CIRAD / IRD / AIRD PROJECT

Drafted: 31 March 2012

Search for trade-offs between production and other ecosystem services provided by agroforestry systems (SAFSÉ)

Main document

Contents

CIRAD/IRD/AIRD **Drafted: 31/03/2012**

PROJECT SHEET

TITLE: **Search for trade-offs between production and other ecosystem services provided by agroforestry systems (SAFSÉ).**

KEYWORDS: Provisioning services, support and regulation services, agroforestry system composition and structure, stakeholder dynamics and strategies

CONTACT INFORMATION:

Jean-Michel Harmand for **CIRAD**,
UMR Eco&Sols - Ecologie Fonctionnelle & Biogéochimie des Sols & Agroécosystèmes - (Montpellier SupAgro–CIRAD–INRA–IRD) 2 Place Viala (Bat. 12)
34060 Montpellier cedex 2, France
Telephone: 33 (0) 4 99 61 21 68
CIRAD secretariat: 33 (0) 4 99 61 30 46
E-mail: jean-michel.harmand@cirad.fr

Josiane SEGHIERI for **IRD**
UMR HSM - HydroSciences Montpellier (CNRS-UM1-UM2-IRD)
Place Eugène Bataillon - CC MSE
F-34095 Montpellier cedex 5, France
Telephone: 33 (0) 4 67 14 90 72
Fax: 33 (0) 4 4 67 14 47 74
E-mail: josiane.seghieri@ird.fr

SUMMARY

Agroforestry systems (AFS), which are expected to be environment-friendly and to guarantee food security through crop and income diversification, appear to be a promising model for sustainable agriculture in developing countries. However, optimum management of AFS will be only possible with a better understanding and control of production factors. The project proposes to analyse trade-offs and synergies between provisioning services (production) and the other types of ecosystem services (support, regulation) provided by AFS. By enhancing knowledge of the biophysical and socio-economic mechanisms underlying the functioning and dynamics of AFS, the project intends to provide a generic basis for optimizing trade-offs between production and other ecosystem services in order to help increase the resilience of these agro-ecosystems and the societies that depend on them.

Studies will be undertaken in contrasting situations, (i) in the humid tropics, on multi-strata AFS with perennial crops (principally cacao and coffee), (ii) in a dry region of sub-Saharan Africa, on the tree and shrub parklands supporting cereal-based rotations.

The project will establish a shared conceptual framework that will be structuring for the communities of researchers from CIRAD, IRD, their national partners in France, and other partners in the South, relying on collaborative research facilities already existing in partnership.

1. Issues and justifications

Agroforestry is a set of land-use practices based on the simultaneous or sequential association of woody perennials including trees, shrubs, palms and bamboos with agricultural crops and/or pastures and animals. For centuries it has been one of the traditional land-use practices on every continent, particularly in the tropics. Agroforestry can be considered as a promising sustainable agricultural model, provided production factors are better understood and more effectively controlled. Indeed, although agroforestry systems (AFS) have often been criticized for their lower agricultural production than monocultures, the contribution of AFS to global production and development in tropical zones is significant according to the large agricultural areas they occupy and the dependence of many rural societies on them.

AFS offer different assets when compared to monocultures, whose environmental and health impacts, and socio-economic vulnerability are likely to severely limit future progress. In general, agricultural systems are sources of ecosystem services, but also of "disservices" (loss of biodiversity, agrochemical pollution, nutrient runoff, sedimentation of waterways, greenhouse gas emissions) (Power, 2010). Compared to monocultures, AFS modify the balance between the provision of ecosystem services and "disservices". Moreover, they are less input- and energy-intensive and combine ecological services and diversified production, while procuring land security. In AFS, **provisioning services** are impacted by modifications to the basic crop yield and by new productions that contribute to diversifying producer incomes, and to ensuring their food security. AFS contribute to **regulating services**, particularly by controlling the water cycle and water quality, regulating the climate by controlling GHG emissions and storing carbon. Also, depending on their composition, structure and management, AFS can make a great contribution to services that support the other services. These **support services** include: primary production, regulation of pests and diseases, soil conservation, regulation of nutrient cycling and the water cycle, biodiversity preservation. They also procure **cultural services** that benefit the community. Therefore AFS appear as a production mode that is potentially stable over time and resilient to environmental changes (climate change) and market globalisation. They thus seem to provide greater security than monocultures for the rural communities that practise them and for the consumers who depend on them. Agroforestry would therefore seem to be one of the solutions required in taking up the challenge for the ecological intensification of agro-ecosystems (producing more and better with few inputs). Thus, AFS possess major potential for improving productivity that has yet to be widely explored, notably in the field of:

- optimizing tree/crop interactions for better use of natural ressources and crop diversification,
- developing varieties adapted to agroforestry conditions,
- pest and disease control with or without pesticides,
- maintaining biodiversity that is of use to primary production and environmental services,
- the vulnerability of systems in the face of disruptions.

The "SAFSÉ" project proposed here fits in with the current growing interest in agroforestry as an answer to the major challenges facing tropical countries: poverty, food insecurity, climate change, land degradation, loss of biodiversity. Indeed, little is yet known about the mechanisms underlying the assumed resilience of AFS. One of the main reasons is the fact that they probably differ in nature and scope depending on whether one considers the resilience afforded by the facilitation/competition relationships in the biophysical system at the plot scale or that afforded by structural diversity and flexibility on a farm or territory scale, which is itself linked to socio-economic constraints. Another major reason lies in the fact that public agricultural policies in tropical zones have shown little consideration to date for agroforestry, due to the fact that it is traditional, often preferring to focus their actions on food or cash monocultures, or else ignoring the tree component in such systems. In the humid tropics, tree crop-based AFS are very widespread. There exists a whole complexity gradient in these systems, along with a management intensity gradient. In the dry regions of sub-Saharan Africa, tree and shrub parklands are also the basis of a food crop agriculture that is still particularly precarious. In these two regions, AFS exhibit contrasting dynamics and involve locally a wide range of stakeholders and practices in diverse contexts. It is this diversity that the "SAFSÉ" project intends to examine and conceptualize, by bringing together teams from CIRAD, IRD and their national partners with sound experience of these environments. The expected results should shed light on the choices of stakeholders and decision-makers in these regions between immediate food security, whose sustainability is undermined by high vulnerability to global changes, and food security over the longer term, through autonomous and diversified production contributing to increased resilience of the agrosystems and the societies that depend on them.

