existence of different types of coupling between several model components, loose connections between components, running in parallel, and sophisticated protocols to allow for close connections of modules that require frequent synchronizations.

The first prototype of RECORD should be ready at the beginning of 2008 and tested on a few case studies during 2008 and 2009.

Resumen en español

Estudiando el manejo de sistemas de cultivo por simulaci n: Proyecto plataforma RECORD

La necesidad apremiante de adaptar y mejorar las prácticas agrícolas ha motivado la realización de esfuerzos de investigación para extender los análisis clásicos de sistemas de suelo-cultivo-clima a consideraciones de su manejo a niveles de campo, finca y región. Para el problema específico del análisis y diseño de sistemas de cultivos innovadores, el INRA (Instituto Nacional Francés para la Investigación Agrícola) ha lanzado el desarrollo de una plataforma de modelaje llamada RECORD. Esta plataforma tiene el fin de facilitar el desarrollo de modelos complejos y promover la reutilización de modelos existentes.

El analizar y diseñar sistemas de cultivos por medio del modelaje y de simulaciones requiere de considerar las interacciones entre componentes agronómicos, ambientales y socioeconómicos. Una característica clave del proyecto es colocar el manejo de sistemas de cultivos al mismo nivel que los aspectos biofísicos. Para poder abrir la plataforma para todos los modelos, escogimos hacer no restricciones en el tipo de modelos biofísicos y decisorios que serán desarrollados o integrados en nuestro ambiente.

La plataforma también ofrecerá métodos comunes para estimar parámetros de los modelos, analizar resultados de simulación y optimizar políticas de manejo.

La contribución principal de la estructura debe ser el animar a los modeladores a adoptar un enfoque sistémico. El paradigma orientado a objetos y las ideas incorporadas de polimorfismo, herencia y comunicación basada en la interfase ofrecen medios nítidos y eficientes en el proceso del modelaje. En otras palabras, la representación orientada a objetos idealmente debería estar integrada con el enfoque sistémico estructurante.

Esta plataforma permitirá la coexistencia de diferentes tipos de acoplamientos entre componentes del modelo, conexiones sueltas entre componentes que operan en paralelo y protocolos sofisticados para permitir conexiones estrechas entre componentes que requieren sincronizaciones frecuentes. El primer prototipo de RECORD debe estar listo para principios del 2008 y probado en algunos estudios de casos durante el 2008 y 2009.

Building a Biophysical Conceptual Model of Agroforestry Systems (AFS) with Coffee Incorporating Scientific, Expert and Farmers' Knowledge in Costa Rica

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Abstract

In Costa Rica coffee is an important crop with cultural values and covering an extensive land area. Coffee production is in a context where achieving production demands while still meeting resource conservation is becoming a challenge. Agroforestry systems (AFS) have been proposed as an alternative for land use providing a solution. However the inconsistency of coffee yields with or without shade depending as well on site conditions make the design of new adapted AFS necessary. Although agroforestry as a science is recent, its practices are old. Thus it is argued that gathering of local knowledge has an important role to play in agroforestry development.

The study was held as part of the PCP project (Mesoamerican Scientific Partnership Platform) for Agroforestry Systems (AFS)

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with perennial crops. The project initiative aims at building a model to assist in the design of AFS with coffee. Research was carried out in three districts of Costa Rica: Turrialba, Orosi and Tarrazú.

The research objective was to build a biophysical conceptual model reflecting crop-environment interactions that occur in shade coffee crops, focusing on the variation of coffee productivity and quality.

The conceptual model was founded on scientific, expert and farmer's knowledge about factors affecting coffee yield and quality elaboration. Semi-structured interviews with 42 persons were held on farms, technical institutes and coffee processing units. Interviews were entered on a knowledge base system, AKT (Agroecological Tool Kit).

Outputs of the knowledge base as diagrams enabled the comparison of knowledge, from different sources, on processes and environmental factors affecting coffee yield and quality components.

Comparison of farmers, experts and scientific knowledge revealed complementarities, with each knowledge system also providing added individual detail that did not contradict the other. In that way it was possible to propose for each component factors or processes that were not taken into account in the academic model.

General processes of shade trees and coffee interactions were understood, although the new processes elucidated by experts or processors and that did not appear in the academic model were not related to the presence of shade trees.

However this work represents interesting ideas on the utility of a base of knowledge to gather different stakeholders' knowledge and could provide a basis for further investigation.

Resumen en español

Construcci n de un modelo conceptual de sistemas agroforestales con caf incorporando conocimiento cient fico, de expertos y de productores en Costa Rica

El café está en una encrucijada, donde se tiene que seguir produciendo rentablemente, pero a la vez se tiene que conservar los recursos naturales. Los sistemas agroforestales (SAF) han sido vislumbrado como una alternativa de uso del suelo que puede responder a este desafío. Sin embargo, la inconsistencia de los rendimientos de café con o sin sombra, que dependen de condiciones locales, requieren que se elaboren nuevos SAF mejor adaptados a estas condiciones. Aunque el interés de los científicos en la agroforestería es reciente, la práctica de ésta es antigua. Por lo tanto, se considera que la recolección del conocimiento local tiene que jugar un papel importante en el desarrollo de la agroforestería.

El estudio, enmarcado en el PCP (Mesoamerican Scientific Partnership Platform for Agroforestry Systems with Perennial Crops), tiene como objetivo la construcción de un modelo conceptual biofísico que refleje las interacciones cultivo-ambiente que ocurren en cultivo de café bajo sombra. Se concentra en las variaciones de productividad y calidad de café. La investigación se llevo a cabo en tres distritos de Costa Rica: Turrialba, Orosi y Tarrazú.

El modelo conceptual se fundamento en agregar conocimiento de investigadores, técnicos de campo, beneficiadores y productores sobre los factores que afectan los rendimientos de café y la elaboración de su calidad. Se realizaron entrevistas semiestructuradas con 42 personas en fincas, el instituto del café y beneficios. Las entrevistas fueron procesadas en un sistema de manejo de bases de datos de conocimiento, AKT (Agroecological Tool Kit).

Productos de la base de conocimiento tales como diagramas permitieron la comparación del conocimiento de varias fuentes

sobre los procesos y factores ambientales que afectan los rendimientos y la calidad del café.

Las comparaciones del conocimiento de productores, técnicos e investigadores mostraron complementariedades, cada sistema de conocimiento provee detalles individuales que no contradicen los otros sino que los complementan. De esta manera se pudo proponer, para cada componente identificado, factores o procesos que no habían sido tomados en cuenta en el modelo académico.

Los procesos generales que influyen sobre las interacciones entre cafetos y árboles de sombra fueron entendidos. Sin embargo, los nuevos procesos aportados por expertos y productores que no aparecían en el modelo académico, no estaban relacionados con la presencia de árboles de sombra.

Context

Coffee is an important crop in Costa Rica: its covers 100,000 has and is an historical crop with cultural values. Intensive coffee production has been questioned because of its financial vulnerability even for successful farmers (Haggar, 2007). From 2001 to 2006 yields in Costa Rica decreased from 30 fanegas[4]/ha to 24 fanegas/ha (ICAFE, 2006). In additoon there is an important reduction in coffee areas: -13.9% from 2000 to 2006 (ICAFE, 2006). This is probably a result of the world coffee price crisis, leading to the reduction of coffee assistance and renovation investments. At the same time, this crisis provided an opportunity to explore alternative cropping systems and markets.

Agroforestry systems (AFS) have been proposed as an alternative to intensive sun grown coffee. *Coffea arabica* originated in Ethiopian highland forests (Huxley and Cannell, 1970), therefore inclusion of shade trees in a plantation may bring beneficial effects. However

[4] Measure unit used by farmers and processors in Costa Rica.
1 Fanega = 256 kg of coffee cherries, the quantity supposedly needed to produce 100 lbs of green coffee.

coffee plants have a big plasticity, and if enough fertilizers are supplied, yields may be substantially increased in full sun (Da Matta, 2004).

AFS in the Tropics are suggested to provide a promising combination of natural resources conservation and productivity (Steffan-Dewenter et al., 2007). Indeed, there is in Costa Rica an increasing concern about the use of natural resources by agricultural systems, particularly about loss of biodiversity (Gordon et al., 2007), excessive pesticide and fertilizer use (Aranguren et al., 1982) and consequent water pollution, soil erosion and nutrient loss (Romero-Alvarado et al., 2002).

The estimation of environmental services provided by AFS and their valorization could be a way to improve the economic sustainability of rural communities and reduce their vulnerability by increasing the revenue and diversifying its sources. Furthermore, AFS, with its reduction in chemical inputs and increased bean quality, open new marketing opportunities as organic, nature friendly or specialty coffees.

To explore existing AFS and propose innovative AFS, combining in a more efficient manner bean productivity and provision of environmental services, modelling appears as a solution. However there are no validated models taking into account (1) coffee behaviour in AFS, (2) the perennial coffee plants characteristic, (3) the elaboration of quality and (4) pest and diseases stress. Thus, in a first stage of the PCP project[5] (presented elsewhere is this volume), there is a need to gather knowledge about coffee productivity under shade and to find out the main processes responsible for this productivity that a model would need to take into account.

Although agroforestry as a science is recent its practices are old. Therefore, the knowledge needed to identify the best management strategy may be more scattered between different kinds of stakeholders than is the case for more industrial crops. Local knowledge has been defined as knowledge based on real-life observations and experience (Walker et al., 1995). Farmers based their practices on their understanding about natural processes and biological interactions in particular environments. Thus, it is argued that gathering of local

[5] The study was held as part of the PCP project (Mesoamerican Scientific Partnership Platform) for Agroforestry Systems (AFS) with Perennial Crops.

knowledge has an important role to play on agroforestry development. Research looking at local knowledge in Costa Rica has proved to be useful. For example, a classification for trees according to their effect on biodiversity and soil conservation was reported, showing farmers' preference for particular shade tree species (Cerdan, 2008).

Diverse knowledge must be stored in a form that allows different sorts of analysis and interpretation to be done, during and after the acquisition of knowledge. Agroforestry Knowledge Toolkit (AKT)[6] is a tool for a systematic collection of ecological knowledge. It enables creation of a knowledge base about a chosen topic by collating knowledge from a variety of sources: farmers, scientists, extension workers (Walker et al., 1995). Data are recorded as a set of qualitative or quantitative observations. Inputs are a collection of statements. Each statement is referenced with the source of the knowledge. Outputs of the analysis can be displayed as diagrams to investigate causal processes. Thus, this function could be used to build conceptual models and compare knowledge of different origins. Finally AKT proposes a methodology to perform the collection of knowledge.

Objectives and research questions

The project initiative aims at building a model to assist in the design of AFS with coffee. Research was carried out in three districts of Costa Rica: Turrialba, Orosi and Tarrazú. The objective was to build a biophysical conceptual model of coffee productivity and quality reflecting crop-environment interactions that occur in shaded coffee crops.

To create a complete representation of knowledge on coffee yield and quality elaboration, we first searched for academic, published knowledge on coffee productivity. Then we interviewed actors in the coffee productive chain: farmers, technicians and first coffee processors.[7] Once each knowledge was represented in the database, we undertook a comparative analysis.

[6] AKT methodology has been developed by university of Wales, Bangor.

[7] «Processors» and «Coffee processors» are the terms used here to name the managers of coffee processing units.

Materials and methods

Location of research

Agroecological situations determine shade coffee management. To increase the diversity of knowledge gathered and enrich our scientific model, we looked for coffee plantations in three different agroecological situations: the Turrialba Valley, the Orosi Valley and the Tarrazú region. Costa Rica is divided by folded mountains in two versants, the Atlantic (Orosi, Turrialba) and the Pacific (Tarrazú). Altitude is the other main difference in environment among the three: Turrialba is on the low side of altitudinal range for coffee (600–900 m), while Tarrazú is on the optimal to high side (1,200–1,700 m). Orosi is intermediate (900–1,200 m). Coffee practices did not differ between Turrialba and Orosi. Differences with Tarrazú were mainly caused by the presence of a well-defined dry season from December until March.

Building the academic model

The conceptual model was based on yields components, where the value of each yield component depends on the previously formed components and environmental factors during the formation of the yield component (Doré et al., 2008). Crop yield is the volume of cherries harvested per hectare and per year. The individual components of the yield were identified as follows:

Yield (bean weight/ha) = Number of (N) plants/ha
X N vegetative nodes/plant
X N floral buds/vegetative node
X N flowers/floral bud
X N pinhead/flower
X N green fruits/pinhead
X N ripe fruits/green fruit
X mean fruit weight
X (bean weight/fruit weight)

The processes included in the model were based on coffee physiology. Coffee phenological phases were chosen in function of their easy identification in the field and their importance to determine the yield components and quality attributes. The quality attributes considered were physic, organoleptic and chemical composition of coffee beans.

Coffee is a perennial crop, and its growth is indeterminate. Yields on successive years are interlinked and this pattern is part of the yield elaboration scheme. However, we limited our model to annual processes. The biannual cycle depends mainly on the number of vegetative nodes; it was included in the model.

After a validation of the model by researchers interviewed, the information was entered on AKT. Its diagram function was used to build the conceptual academic model.

Incorporation of knowledge to the academic model

To add a diversity of knowledge to the conceptual model and discuss the academic model, we chose and designated three groups of interviewees, based on hypothesis of the kind of knowledge each group is supposed to have. (1) Farmers knowledge is local, built from their observations and work in the field; it results from a relatively large time span. Thus, they have much more intimate experience of their production practices than external professionals (Thapa et al., 1995). (2) Knowledge from technical experts is a result of experience, coffee farm evaluations and unpublished observations (Thapa et al., 1995). (3) Coffee processors are the only ones having an understanding of coffee quality aspects in their region (Larrain, 2004).

The aim of our study was to gather the most diversified understanding of factors affecting coffee productivity. We were not looking for a group description but for a diversified knowledge. Therefore selection was done by a nonrandom sampling method and the sample was not intended to be representative of the population under study. Thus, we looked for key informants, i.e., farmer, technician or coffee processor with experience in coffee work and possessing an ample understanding of the relations between coffee management, coffee biology and their effects on coffee productivity and quality.

Based on the knowledge learned from the construction of the academic model, we build the interviews. A diagram based on yield components and general themes was built and used differently, depending on the group interviewed. All interviews were recorded for later processing using AKT software. Interviews with farmers and processors lasted at least two hours; interviews with technicians, no more than one hour.

Farmers
From already existing coffee farm typologies in Turrialba, based on a description of practices (Cerdan, 2008; Llanderal Ocampo, 1998; Porras, 2006), four groups were defined based on two factors: the intensity of crop management (intensive/nonintensive) and the use of artificial inputs (organic/conventional). Finally 24 key informants were interviewed. From the initial objective of interviewing two informants from each category in each region, we had to adapt the sample to take into account the actual existence of such farmers in each zone.

During the semi-structured interviews, we delimited with the farmer a coffee plot, unit of similar management and site conditions (soil conditions, shade amount, shade diversity, coffee plant age and varieties). Coffee plants were used as a support to find out morphological differences and elucidate knowledge about yield components. Then we looked for how environment affected those components; finally, we tried to find out how shade trees could modify those relationships.

A diagramming was used to follow the elicitation of knowledge. It allowed the interviewer to follow the keywords to check whether all the main themes were treated, and at the same time ask open questions in a semi-structured way on the basis of what interviewees saw in their coffee plots. We occasionally used as well a detailed questionnaire accompanying this diagram to ensure a more detailed support.

Technicians
In total eight technicians were interviewed: four in Turrialba, one in Orosi and three in Tarrazú. To select technicians and processors, we asked regional offices of ICAFE in Turrialba and Los Santos to select the oldest and most experienced in coffee production. The same semi-structured interviews used for farmers' interviews were used for technicians. However the diagram, which was used as a checklist with farmers, was used in this case as an iterative diagramming. This method was useful to involve technicians, giving them a support for their answers, and to organize their knowledge about factors affecting productivity on one productive year and at plot scale.

Processors

We visited six processors: one in Turrialba, two in Orosi and four in Tarrazú. In Tarrazú there are an increasing number of farms with their own processing units. Thus, we included two farmers in such a situation because we thought they might have more knowledge about quality and its relation to coffee management.

Interviews with processors were carried out in two steps. The interview used for the technicians was used as a first step. However, the processors did not provide much detail on the first four phenological phases and we spent more time on the fifth phase, which includes quality elaboration. For each quality characteristic cited, we asked them to link it to conditions or practices in the field. When the answer was considered too general, we tried to put the interviewee in the situation of a producer asking what he would do to improve coffee quality.

For the second part we visited the processing plant, where processors explained each step of the process—we asked for coffee bean characteristics obtained at the end of each step. Then we asked them to link those characteristics to practices in the field.