2. State of knowledge

Coffee-based agroforestry systems in humid zones:

Apart from Brazil, coffee AFS account for over 70% of the coffee plantation areas in the world's producing regions, despite the promotion of monocultures by agricultural research and extension services during the last decades of the 20Th century (Vaast and Harmand, 2002). The range of systems includes complex AFS in which coffee trees are associated with a mixture of banana, forest tree species, fruit trees and food crops, and more intensified systems with specialized shade, comprising one or more forest species, usually legumes and/or timber and firewood species.

These coffee systems play a part in structuring the landscape in the regions covered by this study, with areas estimated at 900,000 hectares in Central America and 2,000,000 hectares in East Africa (FAO 2012). Arabica (*Coffea arabica* L.) based AFS, which are mainly located in fragile mountain zones (800-1500 m asl) with abundant rainfall (1500- 5000 mm/year), help to conserve soils by limiting erosion and assist aquifer replenishment (Gomes et al., 2011). Their tree stratum increases the connectivity of forest landscapes (Mesoamerican biological corridor), plays a buffer role around natural reserves (Rungwe mountains and Kenya) and provides a habitat for wildlife (Vaast et al. 2005). In addition, these AFS help to diversify farm incomes through the production of timber and firewood, helping to reduce the pressure on forests, and sequester substantial amounts of carbon (Hergoualc'h et al, 2012).

Shade intensity and its distribution are determined by the specific composition and structure of the tree strata inside the plot and influence the performance of the coffee trees (Soto Pinto, 2000; Somariba et al. 2004; DeClerk et al. 2006). In general, the shade trees reduce coffee yields compared to monocultures under optimum conditions and under intensive management due to the negative effect of shade on flowering (Harmand et al. 2007; Vaast et al., 2007; Siles et al, 2010). However, their effects are beneficial when compared to a monoculture under sub-optimum ecological conditions and/or an absence of fertilization (Vaast et al, 2007). Shade reduces inter-annual variability and increases the productive lifespan of coffee trees (Beer et al 1998), whilst improving bean quality compared to monocultures (Vaast et al. 2005).

Shade also has contrasting effects on pests and diseases. Trees form a rain barrier making it possible to reduce the incidence of a disease such as coffee berry disease which is dispersed by rain (Mouen, 2010). On the other hand, the microclimatic conditions created by shade seem favourable to the development of several pests and diseases such as coffee berry borers *(H. hampei)* (Bosselmann et al., 2009) or American Leaf Spot (*M. citricolor)* (Avelino et al., 2007)..

Many studies have shown the positive effects of trees in terms of increasing organic matter in soils and their nitrogen richness through symbiotic N_2 fixation by legume trees, and improving nutrient recycling (Beer 1987; Barradas and Fanjul 1986). However, further knowledge is needed about how trees affect soil biology and their contribution to nutrient bioavailability. Water consumption is greater in AFS than in monocultures due to the surplus evapotranspiration of the associated trees, which can lead to competition for water with the shaded coffee trees, especially in the occurrence of prolonged dry seasons (Cannavo et al., 2011).

This project will contribute to a better understanding of the effect of trees and of pedoclimatic factors on the yields and ecosystem services provided by these systems, and will make recommendations for tree canopy management and agricultural practices to promote trade-offs enabling sustainable management of these AFS.

Cacao-based agroforestry systems in humid zones:

These systems, in which cacao trees are associated with numerous perennial species, forest trees and fruit trees, with multiple uses, are found in Brazil (Ruf and Schroth, 1995), where they are also known as *cabrucas*, but also in Indonesia (Juhrbandt et al., 2010), Nigeria (Oke and Odebiyi, 2007), Ghana (Asare and Tetteh, 2010) and Cameroon (Laird et al., 2007, Sonwa et al., 2007).

However, little is known about the functioning of cacao-based AFS as they have generally been overlooked, or even criticized, by agronomists mainly due to their low yields of fermented dried cocoa. It is also true that these generally complex systems remain difficult to assess due to the methodological problems arising when evaluating the species that make them up, whose uses, nature of the harvested products or the services provided, and development cycles are different (Nair, 1993). In certain cases, some species have several uses, some of which, notably ecological, are difficult to quantify and raise the question of the common unit to be adopted (Huxley, 1999).

Most of the recent analyses of cacao AFS have mainly focused on their environmental impact in terms of biodiversity conservation, maintaining soil fertility and carbon sequestration (Schroth and Harvey, 2007; Dawoe et al., 2010; Gockowski and Sonwa, 2010). In central Cameroon, several descriptive studies have focusedon the degree of biodiversity in these systems through inventories of the species associated with cacao and their uses (Zapfack et al., 2002; Sonwa et al., 2007). Uses of the most frequently encountered species have thus been listed; many species , while providing shade to cacao trees, procure for farmers a multitude of products (fruits, wood, leaves, bark, etc.), which are marketed or not, and which are involved in the self-sufficiency and food balance of households, the pharmacopoeia, the construction of dwellings and farm liquidity. Other work focused on soil fertility (Snoeck et al., 2010) or on the link between the structure of these systems and their degree of intensification (Bisseleua and Vidal, 2008).

Despite all their merits, these analyses do not enable an overall evaluation of these systems and provide little information about their management, notably regarding trade-offs realized by farmers. In addition, very little work has been done on the functioning and management of the cacao strata in complex agroforestry systems and all the technical references seek to optimize cacao tree productivity in barely diversified systems and monocultures (Wood and Lass, 1985). By identifying the factors involved in cocoa yields and the multiple functions of complex agroforestry systems, it will be possible to propose good practices improving trade-offs between commodity production and other ecosystem services, acceptable for farmers.

Cereal-based agroforestry systems in dry zones:

For several centuries, agroforestry has been part of the oldest adaptive strategies of rural societies in the drylands of sub-Saharan Africa. Through its composition and spatial structure, linked with the role assigned to it, the tree reveals the strategy that each society is operating with regard to its environment (Pélissier, 1980). The selected species have a use value for households, or a commercial value on the local, regional or, more rarely, international market (Ouédraogo and Devineau 1996). Some recent attempts to increase the density of woody cover to promote agroforestry have been disappointing, because underground competition for water between the crop and the trees frequently cancelled out the benefits of soil enrichment and microclimate improvement (Ong and Leakey 1999). However, the assisted natural regeneration of trees and shrubs is a widespread practice among farmers in this area and it is locally characterized by an extension and densification of trees in cultivated territories (Garrity et al, 2010). An improvement therefore seems possible if it is based on the experience of the stakeholders. For example, in the southern Sahel, the *Faidherbia albida* parklands are the most successful example of integrated agro-sylvo-pastoral construction of the landscape and they play a role in soil fertility management (Peltier 1996, Dugué 1999, Milleville 2007). In the Sahel, shrubs, such as *Guiera senegalensis, Piliostigma thonningii* or *P. reticulatum*, are even more dominant, often in sparse single-species stands, in millet fields or in very open landscapes (Lahmar et al. 2011). Their socio-economic and agroforestry role is important (Louppe, 1991; Wezel et al. 2000; Bellefontaine, 1997). Most of the ecological and hydrological studies (Gaze et al., 1998; Kizito et al., 2006, 2007) and studies on their impact on soil fertility (Dossa et al., 2010; Wezel et al., 2000) have been carried out on sandy soils. Further south, trees, such as the shea tree (*Vitellaria paradoxa*), are typical of the Sudanian region over the entire belt extending from Senegal to the Sudan and Ethiopia borders (Teklehaimanot 2004). They provide edible fruits, cooking oil and are consumed locally, but they are a resource increasingly exported for industries in developed countries, such as the famous shea butter (Pelissier 1980; Glèglè Kakaï et al. 2011). Research on these parklands have been mainly conducted in Burkina Faso and Mali (Kater et al. 1992; Kessler 1992; Boffa et al. 2000; Bayala et al. 2002; Gbemavo et al. 2010).

Lastly, in the sub-Saharan zone, the trees also play a major role in land tenure. Unfortunately, few studies have looked at stakeholders and their level of decisionmaking in parkland management (Assé & Lassoie 2011). Dynamics of transformations in rural societies in dry tropical zones are powerful: they are driven by strong climatic constraints in a context of high population growth (Guengant et al. 2002), new pattern in rural-urban exchanges (Pelissier 2001, Bonnassieux 2007) and changes in economic and environmental policies (Dia et al. 2008). Many questions still remain, often generated by local studies.

1. Objective

The challenge for sound AFS management is to improve the trade-offs and even, if possible, promote synergies between production and other ecosystem services. The project will therefore attempt to study the trade-offs and synergies between provisioning services, and other ecosystem services (support, regulation) and cultural services provided by AFS in contrasting situations, in order to document a generic basis for optimizing those tradeoffs. The project is particularly ambitious, as its objective involves:

- switching from *partial analyses* of ecosystem services to an *integrated analysis* of the trade-offs between production and the other ecosystem services provided by AFS,
- for that purpose *developing interdisciplinary scientific dynamics* combining, within the same systemic approach, visions, concepts and methods (ecosystem services, trade-offs, ecological intensification, modelling etc.) that seem unifying, but which in fact are highly

specific to each discipline (ecology, economics, agronomy, etc.) and to the unit and individual research position (cognitive analysis versus agro-ecological engineering),

- *unifying* on this integrated approach organizations and teams working on AFS highly diverse in their ecological and socio-economic contexts, especially between humid tropical zones (HTZ) and dry tropical zones (DTZ).
- delivering both (a) scientific results *that may be easily adopted by the stakeholders* in each territory, *supporting* trade-off finding in each specific system, and (b) a methodological framework *useful for researches* in other territories and for *training*.

2. Approach

In order to understand AFS multifunctionality and trade-offs between production and ecosystem services that enable sustainable and acceptable management by stakeholders, an integrated approach will be undertaken, which could lead to innovations in the management of these systems and in public policies. The analysis will focus on understanding and characterizing ecosystem services and socio-economic and environmental benefits provided by AFS compared to monocultures. In general, ecosystem services are not independent from each other and their relations are probably non-linear (Power, 2010).

Providing a specific service may reduce another one. Then it is referred to as trade-offs. Maximizing provisioning services may lead to some very substantial trade-offs with support and regulation services, as is the case in monocultures. Biodiversity conservation and cultural services are also often considered as being trade-offs with production, which is itself varied and whose diversity and temporality are largely unexplored. However, in the project, we assume that maintaining support and regulation services promote system resilience to climate change.

The comparative analysis will cover a large gradient of AFS structures (from monoculture to complex agroforest) and biophysical, ecological and socio-economic contexts (between HTZ and DTZ and within each of these zones). However, the project will be centred on two perennial crops in the humid tropical zone (HTZ), coffee and cacao, and on the cereal-based rotation in the dry tropical zone (DTZ). Socio-economic aspects and the stakeholder strategy governing the structure, diversity, dynamic properties and evolution of the AFS will also be taken into account in an approach making explicit the link with the identification of different types of action vectors (technical, training, public policies, market foothold, etc.) at different scales (plot, farm, territory).

Relationships between ecosystem services will be assessed during the AFS life cycle. The different spatial scales will be taken into account by integrating evaluation criteria which are specific to each scale and to the stakeholders involved. Action levers to improve trade-offs between production and services will be identified and formulated in such a way that they may be assessed in this project or in futur programmes as extension of this project. These levers may be technical (e.g. choice and management of species combinations), economic (e.g. payment for a service, a product, such as timber) or public policy related (e.g. type of wood ownership).