Processing with Agroforestry Knowledge Toolkit (AKT)

Each interview was recorded. The record was played in the office and casual statements were transformed into formal statements on causal relationships in AKT (See Walker and Sinclair,1995 for a detailed presentation of AKT).

After entering all the statements into AKT, we built conceptual models for each step, using a special diagram capability of AKT. Each cause and effect linkage was diagramed from stored statements, and each link has a value qualifying each relationship (examples given in results section). Moreover AKT gave a way to detect incomplete or incoherent information. Each region was visited two times: at the end of the first visit we looked at dispended statements using an option of AKT. Those relationships correspond to statements without any link in the model. On the second visit, we tried to ask more precise questions to add those statements to our model.

A knowledge base was made for each group of actors, to make the diagram construction within a group and the comparison between groups easier.

Results and discussions

We entered 228 statements in the knowledge base for the academic model, 520 statements in the farmers' knowledge base, 150 statements in that of the processors and 190 statements in that of the technicians. A model for each yield component was proposed.

The information suggested to be added to the academic model is represented in Table 1.

Table 1. Knowledge complementarities (+: positive effect, -: negative effect).

	Farmers	Technicians	Processors
Carbon	Deficit in carbon is represented as «tired plant».		
Quality	*none*	*none*	More detailed
Yield components			
Number	6	7	5: Did not mention vegetative nodes stage
Vegetative nodes amount	+ of soil moisture, shade - of altitude, fog, diseases as chasparria	*none*	*none*
Floral buds amount	+ of coffee plant stress. Stress is reached with increase in time and in intensity of radiation, water deficit, and high soil or ambient temperatures. - of physical damage.		
Flowers amount	- of wind increasing falling leaves rate - of nutrient deficiency or soil humidity causing crazy flowering	- of wind retarding flowering	*none*
Pinhead amount	- of low temperatures and nutrients deficiency causing sterile	*None*	*none*
Green fruits amount	- of nutrient deficiency causing shedding	*None*	- soil green fruits harvested
Ripe fruits amount	*None*	*None*	*None*

These suggestions were based on agronomic factors affecting the yield components.

Yield components were six for the academic and farmers' models, seven for the technicians' model and five for the processors' model (Table 1). For the academic model, we validated the components and processes found in the literature. However, for the other sources we let them to build the "history" of the ripe fruits. This shows what components were mentioned as important by the different sources.

To validate the inclusion of each yield component by each group, we have to check (1) the connection with the previously and the following yield component (continuous line zone) and (2) the processes modifying it (dashed line zone). Component and processes related to quality (dotted line zone) are illustrated in Figure 1.

Components taken into account in the academic model proved to be easy to identify with field experts (technicians and farmers). However, even if the pinhead component was easily visible in the field, factors affecting it were not different from factors affecting the preceding (flowers) and the following components (green fruits). It is proposed to include (1) the effect of sterile flowers on fruit formation in the preceding component and (2) the shortage of carbon causing shedding and the effect of nutrients in the following component.

For farmers, the moment the flowers were formed influences the size of fruits. This illustrates the link with the amount of carbon available: first flowers would have more carbon available for their development, hence for fruit growth. Comparing the academic and farmers' model, we note that both take into account (1) the amount of fruits as a sink and (2) the effect of a lack of carbon on fungal diseases, the amount of leaves and the amount of flowers. These are factors affecting the rate of net photosynthesis and the amount of reserves leading to lower amounts of carbon available or to a "coffee plant tired." However farmers did not report fruits as a source, as is reported in the literature.

There were areas of knowledge where the academic model was more explicit (e.g., initiation and induction processes). Initiation depends on the presence of a signal, mentioned by the four groups. Although

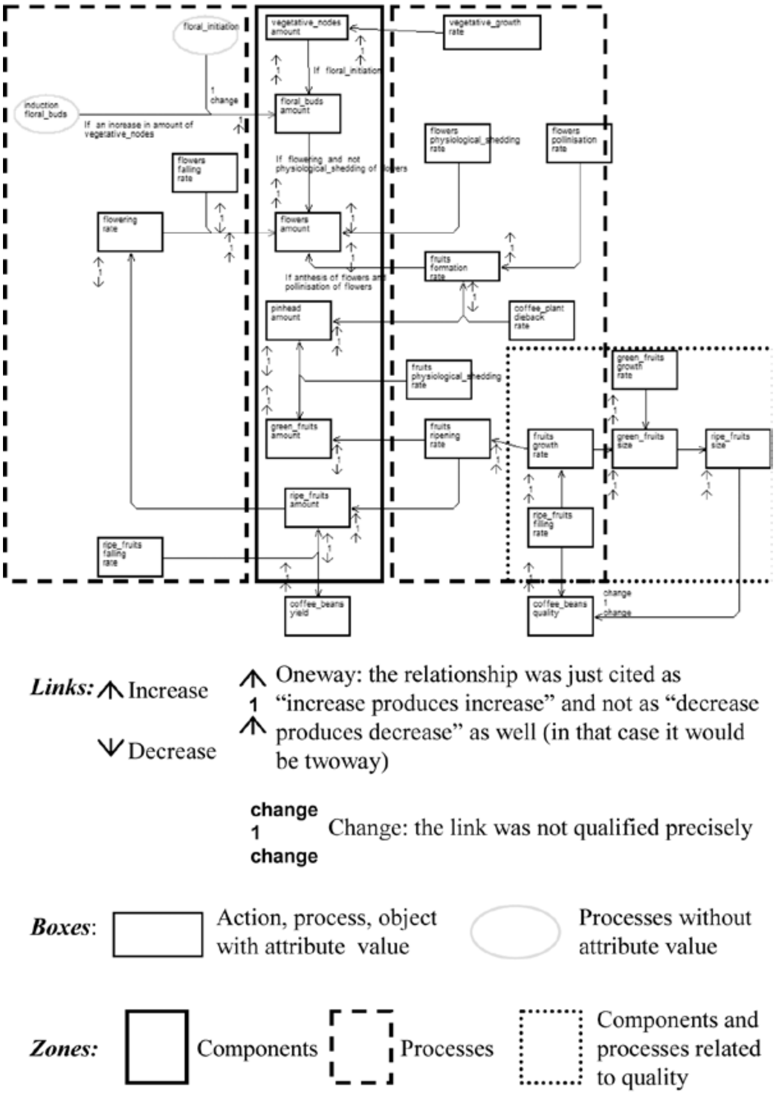

Figure 1. Academic model of yield and quality elaboration validated by scientific interviews.

there is not a common accordance on the signal: temperature, radiation or water stress. In fact for all the four groups we find the term "stress." Behind this term is hiding the time and intensity of radiation exposition and water stress coffee plants had for floral buds induction and floral initiation.

Farmers reported other interactions that were relevant to their site conditions and questioned the academic model. For example, they reported that falling of green fruit was not just during the pinhead stage; it was the only group who linked the process of falling fruits affecting the amount of green fruits.

There was no knowledge to add on the academic model about factors affecting ripe fruits amount. Furthermore, other new processes reported (formation of star flowers, falling of floral buds) were not linked with shade tree effects.

In fact new knowledge about the direct effect of shade trees on productivity did not appear (Table 1). The effect of (1) decreasing amount of carbon sinks avoiding overbearing, (2) the negative effect of reducing coffee plant stress and (3) the reduction of *Mycena citricolor* were the only direct effects on yield components.

Indirect effects like reducing the amount of weeds, improving soil structure, increasing nutrients cycling or favouring control organisms were considered and linked to the amount of nutrients or water available to coffee plant and to the disease rate. Some factors such as the amount of nutrients provided by shade trees (*Erythrina spp*. as a permanent fertilization: fast growth, permanent falling of leaves and fast decomposition) were reported as impossible to quantify; therefore it did not lead to modification of practices.

Processors did actually increase the information on quality characteristics. Field experts reported processes and environmental factors related to physical characteristics. Although processors reported the same, their knowledge on biochemical properties and organoleptic quality is more detailed. However, this knowledge was seldom linked with practices in the field or with physical quality aspects.

The lack of new knowledge about direct effects of shade trees on yield components can be due to the high technology of the farms where interviews were done in Costa Rica. Nevertheless some methodological limitations could also be the reason for this gap. In fact more time is needed to do a quantitative analysis to validate causal and effect relationships. As recommended by Walker et al., (1995) ,a questionnaire survey will be needed to establish how representative the knowledge obtained from key informants is of the knowledge in the broader community and to make a hierarchy of factors from farmers' experiences.

Conclusion and perspectives

This work represents an attempt to build a conceptual model of coffee production under shade trees, incorporating knowledge from different stakeholders of the coffee sector.

AKT, the software we used to process the knowledge, proved to be useful to (1) process interviews, (2) describe causal relationships, (3) detect and clarify contradictions and (4) identify gaps in scientific knowledge. Its diagram representation makes the explanation and comparison of knowledge easier, although its diagram function is not well-adapted to show clearly the many relationships described in the knowledge base.

The study of knowledge from different sources was useful to (1) elucidate how processes as carbon allocation and water stress are represented by farmers, (2) show other environmental factors affecting each component, and which could affect the monofactorial academic relationship (e.g., the effect of temperature on flowering) and (3) detail factors affecting quality and show the gap between processors and experts on this topic. On this last issue, it would be useful to try to better link the knowledge of these two groups to elaborate practical recommendations to improve coffee quality.

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DEBATE of Session 3
Developing Models, Reusing Models, Coding or Using Platforms

Neil I. HUTH (CSIRO)

Session 3 included eight presentations from a wide range of disciplines and encompassing different facets of modelling and model development. These ranged from small-scale simulations of shadows of individual trees to whole-of-plot-scale simulations of resource use and produce, to models spanning several larger scale issues. Two component-based protocols for model development (APES/SEAMLESS, RECORD) were discussed, as was a declarative modelling environment (SIMILE). Although, such wide topics were discussed, some common recurring themes were quickly identified and discussed by the workshop participants.

Relevance of long-term data

First, all modelling efforts, especially the detailed modelling approaches demonstrated, require large amounts of data for building, testing and applying the chosen models. Marcel Van Oijen had clearly described **data deficiencies** in his previous plot-scale modelling work. Long-term and high-quality climate data series are required for the application of most process-based modelling approaches. When investigating the impacts on climate change, the modeller needs to be able to access a long enough record to capture the effects of climate variability within that changing climate. Short-term records are unlikely to adequately capture the range of conditions within a current climate. This will be exacerbated in a climate with high spatial variability, as in the mountainous regions of Costa Rica.

Integration of economical approaches in models

It was suggested that while there was recognition of the importance of variability in climate and soils, and that these lead to variability in production and ecosystem function, there were other areas in which variability is important but perhaps not adequately handled as yet. Variation in costs and prices or resource supply is very important in some systems or analyses. In the case of farm livelihood, the variability of prices introduces a risk for which many households need to account. Economic models will need to investigate the importance of such variability in further analyses.

Integration of different scales

The ability to model across a range of scales is an obvious a strength of modern simulation-based analyses. However, there are logistical and philosophical issues regarding the degree to which individual analyses should cross scales. Consideration needs to be given to the appropriate number of scales to incorporate into a study. It was suggested later in the workshop that perhaps three scales should be an appropriate upper limit for all work (one scale above, one scale below). When multiple scales are chosen, care needs to be taken in how information moves between scales (for example, downscaling of global climate model information into local climate change forecasts) and how one integrates information from lower scales (such as hydrological, economic or demographic information).

From a better collaboration between modellers and users

The wide range of models and modelling frameworks available today, and indeed used in previous projects, led to a discussion on the needs for model reuse and close research collaboration. Where research is to be completed within a given context (e.g., plot scale) there should be benefits in avoiding duplication of work and building upon proven technologies. Collaboration on specific modelling tools can also be used to bring people together and harness the various strengths within the diverse groups of participants. There may be some concerns regarding constraints to scientific freedom; however, these can be dealt with. First, a collaborative effort needs to be built upon a transparent approach to model development. Second, it needs to achieve the benefit of a single framework in providing an environment for testing alternative approaches within a common "test harness." One final concern lies in the exposure to institutional instability and change. This risk will need to be handled at the project management level.

Overlapping of data and models

If collaborative approaches are to be employed with respect to model development, then the lessons learned from the Olympe modelling work should be investigated as well. In this modelling community, there are means for data from individual modelling efforts to also assist in the area of ongoing model application. Data used in one particular model application can be made available to others working within the same domain. The idea of taking collaboration past model development through to ongoing model application would provide great benefit to current project teams.

Relevance of communication tools to lighten modelling results

The final presentation (SIMILE) illustrated the benefit of visualisation tools in demonstrating and communicating simulation results to stakeholders. Models become much more transparent to those relying upon them if they can be communicated in an effective way. In a similar way, the ShadeMotion model provides a way to demonstrate the effects of various canopy conditions upon the light environment of the understorey. As the models grow in complexity, and cross multiple scales, tools to demonstrate the structure and results of the models used will become increasingly useful.

SESSION 4

Databases and Models

Chairman: Bruno RAPIDEL (CIRAD, CATIE)

The EU-CASCA Project: Databases and Models

Philippe VAAST,[1,2] Jean-Michel HARMAND[1] and Olivier ROUPSARD[1,2]

Abstract

The present paper summarizes the results, especially in terms of databases and models, of the EU-CASCA project entitled "Sustainability of Coffee Agroforestry Systems in Central America: Coffee Quality and Environmental Impacts" (CASCA), Contract number: ICA4-2001-10071.

Introduction

Objectives

The CASCA project was developed in 1999-2000 at the peak of the last coffee crisis in Central America when revenues diversification, payment for environmental services and new marketing opportunities (premiums for quality coffee and ecofriendly labels) were identified as strategies to improve the economic sustainability of the Central American coffee sector and to reduce vulnerability of farmers to coffee price volatility. CASCA started in 2001 and aimed to (1) document and synthesize farmers' knowledge on coffee agroforestry (AF) management; (2) assess the impacts of associate shade trees on coffee quality, productivity and plantation sustainability; (3) quantify some of the environmental impacts of coffee AF systems in comparison to

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full-sun coffee monoculture; (4) assess the impacts of management scenarios (shade and ecofriendly versus intensive systems, variation in coffee prices, premium of ecofriendly labels) and other revenues derived from associated trees (timber, fuel wood, fruits and other products) on farm economic sustainability; and (5) develop plot scale models that provide tools to extension workers and policy makers to promote sustainable coffee systems.

Activities and methodologies

More than 50 researchers and graduate students of CASCA partners (CIRAD-France, CEH-UK, CATIE-Central America, IICA-PROMECAFE-Central America, and UNA-Nicaragua) worked more than 770 months to (1): collect socioeconomic data on approximately 900 farms in 10 regions of target countries (Costa Rica, Guatemala and Nicaragua); (2): undertake biophysical measurements in 10 existing trials and more than 80 coffee farms; and (3): develop models improving the understanding on coffee and associate shade trees interactions.

Results

From November 2001 to December 2005, results achieved by CASCA are as follows:

- Financial support and scientific tutoring of 30 M.Sc. and five Ph.D. students
- Databases and synthesis on farmers AF knowledge and main characteristics of coffee AF systems in target countries
- Description of ecological and agricultural factors affecting coffee quality
- Models of light and water partitioning for coffee and associated shade trees
- Models on coffee physiology at different scales (leaf, coffee tree and plot)
- Models on nitrogen cycling and carbon accumulation quantifying environmental impacts and services of coffee systems
- Biophysical plot model with upscaling at watershed level
- Economic model to explore farm economic viability according to various scenarios and diversification options

Dissemination
Through 46 publications (17 in Spanish), 12 oral presentations in international conferences, 15 technical presentations in front of more than 2,000 farmers, development of tools (eight models) and recommendations to stakeholders of the coffee and wood sectors, CASCA has greatly contributed to increase public awareness of the environmental and socioeconomic importance of coffee AF systems in Central America, to improve their agricultural management and to enhance their economic sustainability.

The CASCA project comprises eight different work packages (WP) (Table 1).

WP1: Central America coffee AF knowledge
1. Results: farmers have a good empirical knowledge of shade tree species and their compatibility with coffee. Coffee price is the most important factor conditioning farmers' agroforestry management strategies; coffee farmers also know quite well local tree species, how these species help sustain or decrease the productivity of their coffee plantations, and how these species impact on coffee pests and diseases. Nonetheless, their knowledge of tree management is deficient; tree density is rarely adequate. Tree thinning is rarely well-mastered. Tree pruning is rarely implemented at the right time during the production cycle. Farmers have poor access to information regarding introduced tree species.
2. Databases: Database of current coffee AF practices in Costa Rica, Guatemala and Nicaragua.
3. Models: No.
4. Scientific publications: Two in Spanish and two international (including book chapter).
5. Nine master's and one Ph.D.