The project will will be based largely on existing research facilities shared between CIRAD, IRD and the main partners involved. For perennial crops, the project will focus its activities on three regions: central Africa (Cameroon), East Africa (Kenya, Tanzania), and central America (Costa Rica, Nicaragua). For the cereal crops, the project will focus on the dry zones of West Africa (Senegal, Benin and Niger). Cameroon (IRAD, University of Yaoundé 1, Dschang University, producer federations), in central America (CATIE, University of Costa Rica), in East Africa (ICRAF, Coffee Research Foundation, Jomo Kenyatta University), in West Africa (Cheikh Anta Diop University Dakar, ISRA, Abdou

Moumouni University Niamey, Abome Calavi University Cotonou, DGEAU Benin, INRAB).

This strategy provides several advantages. It makes possible to:

- use existing facilities (long-term monitoring, smallholder plots networks, instrumented watersheds) and data already collected on the systems status and on the variables involved in the relationships to be studied,
- limit the investment dispersion so that it will be possible to structure and to conduct participatory research with stakeholders,
- promote integrated approach and multidisciplinarity within the project teams.

This project will include concepts and approaches provided by four WPs, within a single framework shared by the different disciplines, teams and fields:

- *WP 0: Management and coordination of the project based on a shared conceptual framework*

  It involves the project and WP leaders and leaders of major tasks, and national partners from each country when they are not already included among the task or WP leaders.
- *WP1: Characterization of the system composition, structure and dynamics*

  It involves two tasks, the first will focus on the AFS composition and structure (vertical and horizontal structure and diversity), the second will identify the socio-economic determinants of AFS dynamics.

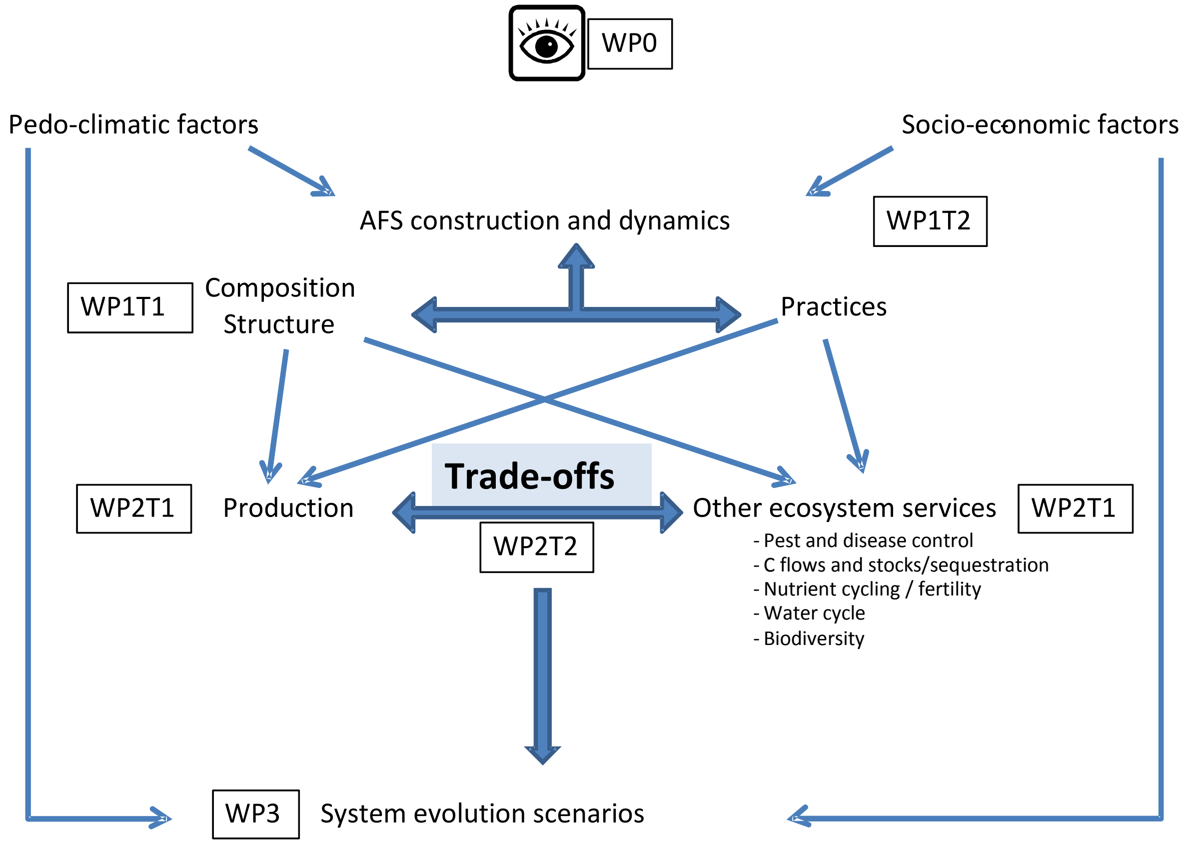
  WP2: Provisioning services and other ecosystem services in the agroforestry systems, interactions and trade-offs

  It is composed with two tasks. The first task will quantify the impact of AFS on ecosystem services from studies of biophysical processes using indicators and models usable under experimental conditions and in smallholder plots. The second task will promote meta-analysis to characterize the relationships between AFS structures and services; it will identify the key factors (biophysical and socioeconomic) determining the establishment of trade-offs between provisioning services and the other ecosystem services within an AFS gradient.
- *WP3: Analysis of possible AFS improvements through technical or institutional innovations*

  This WP is also organized in two tasks which will analyse space of the trade-offs between different services in order to identify, through participatory approaches, the levers for technical and socio-economic action that can move these trade-offs towards a more desirable zone for stakeholders. This approach will be applied at plot and farm scales through task 1 and at territory and farm network scale through task 2.