WP2: Light and water partitioning at plot scale
1. Results: 700 hemispheric photos of shade tree canopies in five coffee agroforestry systems with *Terminalia amazonia, Eucalyptus deglupta, Cordia alliodora, Cedrela odorata, Erythrina poepiggiana.* Measurements of the terms of water balance (transpiration by sapflow, soil water content, rain interception, PET in various conditions).
2. Databases: No.

3. Models: Light interception by coffee canopy and shading trees (3D); plot water balance (PASTIS, inc. drainage calculation); coffee plant transpiration (3D).
4. Scientific publications: 10 in Spanish and six international.
5. One master's and two Ph.Ds.

WP3/1: Coffee ecophysiology
Objectives: physiological responses of coffee leaves to microenvironment, carbon production and allocation in coffee.

1. Results: How shade affects coffee vegetative and reproductive, compartments in competition; shaded plants may develop higher leaf area indices (LAI); flowering is reduced if shade is maintained during the critical period of flowering at the end of dry season. Coffee fruits are the most important plant sink; alternate production pattern of coffee trees and die-back of branches in the presence of a heavy fruit load.
2. Databases: No.
3. Models: Photosynthesis models (leaf, plant and plot scales), effects of light, temperature, VPD, feedback of sugars accumulating in the coffee leaf, photo-inhibition; Coffee C allocation and reproductive model.
4. Scientific publications: several.
5. Seven master's and two Ph.Ds.

WP3/2: Coffee ecophysiology and quality
Objectives: Some of the mechanisms responsible for coffee quality.

1. Results: Altitude and shade permit a better growth and development of coffee berries in a cooler environment, which delays the pulp maturation and hence results in a longer and enhanced bean filling, larger bean size, better bean biochemical composition and higher quality of coffee beverage. Shade also decreases flowering intensity; increasing nitrogen resulted in higher aroma of the coffee beverage without affecting significantly the overall cup quality, while a survey of 67 farms in Nicaragua show that adequate fertilization regime improves the overall coffee quality.
2. Databases: No.
3. Models: No.
4. Scientific publications: Two in Spanish and four international.
5. One master's.

Table 1. Synthesis of available databases and models of the CASCA project.

WP	Title of WP	Databases	Models
1	Central America coffee AF knowledge	Current coffee AF practices in Costa Rica, Guatemala and Nicaragua	No
2	Light and water partitioning at plot scale	700 hemispherical photos	Light interception by coffee canopy and shading trees (3D); Plot water balance (PASTIS, including drainage calculation); Coffee plant transpiration (3D)
3	Coffee ecophysiology Coffee ecophysiology and quality	No	Photosynthesis models (leaf, plant and plot scales), effects of temperature, VPD, feedback of sugars accumulating in the coffee leaf, photo-inhibition; Coffee C allocation and reproductive model;
4	Nitrogen cycling, leaching, uptake and emissions		N flux and cycling model; N_2O production model
5	C sequestration	Database of C sequestration in biomass and soil of coffee AF in Central America (20 studies)	C sequestration at plot scale and regional scale C sequestration at plot scale and regional scale
6	Integrated plot Modeling	Literature database about biophysical aspects of coffee AF systems in Endnote with 600 references; Biophysical parameter database in Word	Competition model for light, water and nitrogen at patch scale; Integrated plot model
7	Economic modelling at farm scale	Farm typology with 300 farms	The economical model, farm economic profitability according to various scenarios (especially, fluctuations in coffee price) taking into account the importance of revenues derived from other productions (dairy, husbandry, grain, fruits, timber, etc..), the availability of labor and costs of production.
8	Regional up scaling and policies	Labels survey; Non market benefits of shade coffee	No

WP4: Nitrogen cycling, leaching, uptake and emissions

1. Results: *In situ* measurements of N inputs (N fertilizer), N fixation, soil N mineralization, N accumulation in biomass and soil (nitrate retention), N exports (coffee berries harvest, nitrate leaching, mineral N loss in runoff and nitrous oxide emissions). To recommend adequate of N fertilization in relation to coffee seasonal demand and annual level of production, soil N availability, and contribution of associate trees via pruning and N_2 fixation. Nitrate contamination of the aquifers and emission of N_2O. Soils of Central America generally exhibit high permeability allowing large water drainage but distinct adsorption patterns resulting in different nitrate dynamics.

Increasing the N fertilizer level above 150 kg N ha^{-1} yr^{-1} does not provide significant additional coffee production in the long term but results in water contamination. Integrating a legume tree stratum into a low-input organic coffee system strongly increases the rate and amount of the N cycling, resulting in a high coffee yield response and a slight increase in nitrate leaching and N_2O emissions, which remain rather low.

2. Databases: No.
3. Models: N flux and cycling model; N_2O production model.
4. Scientific publications: Four in Spanish and four international.
5. Six master's and one Ph.D.

WP5: Carbon sequestration

1. Results: Database of C sequestration in 20 coffee AF studies of Central America and a few others in other parts of the world coffee: 80% of the C is located belowground in soil organic matter and roots and 20% is aboveground. A mean value of 26 tC ha^{-1} is located in the aboveground biomass, of which 50% is in the shade trees, 30% in the coffee plants and 20% in litter and weeds. CASCA work shows that carbon accumulation in the coffee biomass varies from 5 to 16 tC ha^{-1} whereas that of associate shade trees ranges from 0.5 to 35 tC ha^{-1} depending of species and age. Carbon accumulation in soil can account to up to 220 tC ha^{-1}. Coffee AF systems can greatly increase organic matter content of the top soil layer with an extra carbon accumulation in the litter layer of 0.5 to 3 tC ha^{-1}.

In spite of a higher rate of GHG emission due to a higher N_2O emission, the rate of CO_2 sequestration is more than twofold higher for an

AF system than for coffee monoculture, showing the interest of coffee AF management for global warming mitigation. First estimations of N_2O emissions in the different coffee AF systems account for 0.3 to more than 1 tC-CO_2 Equivalent ha^{-1} yr^{1}, which represents 7% to 25% of C accumulation in the coffee and tree biomass and litter.
2. Databases: Database of C sequestration in biomass and soil of coffee AF in Central America.
3. Models: C sequestration at plot scale and regional scale.
4. Scientific publications: Three in Spanish and two international.
5. Three master's and one Ph.D.

WP6: Integrated plot modelling
1. Results: See paper of Marcel van Oijen, (Session 3 of these proceedings).
2. Databases: Literature biophysical aspects of coffee AF systems in Endnote with 600 references; biophysical parameter database in Word.
3. Models: Competition model for light, water and nitrogen at patch scale; integrated plot model.
4. Scientific publications: One in Spanish and one international.
5. Ph.D. thesis: No.

WP7: Economic modelling at farm scale
Objectives: Economic and household surveys in coffee regions, cost of labour, inputs and revenues (diversified), model impact of management scenarios on farm economic sustainability.

1. Results: Farm typology from 300 farms. Contribution of timber and firewood that can account for 10% to 33% of the present value of coffee and up to 76% of the farm revenues in one coffee region of Guatemala. Demand for timber trees is increasing in Central America.

Pilot program CAFE Practices appears to be mostly a strategy for Starbucks to secure medium-term access to high quality coffee produced in high altitudes zones rather than promoting farmers' adoption of sustainable coffee practices.
2. Databases: Farm typology with 300 farms.
3. Models: The economical model, farm economic profitability according to various scenarios (especially, fluctuations in coffee price) taking into account the importance of revenues derived from

other productions (dairy, husbandry, grain, fruits, timber, etc.), the availability of labour and costs of production.
4. Scientific publications: Three in Spanish and one book chapter.
5. Six master's.

WP8: Regional upscaling and policies
Objectives: To determine the management requirements for environmental coffee labels and associated markets, to assess the nonmarket environmental services of shade coffee as an aid to economic upscaling of results from WP7, and to examine methods of using the biophysical model developed in WP6 at a regional scale.

1. Results: Coffee labels and markets literature surveys of all sustainable, fair-trade and ecofriendly labels used in Central America and current and potential markets for these labels in Europe and the United States. The environmental and social conditions for award of these certificates have been reviewed. Extrapolation from socioeconomic farm model to the level of administrative region. Nonmarket benefits of shade coffee: climate risk (maintaining stable vegetation covers), climate amelioration (at the meso-scale), carbon credits (using the clean development mechanism), biodiversity (biological corridors, species diversity, refuges), genetic resources (planting of improved and threatened shade trees), water quantity and regularity of supply (avoiding floods and low flows), water quality (limiting nitrates and other pollutants), erosion reduction (reducing loss of carbon and nutrients), reducing sediment load (avoiding siltation of reservoirs), protecting forest resources (timber and firewood elsewhere), landscape value (scenic beauty, diversity, tourism and recreation). Extrapolation from biophysical plot models to a wider region. See extrapolation of WP6 delivery of management and policy guidelines taking into account different climate, soil, market price and incentive scenarios. CASCA project report.
2. Databases: Labels survey, nonmarket benefits of shade coffee.
3. Models: No.
4. Scientific publications: No.
5. Ph.D. thesis: No.

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Shade-Productivity Interactions in Coffee Agroforestry Trials in Costa Rica and Nicaragua

Jeremy HAGGAR,[1] Mirna BARRIOS,[1] Marvin MERLO,[2] Rodolfo MUNGUIA,[3] Charles STAVER,[4] Elias de MELO[2] and F. VIRGINIO[2]

Abstract

Two long-term coffee systems experiments were established in Costa Rica and Nicaragua with shade of legume and timber species, or full sun, combined with organic and conventional managements. Production under full sun was significantly higher than under shade over the first two years in Costa Rica, but not subsequently. A weak negative correlation (r^2=0.33 p<0.01) was found between shade and production; the highest levels of shade were found with *Erythrina* (80%). In Nicaragua accumulated productivity over four years under full sun (24.9 t/ha) and under shade systems with *Tabebuia* (21.2 to 24.5 t/ha) were significantly higher than shade systems with *Inga* (16.3 to18.0 t/ha). In Costa Rica accumulated moderate conventional production over the four years (25.8 t/ha) was significantly greater than intensive organic production (18.8 t/ha), both under shade. In Nicaragua intensive organic production (21.6 t/ha) was not significantly different from intensive conventional production (24.6 t/ha), both of which were

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significantly more productive than extensive organic production (14.6 t/ha). Under the pruning and thinning regime employed *Inga* and *Erthrynia* showed indications of being competitive. *Erythrina* reduced growth of the other timber species, and tended to reduce coffee production when shade cover was high. Inga shade systems had lower coffee yields possibly linked to more shade in the dry season. During these first years it appeared that the timber shade systems created more favourable conditions for coffee production than the leguminous trees.

Resumen en español

Interacciones de producci n de sombra in ensayos agroforestales de caf   en Costa Rica y Nicaragua

Dos ensayos de café de largo plazo fueron establecidos en Costa Rica y Nicaragua con sombra de leguminosas y maderables o pleno sol combinado con manejo orgánico y convencional. La producción bajo pleno sol fue significativamente mayor durante los primeros dos años en Costa Rica, pero no después. Se encontró una correlación negativa (r^2 =0.33 p<0.01) entre el grado de sombra y la producción; la sombra mayor fue con *Erythrina* (80%). En Nicaragua la producción acumulado durante cuatro años a pleno sol (24.9 t/ha) y con sombra de *Tabebuia* (21.2 a 24.5 t/ha) fue significativamente mayor que con sombra de Inga (16.3 a18.0 t/ha). En Costa Rica la producción acumulado del convencional moderado fue significativamente mayor (25.8 t/ha) que el orgánico intensivo (18.8 t/ha), los dos con sombra. En Nicaragua la producción del orgánico intensivo (21.6 t/ha) no fue significativamente diferente del convencional intensivo (24.6 t/ha), los dos fueron significativamente mas productivo que el orgánico extensivo (14.6 t/ha). Las sombras leguminosas mostraron indicaciones de ser muy competitivas. *Erythrina* demostró competencia con los árboles maderables, y posiblemente redujo la producción de café cuando la sombra fue densa. Las sombras con *Inga* tuvieron menor productividad

aunque los niveles de sombra solo fueron mayores en la época seca. Al menos durante los primeros años parece que los árboles maderables crearon mejores condiciones para la producción de café.

Introduction

In Central America high-input or modern coffee production technology has achieved high yields for a select group of favored producers who cultivate coffee in optimum growing conditions. This tripling or quadrulping in yields has been achieved by short-cutting ecological processes such as semi-closed nutrient cycles and food web diversity. These processes have been minimized or replaced by the use of petroleum-based fertilizers and pesticides in minimal shade or open sun coffee. For example, a healthy soil built up from leaf litter under shade has been replaced by nematicides and chemical fertilizers. Pesticides have replaced a buffered shade environment that helped keep pests at nondamaging levels. Efficient, organic nutrient cycles have been replaced by leaky, open inorganic fertilizer flows.

The high cost of purchased inputs coupled with the volatile prices for coffee have contributed to greater economic vulnerability of intensive coffee production, even for successful farmers. In the open-sun system, costs of production cannot easily be reduced, even when coffee prices are low, without substantial deterioration in yield potential in future years. Second, the model has not proven widely applicable for farm families with a small land base and limited resources. The majority of coffee-producers continue to harvest 5–15 hundredweights per hectare in most of Central America, only a third or less of potential yield. Third, the elimination or simplification of shade has generated concern for the loss of biodiversity (Perfecto et al. 1996). Finally, excessive pesticide and fertilizer use, soil erosion and inadequate coffee waste processing have contributed to pollution and environmental deterioration in fragile, yet vital, upper watersheds. Coffee growers have begun to experiment with alternative production technologies to reduce costs, to access specialty markets and to diversify income. These include organic production, often with leguminous shade trees, which have been used traditionally in coffee. Conventional farmers have cut back on fertilizer and pesticide use. Farmers have also continued to look for economic diversification of the tree component with non-leguminous timber and fruit trees.

To contribute to this search for more viable coffee production technologies, CATIE and national partners in Costa Rica and Nicaragua established a long-term experiment of alternative coffee production systems with the following objectives:

1. Determine the effects of shade composition and structure, type and level of nutrient inputs, pest control approaches, and varieties on pest dynamics and other flora and fauna, coffee growth, yield, and quality, and nutrient cycles and soil organic matter.
2. Measure the growth and development of different tree strata in terms of biomass accumulation, timber and firewood production, and litter contribution and their effect on microclimate, nutrient inputs, and soil biology and organic matter.
3. Contrast interactions among shade, nutrient and pest strategies, and varieties for distinct coffee producing zones by rainfall, altitude, and soil fertility.
4. Develop methods for the identification of ecological efficiencies and the evaluation of economic, ecological, and productive sustainability for coffee systems.

The study should contribute to the design of systems that make use of ecological efficiencies for lower costs, higher quality coffee and additional income.

Materials and Methods

In 2,000, two experiments were set up in a low, wet coffee zone and in a low, dry coffee zone. Turrialba, Costa Rica, represents a low, wet coffee zone with fertile soils. Annual rainfall is 2,600 mm with a period of lower rainfall, although no dry season. Altitude is 685 meters above sea level. Masatepe, Nicaragua, is a low, dry coffee zone with fertile soils. Annual precipitation is 1,386 mm. The six-month dry season receives only minimal rain. Altitude for Masatepe is 455 meters above sea level. Main treatment plots were tree strata with subplots for input levels for nutrient and pest management. A different set of timber and service tree species was used for each site, drawn from the most common species used in association with coffee (Tables 1 and 2). Trees were planted at four times their expected final density and have been reduced by 50% by one thinnings approximately six years after planting.

Each experiment has an open-sun treatment and different combinations of the tree species to develop a gradient of nitrogen fixation and contrasting combinations of evergreen/deciduous and canopy type (Table 3).

Four input regimes for nutrient and pest management were designed (Table 4).

Coffee cherry production data was taken from a measurement plot that had at least four rows of coffee buffer between different treatments. Tree height and basal and breast-height diameter were measured annually (Nicaragua) or biannually (Costa Rica). Shade levels were measured twice per year in Nicaragua using a densiometer and using a LiCOR light meter in Costa Rica.

Table 1. Tree species to be used in coffee systems comparison in Masatepe, Nicaragua.

Species	Phenology	canopy shape	N-fixer	Use
Simarouba glauca (SG)	Evergreen	high narrow	No	Timber
Tabebuia rosea (TR)	Deciduous	high narrow	No	Timber
Samanea saman (SS)	Briefly deciduous	high spreading	Yes	Timber
Inga laurina (IL)	Evergreen	low spreading	Yes	Service

Table 2. Tree species to be used in coffee systems comparison in Turrialba, Costa Rica.

Species	Phenology	canopy shape	N-fixer	Use
Terminalia amazonia (TA)	evergreen	high compact	No	Timber
Chloroleucon eurycyclon (CL)	Briefly deciduous	high spreading	Yes	Timber
Erythrina poepiggiana (EP)	evergreen	low compact	Yes	Service

Table 3: Main plot and subplot treatments (see Table 4 for key to subplot treatments).