Based on three major types of AFS distributed among contrasting sites (presented in the annex), the SAFSÉ project, conducted by CIRAD and IRD, will pool multidisciplinary skills and financial and human resources, which will be mutually strengthened around an integrated, multidisciplinary approach with and for the South. This approach has been designed in order to answer a certain number of questions raised by the search on trade-offs between production and other ecosystem services, whilst bringing out some innovative guidelines beyond the case study, in the field of designing and driving these systems, as well as in public policies.

3. Graphical presentation of the SAFSÉ project's components



4. Description of the Work Packages

WP0: Management and coordination of the project based on a shared conceptual framework

Leaders: Jean-Michel Harmand (CIRAD), Josiane Seghieri (IRD), Jacques Wery (Montpellier SupAgro), Lucien Bidzanga Nomo (IRAD Cameroon)
Participants: All task managers + country managers

Overall objective

WP0 is the coordination and management unit of the project. It is responsible for coordinating the activities of the other WPs, and for maintaining the overall coherence of the project. It promotes the joint and transversal dissemination of results. It ensures that activities are undertaken in a context of a shared culture between the different disciplines, sites and research teams involved in the project.

Through this WP0, the project will be run by a coordination and management unit, which will organize an annual gathering of the project participants and a scoping meeting with the steering committee, comprising 1 member from CIRAD DG-DRS, 1 member from IRD DG-DS and a representative from AIRD.

Specific objectives

- Make sure that a systemic, interdisciplinary and multi-scale framework is maintained in **the implementation of activities** on the dynamic and structure of AFS, the ecosystem services they provide and the analysis of trade-offs between these services. To reach these objectives a shared conceptual framework will be defined and used during the project duration. An initial version of the framework will be drawn up by a small group of task managers from the other WPs to serve as a basis for a project launch seminar which will deal with the objectives, concepts and associated methods.
- Implement the common start-up framework shortly after notification of the project in the last quarter of 2012 in Montpellier. During this seminar, funded by the project, it will be a matter of making sure that the questions dealt with in the different terrains, tasks and operations fit in with a systems-services typology. For each of the main crops of the AFS selected for this project (coffee and cacao in HTZ and cereal-based rotation in DTZ) and for each of the experimental sites and territories identified, the scientific issues, processes and services studied by each task will be positioned within the previous analytical framework. For each case, the spatial and temporal scale of analysis, the method used to characterize the agro-ecosystem structure, the services studied and the indicators for characterizing them, the levers for action studied and the hypotheses underlying the analysis of trade-offs will be particularly made clear. In this way, it will be possible to identify from the outset and analyse after the event, the way in which each project task and terrain contributes to the assessment/improvement of the analytical framework.
- Coordinate the activities of the different WPs at the different sites (between AFS-Humid Tropical Zone and/with AFS-Dry Tropical Zone), ensuring good communication between the teams and between the sites, paying all the necessary attention to the coherence and articulation between the WPs. In particular, WP0 will aim to (i) identify, at the start of the project and at the end of each year, the achievements of the other WPs that might enrich this framework; (ii) missing elements for moving on to the analysis of structure, services and the relations between them (WP1 and WP2), the analysis of trade-offs in some scenarios that can be shared with the stakeholders in the territories involved (WP3); (iii)

propose corrective measures in the actions and budget to facilitate this continuum. It will be a matter of stimulating durable interdisciplinary and inter-team dynamics focusing on characterizing structure-service relations and analysing, through scenarios, the trade-off space between production and other AFS services.
- Ensure the dissemination of results within the international scientific community, but also in a form useful for training and for use in other studies. This notably includes joint scientific publications (special issues, organization of dedicated scientific sessions at conferences) on the concepts and methods developed under the project. The network of experimental sites and agroforestry territories emerging from this project is also aimed to to support long-term studies and comparative analyses beyond the project itself. The novel approach for studying trade-offs between AFS services that will be developed and tested during the project at a few sites could, indeed, be usable in other projects that extend or complete this one. For instance, at the end of the project during a joint seminar, WP0 will revise the analytical framework proposed at the start of the project, to produce a version that will structure the communication of project results and will serve as a support for methodological publications on the analysis of trade-offs between AFS services. This framework will serve as a training support in other projects likely to implement, test and improve the approaches and tools produced by the CIRAD-IRD project on other types of AFS.

Expected results
- Interdisciplinary and inter-team dynamics for CIRAD/IRD and partners from the South focusing on characterizing structure-service relations and the analysis, through scenarios, of the trade-off space between production and other AFS services.
- A network of experimental sites and agroforestry territories that could serve as a support in other long-term studies and comparative analyses.
- Project management based on a shared conceptual framework.
- A novel approach for studying trade-offs between AFS services, tested at a few sites and usable in other projects.
- In addition to the annual scientific and operational reports, a final report will be produced at the end of the project.
- Coordinated response to calls for proposals are also part of the project deliverables.

WP1: Characterization of the composition, structure and dynamics of the system

Leaders: Camille Lelong (CIRAD - UMR TETIS), Patrice Levang (IRD - UMR GRED), Isabel Gutiérrez (CATIE – Costa Rica, to be confirmed)

AFS structural diversity (vertical and horizontal structure) will be studied in this WP, along with the biophysical and socio-economic determinants and their dynamics.

WP1T1 (Task 1): Composition and structure of agroforestry systems

Leader: C. Lelong (CIRAD - UMR TETIS)

Issues

Agroforestry systems differ from other cropping methods through their great heterogeneity: the diversity of the plant species present and the complexity of their combinations. Studies on agroforestry systems rarely consider this heterogeneity. There is no standard or representative model but a multiplicity of AFS models. By taking into account this heterogeneity, it would be possible to relate the products and services provided by agroforestry systems to a given type in a referenced table. This table, or typology, illustrating the gradient of AFS complexity, would take into account:

- the *composition* of the system, listing the species according to their functionality (cash crop, food or fruit crop, medicinal resources, fodder, timber, firewood, other functions linked to shade quality, to the nutrient cycle, to carbon storage, to pest and disease control, etc.)
- the structure of the system, taking into account the planting density, the vertical layout of the different strata and the horizontal distribution of individuals (trees, patches of annual crops, etc.) in the agroforest stand
- physical *interactions* between the associated species, particularly the share of light that varies depending on the phenology of the species present, their positioning and respective overlapping
- the biophysical *environment* of the agroforest plots, their representativeness in the landscape, their connectivity with other types of land-use, their position in relation to population settlements.

By characterizing an AFS and placing it within a typology related to a degree of complexity based on the four criteria indicated above, it will be possible to link its impact, in terms of production and services, to that complexity. This task is intended to provide some of the elements needed for analysis and characterization.

Objectives

The first objective of this task is to determine composition indicators (inventory of individuals and species, plant diversity indices) and structure indicators (density, layout, stratification, biomass, LAI, cover, spatial heterogeneity, etc.) making it possible to encompass the whole range of AFS complexity and heterogeneity, starting from a certain number of contrasting cases. To that end, we propose combining conventional observation and field measurements with analysis capacities involving remote sensing and the modelling of radiative transfers in the plant covert.

The second objective is to define a typology of agroforestry systems in order to position them within this range of complexity and compare their agronomic and environmental assessments. This classification will be based on the indicators identified as being relevant in the first part of this study, and which will partly serve for the analyses in WP2, and on the results provided by WP2 involving the measurement of these indicators, along with the dynamic properties identified at the end of task 2 of this WP1.

Specific issues to be addressed

- What are the relevant structure and composition indicators for characterizing the complexity/heterogeneity of AFS with a view to estimating the ecosystem services provided? Which ones can be estimated in the field, by remote sensing, by modelling, respectively?
- Are all these indicators accessible with the same ease and precision for the complete diversity of AFS?
- How can knowledge of different types (botanical, agronomic, geographical, economic, etc.) from different sources (farmer, community, researcher, etc.) be integrated and how can multidisciplinary knowledge be synthesized for the agronomic and environmental diagnosis of agroforestry plots?
- Can a typology be established for agroforestry plots based on the complexity of their structure and composition?

The products arising from this task will thus make it possible to establish an analytical framework enabling answers to be found in WP2 and WP3 to the broader question: Can an agronomic and environmental assessment grid be proposed for AFS based on their place in this complexity typology?

Methodology, operations

Work will primarily be undertaken on a plot scale to characterize the cropping system (composition, structure, radiative climate, phenology, etc.). Then, we shall look at the local and regional scale to position the plot in its topographical sequence and in the landscape mosaic, so as to establish relations between the plot scale and the wider scale. These two scale levels will be perceived by gathering information and measurements in the field and by very high spatial resolution satellite imagery (<1m, called VHSR in the rest of the document) and diachronic high spatial resolution images (SPOT5) as a support for mapping and as a source of information. Modelling will also be tested for its ability to characterize the radiative climate in these cropping systems, and particularly the terrestrial LiDAR approach. Some major data analyses of various types (statistical, geomatic, hypsometric, phenological, physical, etc.) will be carried out to extract the various indicators sought.

In all, 4 operations (described in the annex) are proposed that cover the diversity of the AFS covered by the project. Operations 1 to 3 will be undertaken at the same time, sometimes in parallel, but usually in synergy and close collaboration. Their purpose is to (i) establish indicators of AFS composition and structure based on measurements in the field, remote sensing and radiative transfer modelling and (ii) compare these approaches.

WP1T1 Operation 1: Assess the potential of remote sensing for characterizing AFS (composition, structure, phenology, hypsometry, position within the landscape matrix) on the following systems, of which four in a humid zone and one in a dry zone:

- a cacao-based agroforest in the Bokito region in Cameroon, representing some complex and diverse systems.
- a coffee-based system in the Turrialba region of Costa Rica, representing some simple AFS (tree crop under variable density legume shade).
- a coffee zone of the Muranga region in the Aberdares range in Kenya, representing some more or less simple systems (tree crop under shade and fruit trees).
- Site 3) will be compared with a neighbouring site located in Tanzania, on the slopes of Mount Rungwe, illustrating a toposequence with a succession of coffee systems associating cereals and banana, and cacao systems with tea.
- in a dry zone, an AFS in the Thiès region of Senegal (Keur Maktar) composed of cereal-based rotation crops (millet and sorghum) and legumes (groundnut and cowpea) in *Faidherbia albida* and *Guiera senegalensis* parklands.

WP1T1 Operation 2: In situ characterization of the systems, measurement and modelling of light interception in a humid zone, in coffee plantations under *Erythrina* in Turrialba (Costa Rica)

WP1T1 Operation 3: Analysis of the spatial structure of AFS in a humid zone, in the cacao plantations of Ngomedzap in Cameroon and in the coffee plantations of the Aberdares range in Kenya.

The fourth and final operation will consist of a synthesis involving all those involved in this ask, but also in task 2 of WP1:

WP1T1 Operation 4: Construction, from the previous three operations, of a multidimensional matrix of indicators that can be used to assess the complexity of AFS.

Expected results

- AFS mapping within and between plots in the study regions.
- Precise and spatially explicit characterization of the range of systems studied: composition, structure, radiative environment.
- Information on the effect of various factors (geographical, pedoclimatic, topographical, date established, local practices, etc.) on the structure and complexity of the systems.
- Information on the effect of the structure and complexity of the systems on services (plant biodiversity, competition for light, habitats for pests, yields).
- A multidimensional matrix of indicators for characterizing the complexity of AFS.