Low, dry zone in Nicaragua	
Main plot treatments	Subplot treatments
Open sun	IC, MC
S. glauca, T. rosea	IC, MC, IO, EO
T. rosea, S. saman	MC, MO
S. glauca, I. laurina	MC, MO
I. laurina S. saman	IC, MC, MO, EO
Low wet zone in Costa Rica	
Main plot treatments	Subplot treatments
open sun	IC, MC
E. poepiggiana	IC, MC, IO, EO
T. amazonia	IC, MC, MO, EO
C. eurycyclon	MC, IO
T. amazonia, C. eurycyclon	MC, IO
T. amazonia, E. poepiggiana	MC, IO
C. eurycyclon, E. poepiggina	IC, MC, IO, EO

Results

Accumulated production over the first four years in Costa Rica was significantly higher for full sun coffee (37.6 t/ha) than shaded coffee (30.0 t/ha) under conventional management. When analyzed by year, this difference was only significant in the first two years of production (first year 3.5t/ha sun vs 1.5t/ha shaded, $p<0.01$, second year 15.7t/ha sun versus 11.3 shaded, $p<0.01$) (Figure 1b). In Nicaragua accumulated productivity over four years under full sun (24.9 t/ha) and under the two shade systems with *Tabebuia* (21.2 and 24.5 t/ha) was significantly higher than the two shade systems with *Inga* (16.3 and 18.0 t/ha). There were no significant differences in coffee production between the different shade systems in Costa Rica. Percentage light intercepted in Costa Rica in the fourth year was highest in shade combination with *Erythrina*, then *Terminalia* and lowest with *Chloroleucon* (80%, 51% and 40% respectively, $p<0.01$) (Table 5). Although there was not significant effect of shade treatment on production, there was a weak negative correlation ($r^2=0.33$ $p<0.01$) between percentage light intercepted and production. Wet season shade cover in Nicaragua was not significantly different among the shade combinations. Only in the dry season when

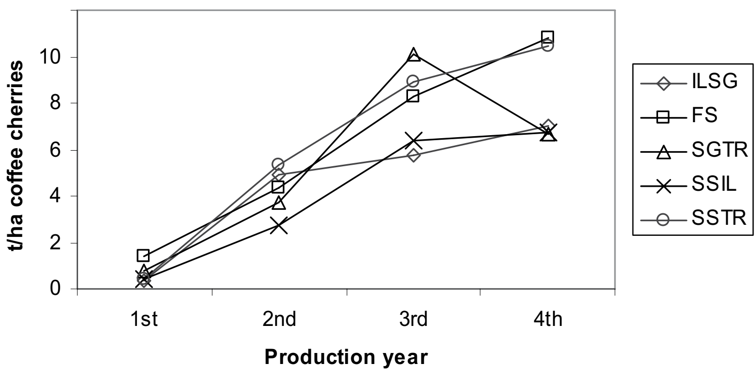
Table 4. Input levels for nutrient and pest management in coffee systems experiments.

	Extensive organic (EO)	Intensive organic (IO)	Moderate Conventional (MC)	Intensive Conventional (IC)
Type of soil amendments	Organic, primarily coffee wastes	organic-coffee wastes, chicken manure, and ground rock	Chemical fertilizer	Chemical fertilizer
Level of soil amendments	Return of nutrients removed during harvest	greater than nutrients removed in harvest	Greater than nutrients removed in harvest	Far in excess of nutrients removed in harvest
Disease management	None	use of botanical and mineral foliar applications	Use of infrequent commercial fungicide applications	Regular use of commercial fungicides
Insect pest management	Gleaning of berries after harvest	manual practices and use of botanical and biological applications	Manual practices and infrequent use of commercial insecticides	Manual practices and regular use of commercial insecticides
Weed management	2-4 routine machete weedings per year	manual selective weed management between row and clean within row area	Selective weed management between row and clean within row area with manual and herbicide	Bare soil with herbicides

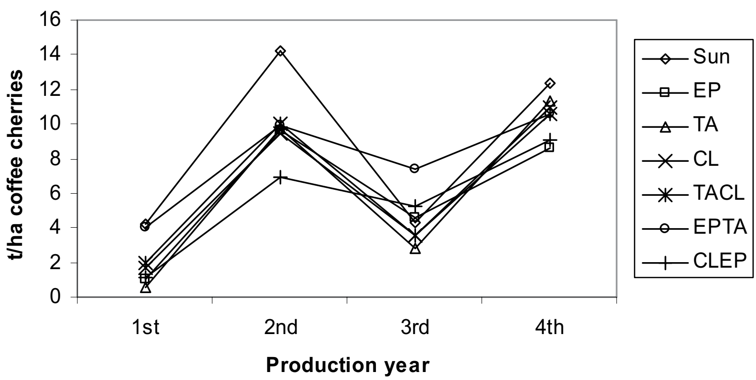
Tabebuia is deciduous was shade cover significantly lower (28% cover) in systems with this species than with *Inga* (50–62% cover). In Costa Rica accumulated moderate conventional production over the four years (25.8 t/ha) was significantly greater than intensive organic production (18.8 t/ha), both under shade, but this difference was only significant in the first and second year, when analyzed on a per year basis (Figure 2). In Nicaragua (Figure 3) intensive organic production (21.6 t/ha) was not significantly different from intensive conventional production (24.6 t/ha), both of which were significantly more productive than extensive organic production (14.6 t/ha).

Table 5. Light interception by different shade types in fourth production year in Costa Rica experiment, values followed by different letters are significantly different, $p<0.05$ (for key to species, see Table 2)

	Shade Type					
	EP	TA	CL	EPTA	CLEP	CLTA
% light interception	80.2a	53.1c	40.6e	86.2a	66.8b	33.5e



a. Nicaragua FS=full sun.



b. Costa Rica.

Figure 1. Coffee production (MC and IO) under different shade types (see Table 1 for tree species).

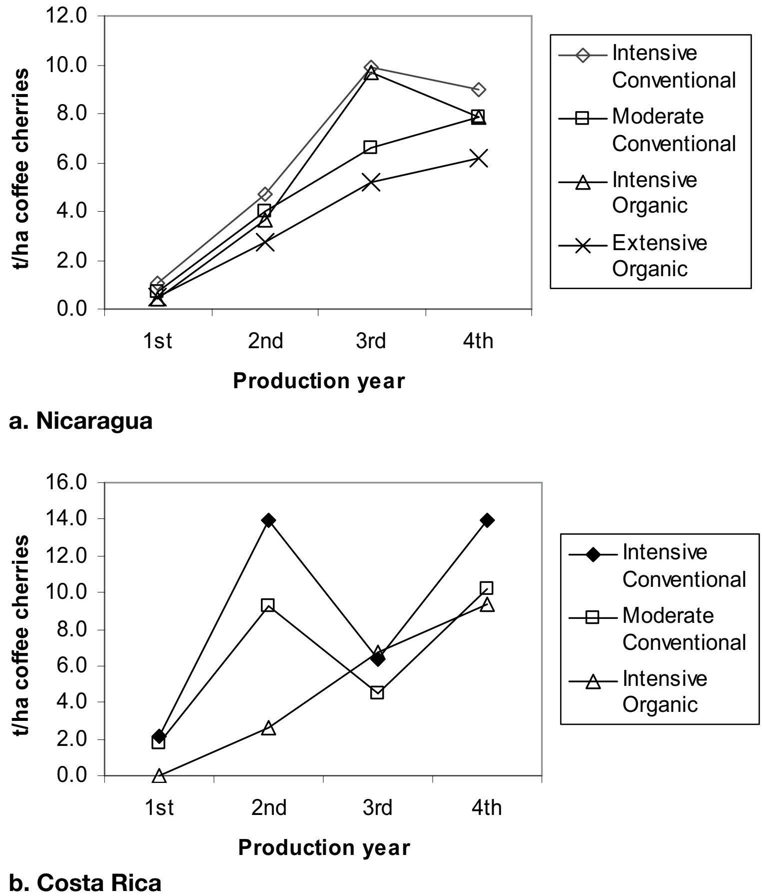


Figure 2. Coffee production under different input regimes.

Basal area per tree when five years old in Nicaragua was least for *Samanea*, which was two years younger than the other species, intermediate for *Simarouba* and similar between *Inga* and *Tabebuia*. The combinations with *Samanea* had least basal area, but there was no significant effect between the presence of *Inga* or *Tabebuia* (Table 6).

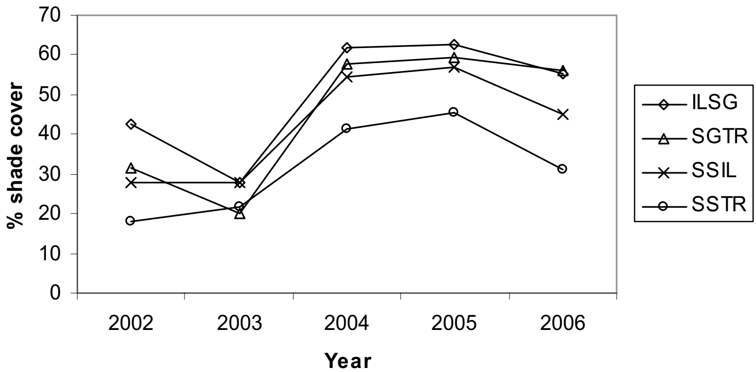


Figure 3. Percentage shade cover during the wet season of different shade tree combinations at the Nicaragua site.

Table 6. Basal area of trees by treatment at Nicaragua site (for basal areas per stand values followed by different letters are significantly different $p<0.05$).

	Basal area per tree cm²				Basal area per stand
Shade treatment	*Inga*	*Simarouba*	*Samanea*	*Tabebuia*	m²/ha
ILSG	199	119			13.4a
SGTR		128		198	13.7a
SSIL	233		29		11.1ab
SSTR			42	167	8.9b
Average	222	125	33	188	13.4

In Costa Rica six-year old *Erythrina* had the greatest basal area, followed by *Chloroleucon* and then *Terminalia* (18.2, 8.3 and 3.8 m^2/ha, respectively). However, basal area of *Chloroleucon* and *Terminalia* were significantly reduced when in combination with *Erythrina* (7.0 versus 4.25m^2/ha and 4.0 versus 2.2 m^2/ha, respectively, $p<0.05$). Furthermore, crown diameter of *Erythrina* was significantly greater when combined with these species (11 m) compared to *Erythrina* alone (5.7 m).

Discussion and conclusions

Coffee productivity was higher under full sun than shade under some circumstances. At the Costa Rica site this was just during the first years, and in Nicaragua only compared to some shade types. The decline in relative productivity of the full-sun coffee at the Costa Rica site is related to higher levels of plant exhaustion and greater frequency of regenerative pruning (Merlo, 2006).

Intensive organic production was found to be equally productive as conventional at the Nicaraguan site, and equal to moderate conventional production in Costa Rica from the third harvest on. This contrasts with an average of only 1.7 t/ha for organic production, but 5.6t/ha for conventional production in the same region of Costa Rica, compared to 4.7t/ha and 6.4t/ha respectively in the experiment (Porras, 2006). We attribute this to higher levels of organic fertilization and better maintenance of plant vigor in the experiment, than is usually achieved on farms.

Under the pruning and thinning regime used in the experiment, the leguminous shade trees showed indications of being competitive. At the Costa Rica site, despite partial biannual pruning, *Erythrina* developed a more dense shade and was found to reduce the other timber species—and possibly reducing coffee production when shade cover was high. It should be noted that in the moderate conventional and intensive organic treatments, *Erythrina* was pruned twice per year to remove some branches so as to provide a constant shade. This is contrary to the traditional management of pollarding the tree twice per year, removing all branches, which was implemented for the intensive conventional treatment. When *Erythrina* is managed in this traditional intensive manner ,Fassbender (1993) found higher productivity of coffee with *Erythrina* than with timber trees. Muschler (2001) also found that lack of regulation of *Erythrina* shade led to a decline in productivity. *Inga* shade systems had lower coffee productivity, possibly linked to higher shade levels in the dry season. Immediately after these results were taken, *Erythrina* tree density was halved at the Costa Rica site and all tree species were thinned to 50% of original density at the Nicaragua site. At least during these first years it appeared that the timber shade systems created more favourable, or at least more easily managed, growing conditions for the coffee production than the leguminous shade trees.

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An Overview of the Existing Databases on Cocoa-Based AFS in CATIE

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Abstract

Since the late 1990s, CATIE and more specifically CATIE's Agriculture and Agroforestry Department, has been involved in different investigation projects which, each one in its own topic, generated data about cocoa-based Agroforestry Systems (AFS). However, there has been little coordination to sum up this information as a single meta-database about cocoa production in AFS in Central America. This paper has two purposes: i) to present an overview of the existing databases, their content in terms of variables, their structure and their location; ii) to propose a framework for the organization of a meta-database accessible for all cocoa investigators belonging to networks such as INAFORESTA or the PCP.

Such a database could be of considerable value for future investigations, especially when they occur to happen in already investigated plots, farms or regions and for modelling purposes.

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Resumen en español

Visi n general sobre las bases de datos existentes sobre cacao en SAF en CATIE

Desde finales de 1990 CATIE, y más específicamente, el Departamento de Agricultura y Agroforestería, ha estado involucrado en diferentes proyectos de investigación los cuales, cada uno en su tópico, han generado información sobre cacao en sistemas agroforestales (SAF). Sin embargo, ha habido poca coordinación para recopilar esta información en una metabase de datos única sobre la producción de cacao en SAF en Centroamérica. Este artículo tiene dos propósitos: i) presentar una visión general de las bases existentes, su contenido en términos de variables, sus estructuras y su ubicación; ii) proponer un marco de trabajo para la organización de una metabase de datos accesible a todos los investigadores en cacao pertenecientes a redes tales como INAFORESTA o PCP. Tal base de datos podría ser de un valor considerable para la investigación futura, especialmente cuando se realice en parcelas, fincas o regiones previamente investigadas y para propósitos de modelaje.

DEBATE of Session 4 **Existing Databases to Parameterize and Test Models**

Bruno RAPIDEL (CIRAD, CATIE)

Various databases were presented at different scales about coffee and cocoa. It was evident that a lot of data have been produced in Mesoamerica on AFS, but there is a lack of organization, which makes very difficult, in certain cases, the reusability of data.

The relevance of the development of database was stressed, and the way toward this development was discussed.

Data are more and more produced during projects with finite duration. To be able to enter in a capitalization process, it was evident to all participants that the strategy has to be defined at the beginning of the project, not at the end.

The PCP is a partnership platform of long duration (10 years). It will host projects of shorter duration that will generate different kinds of data. It is probably a task of PCP to help and induce the project to adopt a common strategy in this respect.

This is the goal. The discussion proved that there are in reality very few experiences of projects that successfully adopted a strategy to build databases. Some examples were given for projects generating huge databases, with very strict protocols, like water and CO_2 flux networks. It was shown that such strategies are highly beneficial, as they give the networks a possibility to make comparisons at a global scale. These projects are designed at the first step to make these comparisons, so it is not such a surprise that they dedicated more efforts on this side than others.

The question of how to motivate scientists to build these database was discussed. The main problem is that the development of databases requires real efforts and resources and that they produce results for publications only on the long term. Another issue is evidently the property of the data shared in a database. One essential step is to have them published, and this is not always the case, slowing down the process of database building.

Databasess must be considered for different disciplines and, probably, for different scales. The successful experiences are more frequent with biophysical or economical data, although some experiences also exist in social sciences. The reason is probably because there are more rigid and accepted definitions of variables and units in the biophysical and economical fields than in the social field. The databases need certainly to be different, but the necessity for capitalization is the same for all disciplines.

Quality assessment must be performed on the database. There are standard tools readily available to perform this analysis.

It was suggested not only that data should be stored. Modelling experiments could also be included in a suitable way. In a similar manner as for data, these experiments can document a model and can be capitalized.

SESSION 5

Hydrological Modelling

Chairman: Olivier ROUPSARD (CIRAD-CATIE)

Spatialization and Modelling of Water Balance Components from Plots to Watersheds in Costa Rica and Effects of Agricultural Land Use and Management Practices on Hydrological Environmental Services, with a Focus on the Coffee Sector and Its Alternatives

Federico GOMEZ-DELGADO,[1,2,3] Olivier ROUPSARD,[2,3] Roger MOUSSA[4] and Bruno RAPIDEL[2,3]

Abstract

This is a proposal for the design and implementation of a coupled model that joins together agronomical and hydrological knowledge as a tool for the proposal of hydrological environmental services (HES). The main objective is the assessment of different productive practices and contrasts such as full-sun agriculture against agroforestry, in terms of their yield, but also of its effects on water quantity and quality for downstream users, from plot to watershed scale. The validation of this model would be based on data sets obtained from the observation of physical processes under an interdisciplinary perspective, in four different case analyses. This forces the modelling exercise to accomplish the demanded

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precision for the explanation of small-scale time-space phenomena (like energy and mass balances in an agroforestry stand) but also of bigger-scaled analysis (such as watershed water balance).

Resumen en español

Espacializaci n y modelaci n de los componentes del balance h drico en Costa Rica, de la parcela a la cuenca y efectos del uso agr cola de la tierra y las pr cticas de manejo sobre los servicios ambientales hidrol gicos, con un nfasis en el sector cafetalero y sus alternativas

Ésta es una propuesta para el diseño e implementación de un modelo acoplado que reúne conocimiento agronómico e hidrológico, como herramienta para el planteamiento de servicios hidrológicos ambientales (HES por sus siglas en inglés). El principal objetivo es la valoración de diferentes prácticas productivas y contrastes como la agricultura a pleno sol contra la agroforestería, en términos de su rendimiento, así como de sus efectos en la cantidad y calidad del agua para los usuarios aguas abajo, de la escala de la parcela a la de cuenca. La validación de este modelo se basaría en una recopilación de datos obtenidos de la observación de procesos físicos con una perspectiva interdisciplinaria en cuatro casos de análisis diferentes. Esto demandará que el ejercicio de modelación logre la precisión requerida para la explicación de fenómenos de pequeña escala tiempo-espacio (como los balances de energía y masa en una parcela agroforestal) pero también de análisis con mayores escalas (como el balance hidrológico a nivel de cuenca).

Introduction

Water balance (WB) components are the constitutive elements of the hydrologic cycle, which is in charge of many small, medium and large scale transformations over Earth's surface. The well-known influence of these components (and the processes that govern them) on productive human activities becomes obvious in the case of agroforestry systems (AFS). Though one can think that water is only one factor out of many others that will define the answer of such AFS (as could be the exposition to sunlight, soil nutrients and management techniques), the watershed integration properties of water gives additional basis for spatially re-scaled AFS modelling. Water-based models could allow us to characterize some properties of AFS at other scales higher than the plot but also to produce watershed representative indicators, associated with the respective hydrological response function. The evaluation of the ecological and socioeconomical effects of agroforestry management practices at higher scale can rely on those indicators that, in consequence, constitute an objective tool for the proposal of payments for hydrological environmental services (HES).

Hydrological modelling in agroforestry

Xu (2005) remarks some of the objectives of watershed hydrological models: a) to gain a better understanding of the hydrologic phenomena that operate in a watershed, b) the generation of synthetic sequences of hydrologic data for facility design or for use in forecasting and c) studying the potential impacts of changes in land-use or climate. From these objectives the latter is very linked to HES and reflects the way in which hydrology can be used for upscaling traditional agronomic assessments that deal with land-use and conservation techniques. For this, the watershed is proposed as a unit of social and ecological organization, being natural unit for multipurpose planning. Some examples of this can be the use of water resources of a particular watershed for the integrated design and operation of hydropower plants or water supply systems. In both cases, hundreds or thousands of users of these services (electricity and freshwater) could be potential clients for HES.

Agronomy and hydrology have overlapped topics, as much as meteorology or geology, among others. Then, some hydrological analysis can go deep into land-use parameterization and build models that are able to study differences between crop field water dynamics and a riparian buffer water dynamics, for example. The concept of Soil-Vegetation-Atmosphere Transfer (SVAT) models are commonly found in both disciplines and have been widely used under different hypothesis and research objectives.

The integration of modelling interests from agronomists and hydrologists is then a valuable asset, which is proposed here in the form of a WB study under tropical conditions (watersheds in Costa Rica). Important emphasis will be placed on agroforestry systems functioning, as a plus for HES in terms of its agroecological importance for sustainable development.

These developments demand a consistent conceptualization and choice of the models to be used. Singh (1988) proposes a classification of runoff models that can be extended to agronomical models as well (Figure 1). This author also provides a rational methodology for the use of the models, though the step concerning the choice of a particular model has not been created yet (Xu, 2005).

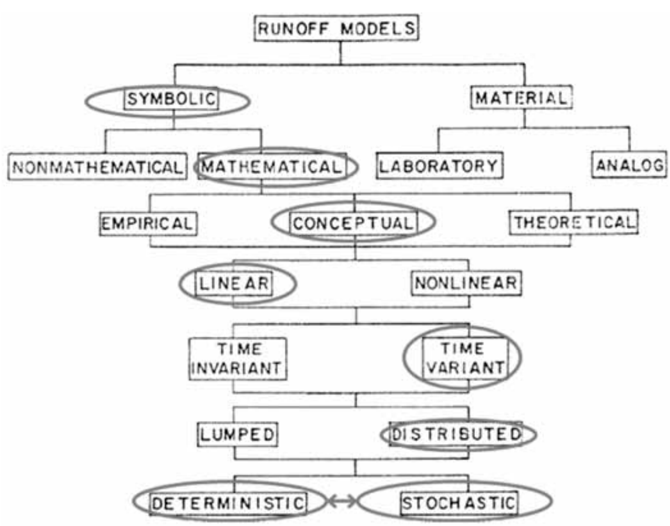

Figure 1. A classification of hydrologic models. The circles show the types chosen for our agrohydro WB modelling.

The proposal here is to follow the route of symbolic-mathematical models, varying from the mechanistic or theoretical (based on physical processes) for very detailed plant physiology to empirical models for wider and general relations that can be encountered at a big scale for watersheds. Conceptual models are the intermediate so will be valuable to define represent many processes in between. Differencing between linearity in the system theory sense (LST) and in the statistic regression sense (LSR), the model for WB will be chosen LST, given the adding consistency of the separate process that lead water components. Time variations will be considered given the seasonality of agricultural practices and of course, the climatic variables, which directly change input-output relations. Given the importance of deterministic processes in agronomy as well as in hydrology, our model is proposed of that nature. However, time series analysis for runoff and sediment yield at the outlet of the watershed can have an important role for a statistic calibration of the models, as much as stochastic watershed models can complement and integrate the precise plot-scaled agronomic and agroforestry models. Once processes nature is defined, model building, calibration and validation are the next steps, given that all databases are available for the watersheds under study (i.e., remote sensing information, evapotransporation, runoff and sediments). Then, this proposal includes a SVAT model interacting with a hydrodynamic runoff+sediment routing models, which should eventually be able to couple with other models that give information or scenarios for very different scales (like general or regional circulation models: GCM/RCM). All this arrangement is located in space under standard digital terrain models.

Sediment yield from plot to watershed: a scaling issue

Basing on the fact that erosion and sedimentation are natural processes but with high sensitivity to human influence; and also on the strong interaction of water-soil-plants-human action, then the joint modelling of WB components along with erosion/sediment yield on a watershed would allow production of robust criteria for the assessment of conservation initiatives and levels of ecoproductivity in agricultural lands. This effort would intend to make compatible the WB and sediment analysis at watershed scale, with the regular agronomical and WB modelling at plot scale.

A coupling procedure is proposed for joining agro and hydro models of physical, conceptual and stochastic nature, departing from a deep bibliographic review, from the classical models to the more current ones. Problems related to the scales of variability of the dominating processes, in time and space, must be especially considered. A diversity of methods and tools can be used to achieve reliable HES assessments and comprehensive criteria production. Some examples of agronomical and hydrological models that will be useful for the purposes here presented are USLE/RUSLE, CALSITE (USLE spatial model; Bradbury, 1995), SWAT (Arnold et al., 1996), PESERA (Gobin et al., 1999), Biome-BGC (Running and Coughlan 1988; Pierce, 1993), Van Oijen model (Van Oijen, 2005), SATEEC (Lim et al., 2005) and MHYDAS (Moussa et al., 2002). Some of them are already distributed models.

Then, sediment yield is highlighted as a common agronomical-hydrological indicator, that depends on agroforestry practices and directly impacts watershed processes, but also that can be measured at the outlet of that integrated area. The ability of modelling this indicator, along with plot and watershed WB, will make possible the proposal of financially feasible HES.

Here it is critical to consider that traditional physically based distributed models cannot be directly applied to large scales with coarse resolutions. The physically based equations used in most distributed models are defined basing on fine resolution data and may not be valid in large scale with coarse resolution due to the spatial heterogeneity and nonlinear nature of soil-vegetation-atmosphere transfer processes (Xu, 2005). Large amount of data used to estimate the parameters of those models may not be available in large geographical regions. Finally, calibration of the large number of parameters of such models might not be feasible in large geographical regions.

Considering sediment yield as a good watershed indicator, but taking into account the upscaling concerns, a final exercise will be done by assessing the impact of sediment production on the usable volume of some reservoirs belonging to Costa Rican national electrical system. Once the process-based component of the model has been validated, some climate change (CC) scenarios could be built, relying on GCM or RCM. Now CC effects on HES could be estimated, using the current climatic conditions as a base scenario.

Conclusions

The multidisciplinary modelling of coffee agroforestry systems is proposed and entails the combination of concepts of agronomy and hydrology. The development of simplified SVAT models, especially for use in larger scales, are of the interest of experts on these two fields of knowledge, but such models must be capable of representing the main processes, basing on a small set of key parameters. These parameters can be linked up to certain values used in the description of land-surface processes at larger watershed scales. So, a coupling procedure has been proposed for joining agro and hydro models, of physical, conceptual and stochastic nature, taking special care of the time and space scales of variability of its constitutive processes. The results will make possible to propose hydrological environmental services schemes supported by objective, quantitative methods, aiming to promote water and soil conservation practices under an eventually changing climate.

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Modelling Erosion in Alternative Land-Use Scenarios Under Current and Future Climate Change: Inputs for Soil Conservation Management Programs in the Birrís Watershed, Costa Rica

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Abstract

The Reventazon watershed of Costa Rica is the most important in national hydroelectricity production for National Energy Company (ICE) and was established as a priority area in the first National Communication to United Nations Framework Convention on Climate Change. Actually, sediment delivery to the hydropower dam is up to 1.5 million ton/yr with corresponding costs expected to amount annually to more than USD2 million. As part of the Reventazon, the Birrís subwatershed, with its high land-use conflict, is considered a priority for conservation, also in relation with the presence of the important hydropower plant system of JASEC.

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In the case of downstream hydropower dams especially, the soil retention capacity of the upstream ecosystem determines maintenance and operation costs related to siltation. Such ecosystem service, as observed in Costa Rica, is threatened by the combined effects of climate change (i.e., increased precipitation and erosivity) and upstream land management. Indeed, increased sediment-dredging efforts and buying of fossil fuels to guarantee energy provision during dredging is increasing energy production costs in Costa Rica.

Alternative scenarios of implementation of soil conservation measures (reforestation, agroforestry, silvopastoral systems, soil management practices) were built on the basis of discussions with stakeholders and review of other studies developed in the area. CALSITE platform was used to estimate total laminar erosion in the watershed. RUSLE model determined the data inputs used in CALSITE according to the following equation:

$$A = R, C, K, LS, CP$$

where A is the total annual erosion (ton/ha/yr), R is the erosivity of precipitation, C is vegetation cover factor, K is the soil erosivity, LS is the length of slope and CP is a factor accounting for soil management practices.

For the elaboration of different land-use scenarios, data analysis required refinement of some factors in the model. Data for factor C and K were recompiled in the watershed to allow finer estimation of the contribution of these factors to laminar erosion. Different levels of erosivity (i.e., current, +1%, +5% and +10% as observed and predicted with climate change) were used to account for differences between current and future possible climate change. LS was accounted for by estimating how some conservation practices might reduce the length of slope run by water along the slope. CP was included using existing data. These scenarios allowed identification of three levels of risk areas to focus actual and potential future conservation efforts. Change in the area covered by each risk class in different scenarios is calculated. The total sediment at the end of the watershed output of CALSITE was used as input in the sediment cost model for the JASEC plant. This last model used STELLA platform to model the cost of dredging and flushing and the cost of importing energy during sediment management period.

An actual land-erosion model is used for identification of priority intervention areas. Nevertheless, considering the deep uncertainty, especially in characterizing future trends in erosivity as well as future landscape configuration, scenarios will be used in structured discussion with multiple stakeholders to elicit values/ objectives and help identify possible mechanisms to implement positive change in the landscape.

Resumen en español

Impactos del sedimento sobre la productividad hidroel c-trica bajo el cambio clim tico: el caso de la cuenca de Birr s en Costa Rica

Projecto: CATIE/UICN-TroFCCA/EU

La cuenca del Reventazón de Costa Rica es la más importante en la producción hidroeléctrica nacional para la Compañía Nacional de Electricidad (ICE) y fue establecida como un área prioritaria en la primera Comunicación Nacional al Convención Marco de las Naciones Unidas sobre Cambio Climático. Actualmente, la entrega del sedimento a la represa hidroeléctrica suma aproximadamente 1.5 millones ton/año con los costos correspondientes de más de USD2 millones cada año. Como parte del Reventazón, la subcuenca del Birrís, con su uso de tierra de muy conflictivo, es considerada una prioridad para la conservación, también en relación con la presencia del importante sistema de planta hidroeléctrica de JASEC.

Especialmente en el caso de represas hidroeléctricas río abajo, la capacidad de retención de suelo del ecosistema río arriba determina los costos del mantenimiento y operación relacionados al atasco de la sedimentación. Tal servicio del ecosistema, como se observa en Costa Rica, está en peligro por los efectos combinados del cambio climático (por ejemplo, erosividad de la precipitación aumentada) y del manejo de la tierra río arriba. De hecho, el incremento en los esfuerzos para dragar los sedimentos y la compra de combustibles fósiles para garantizar la provisión de energía durante la draga están incrementando el costo de la producción de energía en Costa Rica.

Escenarios alternativos de la implementación de medidas para la conservación del suelo (reforestación, agroforestería, sistemas silvopastoriles, prácticas de manejo de suelos) se han construido sobre la base de discusiones con los actores y de la revisión de otros estudios desarrollados en el área. La plataforma CALSITE fue utilizada para estimar la erosión laminar total en la cuenca. El modelo RUSLE determinó los insumos de los datos usados en CALSITE de acuerdo a la siguiente ecuación:

$$A = R, C, K, LS, CP$$

donde A es el total de la erosión anual (ton/ha/año), R es la erosividad de la precipitación, C es el factor de cobertura vegetal, K es la erosividad del suelo, LS es la longitud de la pendiente y CP es un factor que toma en cuenta las prácticas de manejo del suelo.

Para la elaboración de los diferentes escenarios del uso de tierra, los análisis de datos requieren de un refinamiento de algunos factores en el modelo. Los datos para el factor C y K fueron recopilados en la cuenca para permitir una estimación más ajustada de la contribución de estos factores a la erosión laminar. Los diferentes niveles de erosividad (e.j. actual, +1%, +5% y +10% como se observan y predicen con el cambio climático) fueron utilizados para justificar las diferencias entre el posible cambio climático actual y futuro. LS fue determinado por medio de la estimación de cómo algunas prácticas de conservación pueden reducir la longitud del recorrido del agua en la pendiente. CP fue incluido utilizando datos existentes. Estos escenarios permiten la identificación de tres niveles de áreas de riesgo para enfocar esfuerzos de conservación actuales y potenciales. Se calculan los cambios en las áreas cubiertas por cada clase de riesgo en los diferentes escenarios.

El resultado de CALSITE, sedimento total al exutorio de la cuenca, fue usado como insumo en el modelo de costos de sedimentación para la planta de JASEC. Este último modelo utilizó la plataforma STELLA para modelar el costo de dragado y limpieza y el costo de la energía importada durante el período de manejo del sedimento.

El modelo de erosión actual es utilizado para identificar las áreas de intervención prioritaria. Sin embargo, considerando las incertidumbres en la caracterización, especialmente de las tendencias futuras en la erosividad como también en la configuración futura del paisaje, los escenarios serán usados en discusiones estructuradas con variedad de actores para obtener valores/objetivos y para ayudar a identificar posibles mecanismos que implementen cambios positivos en el paisaje.

Introduction

The Reventazon watershed of Costa Rica is the most important for national hydroelectricity production (ICE, 2000). Its main hydropower production facilities are weekly-regulation dams whose life span depends on the quality of water depending on downstream transported sediments. Sediments reaching up to one and a half million tons/yr are removed yearly from the dams to maintain the largest possible life span with an average yearly expenditure of more than USD2 million (Rodriguez, 2001).