WP1T2 (Task 2): Dynamics of agroforestry systems, stakeholder practices and strategies
Leader: I. Michel (CIRAD - UMR Innovation), P Levang (IRD - UMR GRED)

Issues

AFS, which arise from the development of original forest areas or savannah zones, locally cover large areas, display diversity in structure and composition, and **undergo some major changes**. These changes are inherent to the evolution of the global environment, be it natural (climate change, etc.), social (increase in population pressure, worsening of conflicts for access to natural resources, migrations, etc.), economic (variations in prices of agricultural commodities, arrival of new investors local or international, creation of new markets, etc.) or socio-political (new management rules for land resources, creation of protected areas, etc.). These new constraints and opportunities have also led to a modification in AFS practices, techniques and management methods, which differ in form ecologically, economically and socially. Their adaptive nature and their sustainability no longer require demonstration today. The study of the factors (ecological, historical and economic, present and past) that have led to the creation of AFS and the factors determining their installation, maintenance, transformation, and eventually disappearance, appears to be essential for accompanying the on-going changes, improving the ecosystem services that AFS provide and, lastly, drawing up proposals for the development of these systems.

Task 2 of WP1 will therefore endeavour specifically to analyse the changes that have a notable effect on different types of AFS, be it in terms of area and territorial encroachment, or in terms of composition and structure. The stakeholder strategies that lead to the creation and management of these systems, and which explain these evolutions, will be analysed on different temporal and spatial scales, and in different contexts. We put forward the hypothesis that new categories of players are entering the game and that those that remain sometimes see their strategies change. The factors (ecological, social and economic) determining these changes in stakeholders and strategies will be placed in perspective, the challenge being to identify some levers for action with a view to improving the performance of these AFS and target their vulnerability (see WP3).

Specific questions

- Which are the groups of players whose strategies are evolving and which therefore have an effect on the spatial and structural dynamics of AFS?
- What factors are determining these stakeholder strategies and their changes?
- How do these strategies affect the spatial dynamics of the shrinkage, maintenance or expansion of the different types of AFS?

- How do these strategies affect the composition and structure of agroforests and, thereby, the ecosystem services they provide?

Methodology, study sites and scheduling of operations

The methodology of task 2 in WP1 will be based on a comparative and interdisciplinary (agronomy, sociology, economics, ecology, ethnoecology, geography) analysis of contrasting situations. A common approach and analytical framework will be used in the two major types of AFS spread over four countries and seven sites.

Sites and AFS adopted

In the dry zone, we shall be studying **the shea parklands of northern Benin**. Their range is particularly marked in Sudanian Africa. Although they play a paramount role in family food and economics, and are well exploited in equitable supply chains, these parklands are showing signs of ageing and degeneration. Two sites have been chosen, for their dual contrast, in the way access is gained to land and shea trees, and in the stakeholders: (1) a zone of old parklands in Bétamaribé country in northwestern Benin; (2) a forest-agriculture frontier and Bétamaribé immigration zone in the Djougou region, where, moreover, the operations of WP2 are planned (fertility, water cycle).

In the humid zone, we have chosen **cacao-based AFS of Centre-South Cameroon** and **coffee-based AFS in Central America (Costa Rica and Nicaragua)**, which are systems and countries where all of the project WPs and tasks converge. It is in **Centre-South Cameroon** that the oldest, most complex but also the most diversified or even the most threatened systems are found. Indeed, in a context of State withdrawal from the agricultural sector, growing diversification can be seen in the types of growers and their strategies, linked to the functions (economic, heritage, identity, etc.) they attribute to their agroforestry plots. The area involved offers a gradient of contrasting pedoclimatic, ecological and socio-economic situations, whose effects on the stakeholders and their practices will be tested at three sites: Ngomezap, Obala and Bokito. In **Costa Rica**, we have chosen the site of Llano Bonito, where some old, labour- and input-intensive systems dominated by coffee plantations are found. Although the farmers benefit from recognition of the quality of the coffee produced, they are under pressure from environmentalists, whose effects on their strategies and their practices we wish to analyse. In **Nicaragua,** we have chosen the El Cua site, which is in the Mesoamerican biodiversity corridor, which also gives rise to some environmentalist pressures on farmers who are in a situation of abject poverty.

Analytical framework and method

Our methodological approach can be summed up in four points:

- Crossed application at the same sites of approaches from several disciplines
- Working on several spatio-temporal scales in connection with task 1: from territories to individuals to households, from village to plot to bearing trees, levels on which practices and social organization will be analysed;
- A historical approach to the analysis of change carried out over long time steps in order to understand past and current changes, and the adaptations of agroforest managers. Some lessons will be learnt in terms of future planning, in connection with WP3;
- A common entry point, centred on the stakeholders who create and manage AFS, their diversity, their strategies, their activities and practices, along with their own perceptions of their activities and of changes.

The common analytical framework is derived from the "Sustainable Rural Livelihood" model, in which the social group forms the analysis unit and the favoured entry point (Scoones 1998 et 2009)[1]. Our **research approach** will involve different stages, combining interviews and observations: (1) an initial set of interviews with resource persons to carry out zoning and a pre-typology of the stakeholders concerned by the development and management of AFS; (2) a second set of in-depth interviews, with randomly chosen key players, about their strategies, perceptions and practices; (3) the construction of a network of plots in which the effects of stakeholders' strategies on the composition and structure of AFS will be characterized, in connection with task 1; (4) extrapolation of the results to a wider sample, and characterization of the spatial dynamics of the different types of AFS identified in the typology of task 1. As far as possible, this analysis of spatial dynamics will be based on diachronic high spatial resolution satellite imagery (SPOT5).
We shall mostly be using semi-directive interviews so that the interviewee can deliver his own views on the subjects proposed by the interviewer. In order to go into certain analyses in greater depth, we may also use directive interviews and tools for the statistical analysis of summary data.

Structuring of the operations

Not all the issues of task 2 in WP1 and all the stages of the approach will be dealt with everywhere with the same intensity. We have sized the operations in line with the numerical size of the teams in place and the allotted resources, but also in order to more effectively bring them into line with the other project tasks and WPs, or even with other projects such as the Europaid Afs4Food project in Cameroon (see annexes).

Task 2 of WP1 is structured in 3 operations (described in the annex), one for the shea parklands in Benin, one for the cacao AFS in Cameroon, and one for the coffee AFS in Central America.