The quantity of sediments reaching the dams is influenced by two global change factors that have been taken into account by national efforts to protect important watersheds: the distribution of extreme precipitation events and land management in priority areas. As for the former factor, the Reventazon watershed was established as a priority area in the first National Communication to United Nationals

Framework Convention on Climate Change (IMN, 2000) due to its vulnerability to climate extremes and its relevance for national development. As for the second factor, to identify priority areas for targeting soil conservation efforts, the watershed management plan identified three subwatersheds to be targeted by conservation efforts. More specifically, the Birris subwatershed with its high land-use conflict and the presence of a small hydropower hourly-regulated dam has been chosen as a learning site for the National Hydropower Company (ICE). Nevertheless, to establish efficient soil conservation programs in the watershed, we have to consider potential changes in variables that are of concern for two main types of stakeholders: upstream farmers and downstream hydropower. The aim of this paper is to illustrate the use of modelling to develop decision support systems for future negotiations between these two types of actors.

Study area

The Birris is a subwatershed of the Reventazon River (Figure 2). It has an extension of 4,800 ha and is under the influence of Atlantic climate, with 2,325 mm average rainfall, 82.8% of which is concentrated in the period May-December. Topography is characterized by slopes reaching 70%, especially in the upper part of the watershed. The population, the majority locally born, has a density of 161 inhabitants per square kilometer, above the national average (INEC, 2001); most of it (61%) is dedicated to market-oriented agriculture and has been conducting its actual productive activity for 40 years now (ICE, 1999).

This intense process of forest fragmentation and intensive agricultural production makes this area one of the largest sediment-producer in the country (Sanchez-Azofeifa et al., 2002). Average erosion rates passed from 12 ton/ha/yr when, prior to 1978, only 15% of the watershed was under horticulture to the actual 42 ton/ha/yr (Abreu, 1994). However, the effect of such a high level of erosion is only visible in some areas, given that most of the watershed is sloping down from Turrialba Volcano, where deep andisols are largely common (Lutz and Pagiola, 1994; Rodriguez, 2001).

Methods

To support the development of this learning case for ICE, we used a modelling approach to develop land-use scenarios and a sediment-management-cost model for the small hydropower dam. Alternative scenarios of implementation of soil conservation measures (reforestation, agroforestry, silvopastoral systems, soil management practices) were built on the basis of discussions with stakeholders and review of other studies developed in the area as suggested by Scholz et al. (2002). Nevertheless, considering the deep uncertainty characterizing future trends in erosivity as well as future landscape configuration, scenarios will be used in structured discussion with multiple stakeholders to elicit values/objectives and help identify possible mechanisms to implement positive change in the landscape. The overall methodology then included a sequential approach of structured consultations with stakeholders and desk modelling as suggested by Van de Belt (2004) for dynamic system modelling contribution to action research.

Modelling of erosion

CALSITE platform (Bradbury, 1995) was used to estimate total laminar erosion in the watershed using the RUSLE model (Wischmeier et al., 1978):

$$A = R, C, K, LS, CP$$

where A is the resulting field sediment calculation (ton/ha/yr), R is the erosivity of precipitation based on data from 32 meteorological station in the Reventazón watershed, C is vegetation cover factor, K is the soil erosivity, SL is the slope length and CP is a factor accounting for soil management practices. Most of these factors were estimated in previous studies in the area (Gomez, 2004; Arroyo et al., 2006; Arroyo et al., 1994; Bermudex, 1980; Alvaro, 2000, CATIE, 2003; Cervantes et al., 1992; Elizondo 1979; Gomez, 2002; Gutierrez, 1987; Ileana, 1987; MAG-FAO, 1996; Forsythe, 1991, Mora, 1987; Portilla, 1994).

A series of steps (Figure 1) was undertaken to prepare the GIS layers for model run. CALSITE allows for a rapid estimation of watershed sediment output as well as, through its IDRISI-GIS combination, an identification of erosion distribution in the catchment and thus of priority areas for intervention. Moreover, this platform performs a routine that improves the estimation of the previously linear-assumed length of slope (LS).

Erosion classes were the result of weighting erosion production of the plot by its connectivity to hydrological network proxying the immediacy of the process from the soil particle detachment and its transport to downstream hydropower dams. For each management-unit polygon, the average sediment yield delivered to the water network was calculated in the erosion map. This method allows accounting for an important criteria as revealed in consultations with hydropower managers (i.e., sediment reaching their dams).

Land-use scenarios development

Land-use scenarios were developed using a continuous consultation with stakeholders to identify how policy-relevant factors were changing in potential future landscape configuration. As two extreme

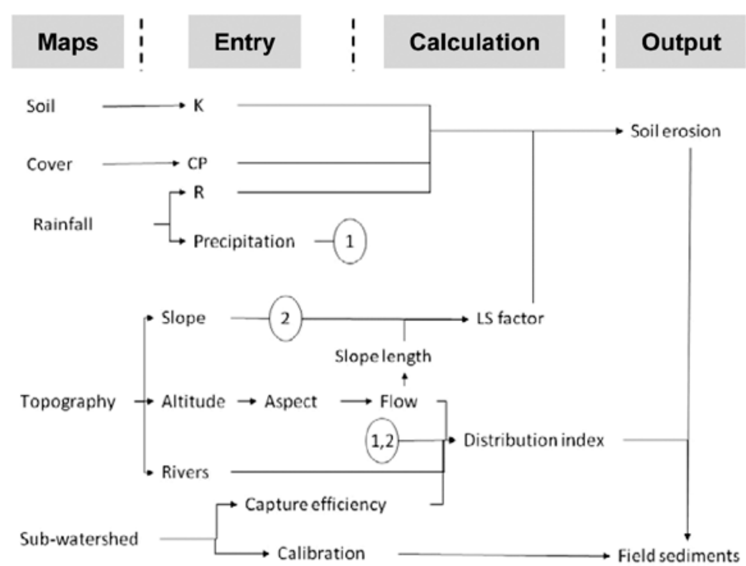

Figure 1. Flow diagram of the steps involved in developing the CALSITE model runs.

scenarios, we take the full forest cover (scenario 1, as a natural baseline production of sediment) and full deforestation (scenario 3) as the boundary of the actual scenario (2). Land-use changes could be achieved by soil conservation programs. Potential implementation of soil management activities and a change in erosion-control-relevant areas were identified based on existing practices.

The scenarios refer to a hypothetical future configuration of the landscape by 2022, thus being more a medium- to long-term prospective input for actual conservation decisions. Each of the conservation practices induces changes in parameters that are relevant for erosion control as promoted or already used by local farmers (Cubero, 1996). For factor C and K in the model, additional field data were recompiled in the watershed. Moreover, to account for possible increases in frequency and intensity of precipitation extremes as the increasing trend observed for the region (Aguilar et al., 2005), we simulated an increase in R, resulting in four climatic conditions (i.e., current, +1%, +5% and +10% as observed and predicted with climate change). LS was accounted for estimating how some conservation practices might reduce the length of slope run by water along the slope. CP was included using existing literature data. The CALSITE simulation allows identification of erosion risk areas in order to focus actual and potential future conservation efforts. Change in the area covered by each risk class in different scenarios is calculated. Erosion produced by different watershed areas and finally the annual total sediment output of the watershed were calculated with CALSITE (Table 1).

Results and discussion

About 37% of the watershed has a high land-use conflict, with estimated laminar erosion of more than 50 ton/ha/yr. It was possible to identify five critical areas (indicated by circles in Figure 2) that should be prioritized in soil conservation programs.

Figure 2 shows the agricultural plots as reported by the vector of the cadastre with their laminar erosion classes. These classes were defined according to their connection to the hydric network in order to indicate those whose sediments are more readily distributed in the water system (i.e., and thus reaching the hydropower dam). In these areas the model estimated that 152 ton/ha/yr are produced and fragmentation of plots is high with an average plots size of lower than 1.4 ha.

Land-use scenarios

Table 2 shows the simulation results for land-use alternative scenarios in the Birris watershed. For the purpose of the analysis and the absence of data, it is assumed that landslide sediment delivery in the alternative land use scenarios stays constant (i.e., 12 ton/ha/yr) as in the BAU scenario.

Table 1. Land-use scenarios description of conservation activities changing RUSLE factors.

<table>
<tr><th>Scenario code</th><th>Description</th><th>Activities
(based on consultation
with MAG, ICE-UMCRE)</th></tr>
<tr><td>1_1</td><td>Business as usual
(actual use)</td><td>Actual technologies implemented in conventional system in the area</td></tr>
<tr><td>1_2a</td><td>Forest in high risk areas</td><td>Forest cover changes only in high erosion areas, using C and K field data from local forest</td></tr>
<tr><td>1_2b</td><td>Complete forest cover</td><td>Complete forest cover using C and K field data from local forest</td></tr>
<tr><td>1_2c</td><td>Riparian deforestation</td><td>50 meters for each riparian side</td></tr>
<tr><td>1_3</td><td>Support for pasture</td><td>Horticulture plots are converted to pastures and actual pastures are converted to grass production for livestock</td></tr>
<tr><td>1_4</td><td>Support for fruit trees</td><td>Horticulture is converted to technified fruit-tree production</td></tr>
<tr><td>1_5</td><td>Slope management</td><td>Contour lines (change in LS) are implemented in pasture and horticulture</td></tr>
<tr><td>1_7[a]</td><td>Conservation packages in high priority areas (>200t/ha/yr)</td><td rowspan="3">Change in factor “C”:
Horticulture → pasture
Horticulture → fruit trees
Pasture → silvipasture
Change in LS:
Stonewall and live barriers
Water channels
Change in P
Low impact ploughing practices</td></tr>
<tr><td>1_7b</td><td>Conservation packages in medium and high priority areas (50 to 200t/ha/yr)</td></tr>
<tr><td>1_7c</td><td>Conservation packages in low (<50t/ha/yr), medium and high priority area</td></tr>
</table>

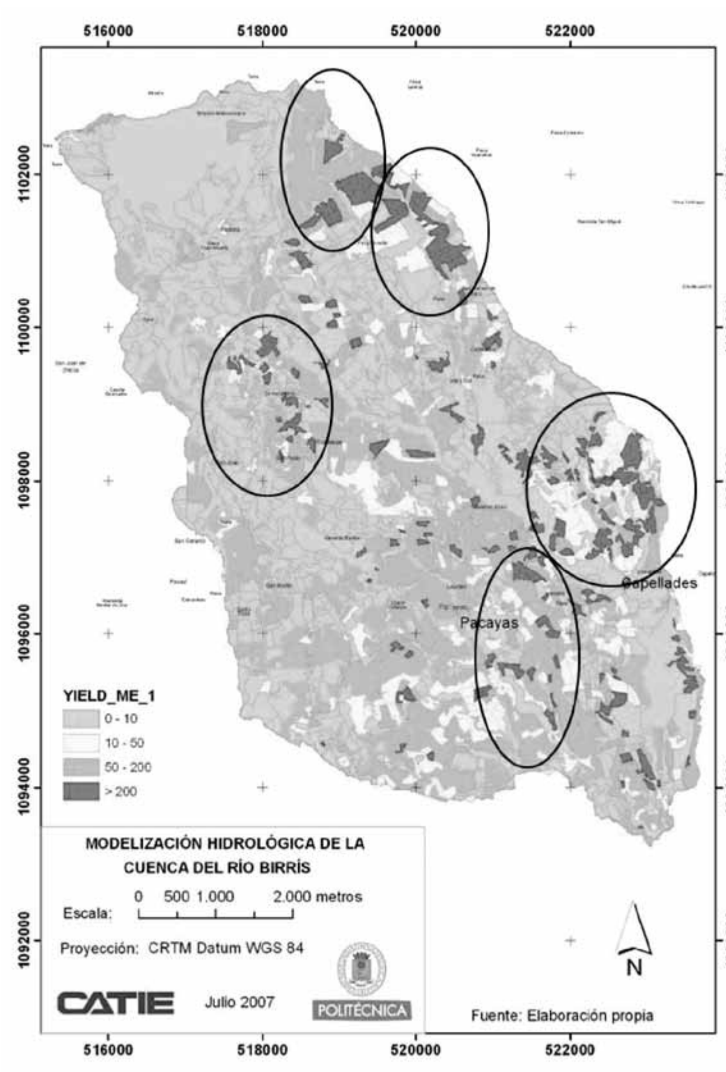

Figure 2. Erosion map for Birris watershed. The circles identify the communities where plots have higher erosion based on four erosion classes.

Table 2. Estimated erosion under different land-use scenarios in the Birris watershed.

Scenarios	1_1	1_2a	1_2b	1_2c	1_3	1_4	1_5	1_7a	1_7b	1_7c
Extent of changes		High risk areas	ALL	ALL	High risk areas	High risk areas	High risk areas	High risk areas	High & medium risk areas	ALL
A-Erosion (USLE) (t/ha/yr)	48.9	1.4	0.4	99.4	1.8	1.5	33.5	1.7	0.9	0.6
C-Sedimentation (t/ha/yr)	61.12	13.6	12.6	112	14	14	45.7	13.9	13.1	13
A-Increment (vs 1_1) (%)		-97	-99	103	-96	-97	-32	-97	-98	-99
Watershed sediment output (t/yr)	293.4	65.4	60.2	535.8	67.3	65.8	219.3	66.5	62.7	61.3

In order to explore quantitative changes in the provision of sediment output from the watershed, we present the erosion effect of increasing frequency and number of extreme precipitation events as represented by a linear increase in the *R* factor (Figure 3).

Size of increments in sediment outputs in each scenario and under different *R* are dominated by land cover change and soil management practices rather than an increase in *R*. However, we acknowledge that our simulated increments in *R* were conservative respect to those found by Aguilar et al. (2005), who identified increases of up to 60% in data from meteorological stations in Central America.

Significant decreases in sediment output are achieved by concentrating soil conservation programs in high risk areas. However it must be acknowledged that we have high uncertainties on how in the future increases in R and upper stream soil management might expand the surface of what is defined as risk areas. Activities such as restoring vegetation cover and implementing soil conservation practices such as water channel control have a high potential to reduce erosion (Cheng, 2002). Each of these two groups of practices has the

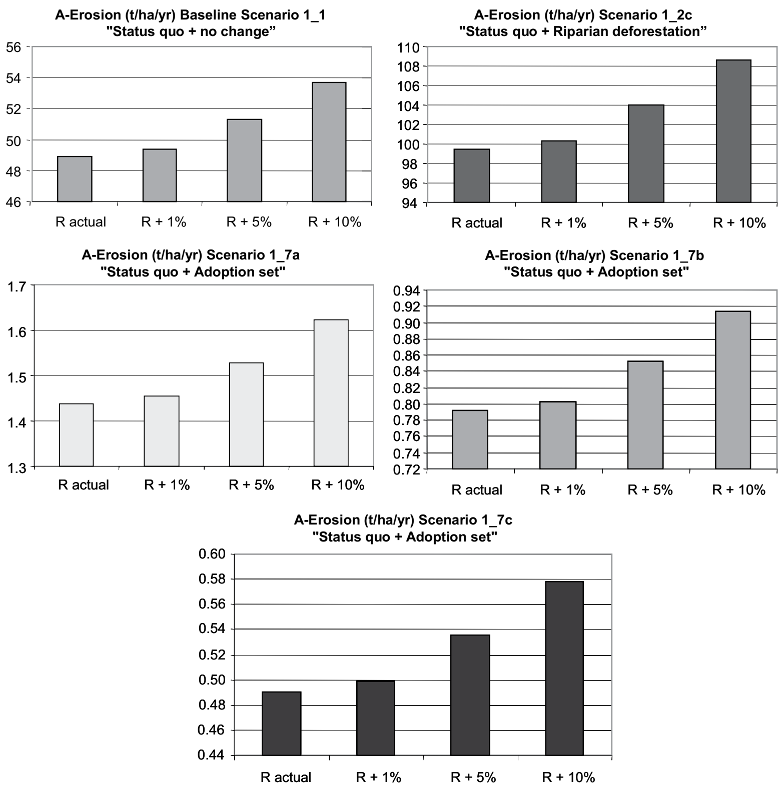

Figure 3. Variation in the potential erosion under linearly increasing R in five different landscape scenarios.

potential to deliver services to additional users. Indeed, if vegetation cover change is achieved through reforestation or natural regeneration, biodiversity benefits can be created. On the other hand, if soil management practices are implemented in key areas, water infiltration is improved so that related recharge of the water table can benefit downstream sectors that depend on quantity and regulation of the hydrological cycle.

Conclusions

The development of landscape alternative scenarios has proven useful identification of priority areas and the potential effect of implementing conservation actions in them. The implementation of a sediment monitoring system is forthcoming and will allow more refined quantification of sediment output from watersheds where ICE is implementing soil conservation actions together with other agencies. However, uncertainties will continue to characterize quantification studies due to poorly known future distribution of climatic events and its interactions with land-use configurations. These depend also on how farmers respond to changes in incentives for sustainable management coming from the market and from conservation programs.

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Impact of Climate Change on Hydrological Ecosystem Functions in Mesoamerica

Pablo IMBACH[1]

Abstract

Terrestrial ecosystems provide an array of hydrological functions important for human well-being. Hydrological regimes will be impacted by climate change through changes in the distribution of ecosystems and the pattern and variability of precipitation and temperature. We aim at evaluating the impacts of climate change on ecosystem hydrological functions in Mesoamerica. For this purpose, we will use a biogeography (MAPSS) and a dynamic vegetation model (ORCHIDEE) to map the potential and actual distribution of ecosystem types and runoff patterns and simulate changes in future climatic scenarios.

Resumen en español

Impacto del cambio clim tico sobre las funciones del ecosistema hidrol gico en Mesoam rica

Los ecosistemas terrestres proveen un matriz de funciones hidrológicas importantes para el bienestar de la raza humana. Los regímenes hidrológicos serán impactados por el cambio climático

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por medio de cambios en la distribución de ecosistemas y en el patrón y variabilidad de la precipitación y la temperatura. Nuestra finalidad es evaluar los impactos del cambio climático sobre las funciones de los ecosistemas hidrológicos en Mesoamérica. Para este propósito, usaremos un modelo biogeográfico (MAPSSS) y un modelo dinámico de vegetación (ORCHIDEE) para trazar mapas de distribución potencial y real de tipos de ecosistemas y patrones de escorrentía y para simular cambios en escenarios climáticos futuros.

SYNTHESIS of Session 5
Hydrological Modelling

Olivier ROUPSARD (CIRAD, CATIE)

Session 5 on the uses of models for evaluating hydrological matters—services (erosion, runoff, quality), water balance and impact of climate change on hydrology, from the plot to the watershed and the region—benefited from four presentations based on current Ph.D. work under development.

F. Gomez Delgado ICE-CIRAD-CATIE	* Spatialization and modelling of water balance components from plots to watersheds in Costa Rica * Effects of agricultural land use and management practices on hydrological environmental services, with a focus on the coffee sector and its alternatives
R. Vignola CATIE	Sediment impacts on hydropower productivity under current and future climate change: The case of Birrís watershed in Costa Rica
P. Imbach CATIE	Impact of climate change on hydrological ecosystem functions in Mesoamerica: Ph.D. proposal
J. Chagoya CATIE	Development of a local scheme of payment for hydrological environmental services using a multidisciplinary approach in a microwatershed located in the subhumid tropics of Mexico

After the presentations, using models to evaluate hydrological services in the context of land use and climate change was debated, as well as the right way to distribute incentives to farmers for the provision of services.

How to evaluate properly the terms of the water, erosion, quality balance in complex landscapes

There is an increasing demand for large scale (regional, continental) and long-term studies and models on forest/agriculture–site–climate interactions. Such extensive applications require robust water balance models using simple soil and stand parameters and basic climatic data, in order to run simulations over many years.

The four Ph.D. candidates presented approaches and results at different scales, from plot to watershed to landscape and finally to region (Mesoamerica). Some works were purely experimental (J. Chagoya), others were purely modelling (P. Imbach) and others were a mixture (R. Vignola, F. Gomez).

At the plot scale, experimental work was based on the terms of the water balance. For the field experimental work, the basis was the general soil water balance equation, includes a total of 10 to 12 parameters (Allen et al., 1998):

$$\Delta\theta = P + Ir + Cr + \Delta SF - In - Ro - T - Es - Dp$$

Where (all expressed in mm): Dθ = variation of the soil water stock; P = precipitation; Ir = Irrigation; Cr = Capillary rises; ΔSF: difference between entering and outgoing lateral subsurface flow; In = Interception; Ro = surface Runoff; T = Transpiration; Es = soil evaporation; Dp: deep percolation

For the modelling work, soil-water transfer models can be classified into three categories (Sansoulet, 2007):

- stochastic models (probabilistic approach, models very specific to the local conditions and poorly transferable)
- functional deterministic models (capacitive models, using two values of soil water content, the wilting point and the field capacity)
- deterministic mechanistic models that couple several phenomenons (deterministic mechanistic models offer the possibility to study interactions among phenomenons or sensitivity to phenomenons.

Some models were currently used by the candidates to predict evapotranspiration and runoff, such as Mhydas (distributed mechanistic model for the scale of a watershed—Moussa et al., 2007), MAPPS a model of evapotranspiration and runoff of climax vegetation (Neilson, 1995), Fisher-Priestley-Taylor, a model of stand evapotranspiration (Fisher et al., 2008a; Fisher et al., 2008b), ORCHIDEE (Krinner et al., 2005), a dynamic vegetation model. Regarding erosion, the general RUSLE equation is very frequently used, although it remains extremely empirical. Also, the CALSITE/STELLA platform was used to estimate total laminar erosion in the watershed (R. Vignola). However, more mechanistical approaches are targeted (F. Gomez). Recent automated techniques for the measurement of turbidity in streams are available (e.g., OBS-3, by Campbell Scientific) and are promising for integrating the time-variability of sediment transport in stream flow.

How to evaluate hydrological services from different land uses and different types of management, e.g., AFS. What is the reference?

Hydrological services span water quantity and regularity of supply (avoiding floods and low flows), water quality (limiting nitrates and other pollutants), erosion reduction (reducing loss of carbon and nutrients), reduction of sediment load (avoiding siltation of reservoirs).

Before starting the modelling exercise, it was clearly necessary to proceed to field experimentation and service evaluation, using specific cases of study.

For scaling-up, soil, cover and climate information is required on a large scale, using maps, surveys and remote sensing.

Regarding the reference scenario, it looks straightforward to consider the current situation as being the baseline and the improved scenario to be compared to the baseline (similarly to CDM Afforestation/Reforestation).

How to adjust the prices paid for the services in order to adjust land use and management

How to distribute incentives for good practices

The question of proper evaluation of the service remains central, although it can also be ignored in many cases. Rather often, farmers from a given watershed receive incentives, irrespective of the true service that they individually provide, simply because no objective evaluation has been made or because it looks easier to manage incentive distribution evenly in a watershed or in a country: for instance, in Costa Rica, FONAFIFO (*Fondo Nacional de Financiamiento Forestal*) simply distributes incentives on the basis of number of trees planted, without truly assessing the service offered by the trees.

Moreover, the incentive may have another target than the sole provision of the service: for instance, incentives can be distributed by the hydropower group not truly in order to reduce erosion but rather to increase the level of acceptance of the hydropower activities by the local population, in spite of its negative secondary effects (on tourism, fishing, river ecology, etc.).

Identification of priority zone from a biophysical point of view, as debated, i.e., zones where the watershed is physically particularly sensitive for the expected provision of service. Should the service be paid evenly to all farmers of the watershed, irrespective of priority zones, or should farmers from priority zones benefit from larger incentives?

Is the objective/scientific evaluation of the service about helping distribute the incentives in proportion to the true service provision or to help service providers (farmers) and service buyers (hydropower companies, tourism agencies, etc.) in negotiating the price of the service.

In conclusion, objective evaluation of the services is certainly lacking, and is a true scientific subject; however, to date, there is little evidence of the use of this objective information for coupling providers of a service and buyers of a service. The CDM has for long remained extremely unefficient in crediting afforestation/reforestation projects, due to highly complex organization. Is this the example to follow for other services, or is it more efficient to distribute the incentives more easily?

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CONCLUSIONS and PERSPECTIVES of Modelling Agroforestry System in Mesoamerica: Specificities, New Issues and Further Orientations

Jean François LE COQ,[1,3] Bruno RAPIDEL[1,2] and Muriel NAVARRO[2]

Introduction

The objective of the workshop, as referred in its subtitle "Connecting Agroforestry Researchers with Modellers," was to identify the modelling and database needs in order to make relevant models available to agroforestry practitioners. For this purpose, many models have been presented, of different kinds, related to different disciplines, applied at different scales and with different objectives. This wide range of existing experiences documented by participants gives us a broad picture of what could be useful for the purposes of the Mesoamerican Platform of Agroforestry Systems (PCP).

The need for interdisciplinarity in agroforestry science is one of the biggest challenges of the PCP. This challenge also concerns the development and use of models in agroforestry. For example, to facilitate the development of innovations, the models need to take into account the structural complexity of agroforestry plots (biophysical sciences) along with the specificity of perennial plant management to be able to facilitate farmers' strategic decisions (socioeconomic or decisions based in science).

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Integration across scales is another huge modelling challenge. Due to the complexity of rural development issues and the changes in governance, today it is not possible to consider only the farmers in the development of agricultural activities. Other stakeholders need to be included, such as farmers' organisations, municipalities, firms, city dwellers, tourists or consumers. The integration of these different stakeholders requires the consideration of different scales from the plot or the farm to the watershed, region (territory/landscape), country or even the Central American region.

In this paper, we propose to sum up the contributions presented during the workshop in order to address these challenges. We will first present the specificities of the agroforestry system (AFS) for modelling, focusing on the AFS of Mesoamerica.[4] In a second part, we explore the needs for modelling of AFS by taking into account AFS specificities and the new stakes that emerge. Finally, we will try to answer the main questions of the workshop: What models are available today? What models do we need to develop to meet these challenges? We conclude with the gaps that we identified between actual modelling activities and needs to cope with pending issues, and propose orientation for PCP teams in AFS modelling activities.

What are the specificities of AFS in Mesoamerica for modelling?

General characteristics of AFS

Agroforestry systems are characterized in general by their complexity: different species are present in the same plot. Most biophysical models that simulate crop growth and development rely on the common simplifying assumption that the crop is horizontally homogeneous and can be analyzed along the vertical dimension uniquely. This assumption is evidently no longer valid for AFS.

AFS based on perennial crops have further specificities: most management decisions have multiannual effects. Cash flows are essential

[4] By Mesoamerica, we consider the region from South of Mexico (Chiapas) to Panama. Its includes Honduras, Salvador, Belize, Nicaragua, Costa Rica and Panama.

to consider, as many improvement strategies suppose investments whose benefits will be obtained years later.

AFS in Mesoamerica

AFS are frequent in Mesoamerica. They concern mainly three major crops: coffee, covering up to 2 million hectares; cocoa, much less extended but present in environmentally and economically sensitive areas, and bananas and plantains (*Musa spp.*) used for shade in coffee and cocoa AFS, or in some cases, cultivated in AFS under the shade of bigger trees. This paper will focus on the two first perennial crops: coffee and cocoa.

The first specificity of AFS in Mesoamerica is that they are structured around one main species, mainly coffee and cocoa, which have high added value and that make the central axis of the system. Economic incomes from the surrounding species, although sometime essential for the survival of the whole system, come in a second position after the main crop.

The AFS in Mesoamerica are diversely managed. Intensively managed systems, such as coffee plantations shaded with *Erythrina spp.* or *Inga spp.* trees pollarded twice a year coexist with agroforests, i.e., half-cleared forests to allow coffee or cocoa crops to grow. Intensively managed AFS are more much more frequent for coffee than for cocoa (Beer et al., 1998). Cocoa is a traditional crop of indigenous communities. In Mesoamerica, the institutional support to the cacao-based AFS producers is less developed than the coffee-based AFS producers.

Both coffee and cocoa crops retain high cultural values, although the references are clearly different. Cocoa has its origin in Mesoamerica, and is embedded in indigenous culture. Coffee introduction is relatively recent compared to cocoa. Nevertheless with about two centuries of introduction, it has had profound effect on the economic and cultural history of Central America. In general, coffee producers are more economic oriented than cocoa producers. For many indigenous cocoa producers, the cocoa trees have a sacred status, and its cropping has many other goals than solely income generation.

The main cash crops of AFS are exposed to a high pressure of pests and diseases (Staver et al., 2001). The berry borer, American leaf spot and rust are the most important ones for coffee in the Mesoamerican region. Moniliasis is at present the most important disease of cocoa. In both cases, significant efforts are dedicated to the control of these pests and diseases, either by breeding varieties, by reducing their incidence in the field through crop management or by spraying pesticides, both organic or nonorganic. AFS management has to take these pests and diseases into account, either because shade may have direct effect on a disease development—as occurs with American leaf spot (Avelino et al., 2007)—or because associated trees may host natural enemies (Perfecto and Vandermeer, 2006).

Coffee and Cocoa are mainly produced for exportation. Thus, producers are exposed to the price variations on international markets and this factor can affect AFS evolution. The sensitivity of the coffee sector to price variations is put in evidence in the yield evolution: in times of high prices, yields tend to increase because producers spend more effort and resources on their coffee plantation than in times of low prices.

Finally, the value chain of the main cash crop (coffee or cacao) of the Mesoamerican AFS is being rapidly modified by environmental signals. Coffee is probably the most dynamic sector in this respect. Following market demand, a large variety of private seals have been developed that incorporates extrinsic value (environmental, ethical, etc.) in addition to the classical intrinsic value of the product (quality, taste, etc.). Certification urged the coffee shade management, which supposedly improved both the coffee cup quality and other feature (biodiversity conservation or carbon sequestration). The same tendency exists in the cocoa value chain, with a high presence of organic cocoa.

What are the needs of modelling for Mesoamerican Agroforestry Systems?

Uses of modelling in agriculture

Past experiences have shown that modelling has been a useful approach to different issues and users. Crop simulation models have been used primarily as research tools to (1) identify gaps in scientific knowledge; (2) generate and test hypothesis, as an support to the design of experiments; (3) determine the most influential parameters of a system; (4) communicate between researchers from different disciplines, and (5) bring researchers, experimenters and producers together to solve agricultural problems (Selingman, 1990). Applications of crop models in tropical agriculture have been reviewed by Matthews et al., (2002). They identified practical applications at numerous scales of intervention: for plant breeding (e.g., identification of desirable plant characteristics), for crop management options (e.g., water or nutrient management), for cropping system design, for farming systems and rural livelihoods, for regional and national planning (e.g., land-use planning, and for environmental research (e.g., climate change impact assessment).

Models have been developed also in human sciences to propose simplified views of reality and to facilitate decision making. Modelling has been developed at numerous scales of intervention: for income options for farmers and for simulating the impact of policy decisions at national or regional or even international level (Le Coq et al., in this book).

The main function of modelling activities for researchers (whatever discipline) has been to facilitate the identification of knowledge gaps to fully understand system functioning. For final users (development partners, producers, extension workers, private organizations, public institutions, etc.), the models have to facilitate decision making through simulating future outcomes from current decisions.

New global issues and new specific needs in modelling of AFS

In recent years, new global issues have arisen, and new specific modelling needs appear to cope with these issues in AFS (Figure 1):

ß the Global Climate Change (GCC) leads two distinct issues: i) how AFS can better participate to mitigate climate change and ii) how AFS can adapt to climate change. Mitigation issues put emphasis on the capacity of AFS to sequester carbon. Adaptation issues raise questions about the identification of innovations in AFS management to cope with (and eventually benefit from) the coming changes in temperature, partial pressure of CO_2, frequency of extreme climatic events and rainfall patterns.

ß the energy crisis characterised by the end of the era of cheap oil and the rise of alternative energy sources. This new situation and perspective raises two specific issues for AFS: (1) how to produce with less fossil (often imported) energy (oil) or inputs derived from fossil resources (mineral fertilizers and agrochemicals) and

(2) how to optimize the capacity of AFS to produce energy (biofuels such as firewood, etc.).
- ß the food security or food sovereignty concern, brought to the foreront by the 2008 world food crisis. This concern questions the role of local agroecosystems to provide a part of the diet in staple foods or diversified foods for the poor population in general and in particular when food prices increase. This raises the following specific issues: How can AFS better contribute to the provision of food for local consumption (in quantity, quality and diversity)?
- ß the increase in competition between producers all over the world as well as the modification in the market demand leads to two interlinked issues: i) in a context of vanishing trade barriers and economic liberalization, how can productivity, efficiency or quality in AFS be increased to stay competitive in global and niche markets and ii) in a context of emerging demands coming from new concerns from consumers and society in terms of food safety and environmental impacts of agricultural production, how can AFS be managed to provide safer products, farm economic sustainability and protection of the environment.

To cope with those new issues, AFS have to face two main challenges: adapt to environment changes and produce more or better new outputs (Figure 1). Those new challenges for AFS call for new AFS modelling needs:

1. include new parameters of the environment that may affect the functioning of the AFS (such as new ranges of temperature, CO_2 atmospheric concentration, inputs prices, rainfall, etc.)
2. diversify the output variables in order to take into account the new demands of society

Dealing with the global issues mentioned in Figure 1 not only asks for inserting new input parameters (to deal with environment changes) and diversify output variables (to integrate society's new demands) but also asks for major integration of various scales. This is of particular importance for estimating the contribution of AFS to the provision of environmental services (ES). Provision of ES results from plant functioning and AFS local features, but they need to be evaluated at a larger scale (landscape for biodiversity, watershed for hydrological services, etc.) to be relevant with the scale at which relevant stakeholders make decisions (community, institutions, private firms).

The other consequence of the issues mentioned above is the need for integration among disciplines. The variations of different parameters of different natures (e.g., change in CO_2 concentration and change in market demands) could have complex interactions.

Finally, the necessity to deal with new global issues and with new actors having various forms of decision-making processes and of governance asks for a plurality of representations. Models may by used to facilitate consensual decision making among multiple stakeholders, often with contradictory objectives. Thus models should be developed that are able to produce multicriteria and multiple scale outputs.

What are the existing AFS models and tools to develop those models?

Synthesis of the existing AFS models: Main characteristics

Many models or model types have been presented during this workshop. We propose a synthesis of the main characteristics of the models

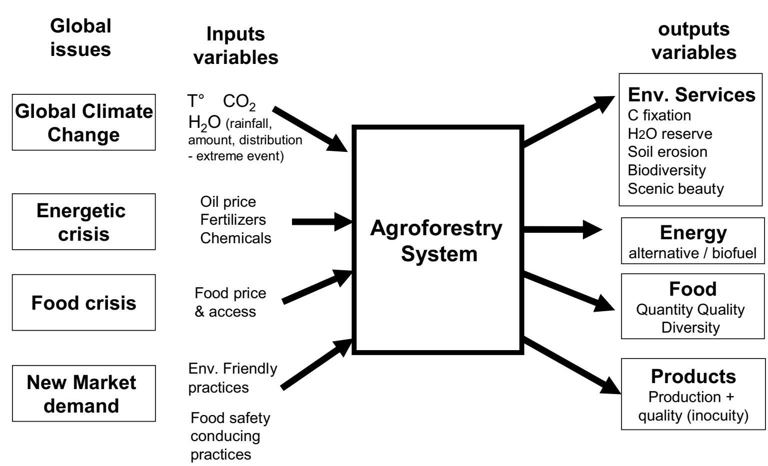

Figure 1. The new global issues and the variables to be considered in AFS modelling
Source: Authors

presented during the workshops (Tables 1a, 1b and 1c). We focus here on some features such as the type of model, the main discipline involved, the main scale of output, the range and number of scale integrated and considered in the model and the users.

Synthesis of the existing AFS models: Limits and advantage to cope with the global issues identified

As a transversal effort, Table 2 puts in perspective the presented models with the issues identified in order to see limitations and advantages of potential application or use of the presented model to integrate the issues presented above.

Main categories of the models presented

We developed a qualitative graphical representation of the models presented during this workshop to synthesize the scales and domains considered by the different models and tools presented. On the vertical axis, the different scales range from plant to international; on the horizontal axis, we display the main domains considered (Figure 2).

Using this representation, we can distinguish three broad categories of modelling experiences and models.

The first category (C1, Figure 2) brings together the biophysical thematic models. These models were the most represented during the workshop. They are centred on plant or ecosystem functioning. Their scientific domain is well-defined, like hydrology (Gómez et al., Session 5), physiology (Franck and Montes, Session 1), ecology (De Clerck et al., Session 3) or entomology (Avelino, Session 1). These models are able to integrate different scales from plants to watershed, landscape or region. For these models, AFS specificities, such as shade effect, complex interaction between plants, human effect of pruning, etc., are important issues. These models offer output variables such as carbon sequestration, erosion level, biomass production, local biodiversity index, pest level. These modelling activities are likely to be useful to evaluate the contribution of AFS to the provision of environmental services.

The second category (C2, Figure 2) brings together the socioeconomic thematic models. These models are developed to deal with issues of market liberalization and evolution of economic policies (such as free

Table 1a. Characteristics of some biophysical models presented during this workshop.

Name of the model	Discipline	Description of the model	Type of model	Goal of the model	Object	Range of scales considered	Users
APSIM: Agricultural Production Systems Simulator (N. Huth: Session 1)	Agronomy	Modular simulation platform that includes mainly annual crops to be simulated in rotations. Considers also trees.	Process-based crop model Simulation/ Prescriptive	Management control for decision support	Cropping system	From plot to farming system	Researcher, Farmer, Developer
CASTANEA (G.Le Maire:	Agronomy	Carbon & water balances model adapted to forests	Process-based forest stand model	Decision support on stand management and assessment of climate change impacts	Forest stand	Forest stand up to large forest	Researcher
	Phyto-pathology	Predictive – simulation model	Mechanistic & Regression model	Predictive assessment of the incidence of coffee rust	Disease development	From molecular to plot scale	Researcher
APES: Agricultural Production and Externalities Simulator (E. Casellas: Session 3)	Agronomy	Modular simulation model inserted in a chain of models, including a farm model and a General Equilibrium model	Process-based crop model	Assessment of Integrated analysis of impacts on wide range of sustainability + Multifunctionality	Agricultural production systems	Agricultural plot	Researcher
CAF2007 - Casca Project (M.Van Oijen: Session 3)	Agronomy	Biophsysical dynamic model that simulates coffee growth and development in agroforestry systems	Process-based agroforestry model	Decision support on agroforestry system management	Coffee AFS	Agroforestry plot, up to watershed	Researcher

Name of the model	Discipline	Description of the model	Type of model	Goal of the model	Object	Range of scales considered	Users
FUNCONN and developments (A. Sanfiorenzo: Session 3)	Ecology	GIS-based model, based on land-use databases and allometric relations to evaluate the landscape effects on bird diversity	Statistical spatial model	Assess the suitability of landscape for bird life and movements	3 species of bird	Plots and landscape	Researcher
OLYMPE	Agronomy and Economy	Model based on a database on farm activities and outputs that simulates the farm (and farm groups) functioning and the possible outputs of management decisions	Farm management simulation model	Diagnostic, prospective analysis and decision making.	Cropping and Farming systems	From crop to farm and groups of farms	Researcher, Developer Decision makers
Shade Motion (F. Quesada: Session 3)	Agroforestry	Physically based model that simulates the shade cast by trees on the ground, depending on plot characteristics.	Simulation software	Modelling the position and movement of tree shadows on the ground	AFS plots	Plot	Researcher Developer, Producer

Table 1b. Characteristic of some socioeconomic models presented during the workshop.

Name of the model	Discipline	Description of the model	Type of model	Goal of the model	Object	Range of scales considered	Users
GTAP Global Trade Analysis Project (J-F. Francois et al. - Session 2)	Economy	A standard static model applied on GTAP database that simulates possible impacts of Cafta on economic features of Centro American countries	Standard static model Macro economic Predictive model	Decision support on regional trade policy setting	National economies	National to Regional	Policy makers
PLS modelling (Partial Least Square)	Economy	Analytical model that integrates human, technical and financial resources, mental models and trajectories of farmers' organisation		Explain farmers' organizations strategic behaviours and results in policy design	Farmers' Organization	National	Researchers
Microeconomic model (G. Navarro - Session 2)	Economy	Analytical model to evaluate economic incomes (using land expecting value) of various AFS practices	Micro economic, analytical model	Analyzing the conversion of perennial agricultural crops into joint production AFS	Production system	Agricultural plot	Researchers Farmers Developers
Non-linear integer simulation model (F Saenz-Session 2)	Economy	Maximization model of the income of the firm and farmers under various market conditions	Non-linear integer simulation model	¨Predict the price level and the institutional arrangement	Farmer and organisation	Plots to commodity chain	Researchers

Table 1c. Tools for Land Use Analysis (adapted from Saenz, in this book).

Name of the model	Description of the model	Type of model	Goal	Scale
CLUE	Projection of likely future trends in agricultural land use	Statistical (regression, GIS) Projective	Likely future developments in land use (what, where & when)	National & Regional
	Medium-term exploration of the effects of bio-physical and socioeconomic constraints	Bio-economic (LP, GIS) Exploratory	Quantification of trade-offs between policy goals ('policy space')	Regional
UNA-DLV	Short-term prediction of policy effects on farmers' land use decisions	Bio-economic (expert systems, LP, econometrics, GIS) Predictive	Effectiveness of policy measures to induce adoption of desired land use systems	Regional
SEM	Short-term prediction of policy effects on land use, associated trade flows and welfare	SEM (LP, econometrics) Predictive	Quantification of policy effects on level and distribution of societal welfare	National
BANMAN	Complementarity between economic and bio-physical sustainability	Precision farming (GIS + field experiments) Proto-typing	Adjustments in farm management Input-output relations of precision agriculture	Farm
TCGs	Provide building blocks for agricultural land use models	Expert systems (process-based and expert knowledge, literature, field experiments) Generation of land use systems	Quantification of input-output relationships for large number of land use systems	Field

Table 2. Estimation of the capacity of the models to cope with the emerging global issues

Emerging issue to deal with	**APSIM**	**CASTANEA**	**NSRMP**	**APES**	**CAF2007**	**FUNCONN**	**OLYMPE**	**Shade Motion**	**GTAP**	**Micro economic model**	**Non linear integer simulation model**
GCC	XX	XX	-	XX	XX	-	X	-	-	X	-
Energy	X	X	-	X	X	-	XX	-	-	X	-
	-	-	-	-	-	-	X	-	XXX	X	XX
Food crisis	X	-	-	X	-	-	X	-	XX	X	X
Integration of scales	X	X	-	X	-	X	-	-	X	X	-
Integration of disciplines	X	-	-	X	X	X	XX	-	-	-	-
Plurality of representations	-	-	-	-	-	-	X	-	-	-	-

XX: the model is able to deal with the issue in its current form
X: the model can bring some elements regarding the issue
-: the model is not suited to deal with the issue

trade agreements, François et al., Session 2), farmers' organization strategy (Maitre d'Hotel et al., Session 2; Saenz, Session 2), farmers' decisions in management (Navarro et al., Session 2). They are not specific to AFS. Their outputs are economic or sociologic variables such as incomes, at different levels (farmers, farmers' organizations, countries). The models of this category are used to understand the behaviour of actors or to support them in the decision-making process.

A third category (C3, Figure 2) brings together the disciplinary integrated models**.** These models tend to integrate the different dimensions of biophysical outputs and up to economic results at a farm level. There output variables are usually yields, production, incomes. They tend to be more pluridisciplinary than the models of categories C1 and C2, as they are mainly based on the agronomic system approach and allow integration beyond the farm household level. They are useful to help producers' crop management. The best example of this category is the APSIM platform (Huth, Session 1), one of the few agronomic models actually used by farmers to adjust their crop management. Castanea and APES (respectively Le Maire, Session 1, and Casellas, Session 3) would enter into this category. One of the current challenges of these models are to include the central AFS crops in Mesoamerica (case of cocoa) or to be calibrated and tested (case of coffee, where a model, CAF2007, exists but is not yet calibrated or tested). These modelling activities are likely to be useful to address issues such as global climate change and, to some extent, food security.

A last category consists of multithematically integrated platforms (C4, Figure 2). These platforms integrate ecosystem functioning models (some aspects of the C1 models), farmer practices and production models (C3), and economic results at local and regional level

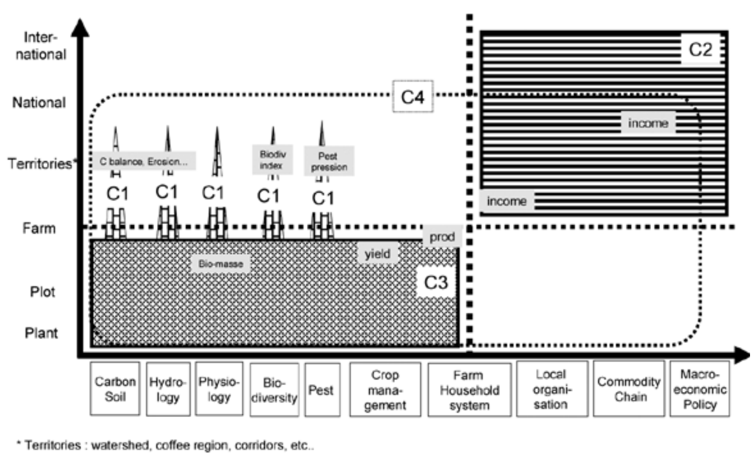

Figure 2. Main categories of models and tools according to scale range and objects.

models (C2). In this category, we can mention the Olympe experience (Deheuvels and Penot, Session 3) that enables aggregatation of economic and externality results at different levels from parcel to regions. Other experiences include, to some extent, the extensions of the CAF2007 model (GIS connection) and the FLORES experience presented in this workshop by F. Sinclair, modelling the interactions among people, agricultural activities and landscapes (Vanclay et al., 2003). These two experiences have in common that they were built using modelling platforms: Simulink (http://www.mathworks.com/products/simulink) and Simile (http://simile.mit.edu), respectively. Other experiences of such integrations have been reported using multiagent system models. They were usually developed on a modelling platform like Cormas (http://cormas.cirad.fr) (Bousquet and Le Page, 2004; Castella et al., 2005; de Koning et al., 2007). All these experiences have in common using platforms to develop a model targeted at a definite outcome (how to manage floods in a watershed, for example).

This synthesis of models presented in the workshop shows a wide diversity of scales and domains. Nevertheless, a gap remains around the nodal point of farm household level (Figure 2), which represents the level where decisions of management practices are taken. This is a junction point between biophysical and socioeconomical modelling. Further efforts are to be developed to better grasp farmer decision rules and especially the trade-off considerations between rising productivity and increasing environmental services (ES).

Finally, few presented models have been developed to facilitate interactions of stakeholders at different scales, such as producers, farmers' representatives, enterprises, municipalities, etc. In this sense, further attention should be given to land use models (Saenz, in this book) or multiagent system modelling that would link spatial dynamics (like new emerging issues) with stakeholders' decisions. They could give elements on the issues of the evolution of land use according to market forces or payment forenvironmental services mechanisms settings. Thus, they could contribute to the setting of more effective mechanisms of land management from plots to territories.

Conclusion

In this paper, we examined the specificity of Agroforestry Systems (AFS) with perennial crops and the needs for modelling due to new global issues, and we compared these to the spectrum of models presented during this workshop. We have stressed several needs in AFS modelling: interdisciplinarity, integration of scales and multitype performance assessment. Nevertheless, none of these goals is easy to meet, and the attempts to reach several of these goals, which may be contradictory, generate tensions.

Building more interdisciplinarity has been called upon for decades without obvious results. It seems that the first impediment comes from difficulties of achieving that scientists from different disciplines understand each other: references and different words do not have the same meaning, etc. A second difficulty arises from possible incompatibilities between specific models; communication between models is not simpler than between scientists.[5]

Therefore, it is essential to evaluate where multidisciplinary models are required in each particular case, as there is a trade off between interdisciplinarity and time efficiency due to inherent difficulties raisin from complexity and disciplinary dialogue.

Integration of scales has long been discussed. As a rule of thumb, it is accepted that integration of three scales in a model is a maximum. For example, it could be useful to integrate from leaf scale to canopy (Baldocchi and Harley, 1995). Further upscaling is considered problematic. It has been proposed that when complexity (e.g., number of parameters) increases, the model outcomes reaches a maximal precision before decreasing again, due to accumulation of errors (Passioura, 1996). Scale integration probably is more successfully achieved by using different models at different scales, as it has been done, for example, in the Seamless experience[6] in Europe for a scale integration from the plot up to European Union (van Ittersum et al., 2008).

[5] This point was discussed in the paper of Casellas et al. on APES, this volume.
[6] As a part of this Seamless project, see APES presented in this volume.

The multiperformance assessment or multicriteria output goal seems easier to meet. Nevertheless, it needs that some solutions have been given to the two challenges mentioned above: the assessment of different types of performances frequently asks for the mobilization of different disciplines and the integration of different scales. A specific trade-off exist regarding this goal in modelling: when the number of performances considered by the model increases, it is usually at the cost of the model intelligibility.

As a conclusion concerning theses challenges, we can only state that the best strategy should be to evaluate the needs with precision to choose the best compromise for each situation.

Another question raised during this workshop concerns the debate between using existing models versus developing new models. The first option, using an existing model, calls for improving modularity and adapting the model to each case. For example, the APSIM platform presented during this workshop answers to this modularity. This option is the best one to capitalize on models. Nevertheless, it seems to be easier when disciplines and scales are sharply focused. RECORD (berguez et al., 2007) is an interesting project of platform development to facilitate models connections (i.e., from crop to decision models scaling from plot to farm). It seems that when integration of disciplines and scales is pushed further, developing new models may be more effective. In this case, the use of a user-friendly development model platform such as Simulink, Simile, Cormas appears to be very convenient.

As a final topic, several participants raised the importance of a database to build, parameterize and check the models. This critical point was illustrated by M. Van Oijen et al., who confessed their great difficulty in parameterizing their agroforestry coffee model.

Thus, in term of biophysical AFS modelling, one of the most vivid challenge for the Mesoamerican Platform (PCP) could be to list and make available all the existing databases from the researches on AFS in Mesoamerica, with a focus on data about coffee and cocoa physiology and shade tree characteristics.

Regarding the sort of model that is lacking, this synthesis shows that efforts are required to address the farm household scale: this is the scale where many decisions on land management are made, but this is also the scale where models are less present.

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