- *WP1T2 Operation 1* (manager Isabelle DROY): the social and economic conditions of shea parkland management in Benin: maintenance or deterioration of a system?
- *WP1T2 Operation 2* (manager Nicole SIBELET): effects of payments for environmental services and coffee certification on stakeholders' strategies and on the coffee AFS of Central America.
- *WP1T2 Operation 3* (manager Patrice LEVANG): effects of the changes in stakeholders and their strategies on the spatial dynamics and structure of the cacao AFS in Cameroon.

Expected results

- Characterization of AFS dynamics on a territory scale;
- Identification of the life history of the farming households and their farm trajectory, with identification of the determinants;
- Identification of the strategies of agroforesters and their families (farming household) and construction of a typology for these stakeholders;
- Assessment of the economic and social performance of the different types of AFS and their place in family economics;

[1] Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis. Brighton, IDS. 72.
Scoones, I. (2009). "Livelihoods perspectives and rural development." Journal of Peasant Studies 36(1): 171-196.

- Representation of provisioning and ecological services provided by AFS as seen by stakeholders;
- Mapping of the spatial dynamics of the different types of AFS;
- Characterization of the composition and structure of AFS and identification of their future trajectory, in connection with the trajectory of the families.

WP2: AFS provisioning services and other ecosystem services, interactions and trade-offs

Laurent Cournac (IRD - UMR Eco&Sols), Jacques Avelino (CIRAD - UR Bioagresseurs), Prof. K.E. Agbossou (Abomey-Calavi University – Agricultural Sciences Faculty, Benin)

Issues

For producers, one central factor that determines the establishment and maintenance of AFS lies in their ability to sustain not just economic profitability but also a longevity and sustainability that is equal to or better than that of non-associated crops. The impacts that AFS will have on **provisioning services** (food crops) or commercial services therefore need to be considered first and foremost. Depending on the sites and contexts, the impact of tree species may help to stimulate crop yields (facilitation). On the other hand, it may have a depressive effect (competition for light, water, or certain nutrients), which will be acceptable provided it is compensated for by other types of use or greater resilience, linked to other **ecosystem services**. These include primary production, control of the water regime and of water quality, soil preservation, regulation of the nutrient cycle, regulation of pests and diseases, carbon sequestration and biodiversity preservation. A better understanding of the processes affecting these ecosystem services is therefore a prerequisite for predicting the abilities of AFS to sustain them, notably in the face of disturbances, be they climatic or of another nature.

Objectives

We shall seek to identify at the different sites how the structure and composition (as identified in WP1T1) on the one hand, and management practices on the other hand, affect the productivity of the systems and impact on the other ecosystem services they provide. We shall analyse the underlying biophysical processes (Task 1 of WP2) in order to pinpoint key mechanisms that determine the **trade-offs** between provisioning services and other ecosystem services. Lastly, we shall seek to determine how the socio-economic environment directs the functioning and evolution of AFS within the physical space of possible trade-offs (Task 2 of WP2).

Specific questions to be answered

Task 1:
- How do AFS govern provisioning services (market and non-market)?
- How do AFS govern the other ecosystem services?

Task 2:
- What are the physical and socio-economic determinants that shape the observed systems?

Methodology

Regarding task 1, a set of specific methodologies primarily based on field studies will be deployed to analyse how each of the different services treated in this project is modulated by the presence of trees in the cropping sytem and by management practices. The ecosystem services studied can be grouped as follows: (i) provisioning; (ii) C cycle and stocks; (iii) water cycle and stocks; (iv) nutrient cycle, soil stability and fertility; (v) pest and disease regulation; (vi) functional biodiversity. These services will be studied in the cacao-based systems in

Cameroon and Costa Rica, in the coffee-based systems in Costa Rica, Kenya, Tanzania and Cameroon, and in the cereal-based systems in Senegal, Burkina Faso, Niger and Benin. It is clear that, for practical reasons, it is not feasible to treat each of these services at each of the sites. The studied service/site combinations were nonetheless chosen to try and cover this diversity as well as possible, taking into account the facilities available at the partners' sites, and seeking to enable transversal actions and comparisons as much as possible. The broad outlines are given in the description of the tasks below and details can be found in the referenced operation sheets (in the annex).

For task 2, a meta-analysis of data from the literature and from the project will be undertaken to analyse the biophysical and socio-economic factors governing the establishment of trade-offs.

Expected results

For task 1

- Quantification, in the studied AFS, of their effect on crop productivity (food and cash crops), including analyses of AFS impact on yield components (primary production, allocation and phenology, crop losses linked to pests and diseases, etc.).
- Quantification of AFS impacts on the six groups of ecosystem services considered, at sites representative of all the pedoclimatic zones covered by the project.

For task 2

- A database grouping transversal indicator data on all the types of AFS studied, compiling data from the literature and data from the project.
- Modelling, from meta-analyses of the gathered data, of the interactions between services making up the trade-off space and of the biophysical and socio-economic levers leading to the establishment of the current trade-offs between provisioning services and other ecosystem services.

WP2T1 (Task 1): Characterization of ecosystem services and biophysical and biological interactions in AFS

Laurent Cournac (IRD - UMR Eco&Sols), Jacques Avelino (CIRAD - UR Bioagresseurs)

The service/site combinations studied and the questions, approaches and research objectives specific to these different combinations are summed up below and the research operations are described in the annex.

Characterizing the impact of AFS on provisioning services:

Characterization of AFS impact on production and provisioning services will be transversal to all the research operations developed under this task. It will involve analysing yield determinants for the basic crop, but also all for the other domestic or market products. It will therefore, in theory, concern all the zones covered by the project. The indicators for characterizing production will be established in connection with WP0 and WP1.

- In the cacao zone of Cameroon (Ngomedzap), the AFS will be assessed by the Regional Agronomic Diagnosis method (Doré et al. 2008), from a fermented dried cocoa production angle and also with regard to the other domestic and market products. A synchronic approach will be taken using a plot network deployed in farmers' fields during the production phase *(WP2T1 Operation 1).*
- In the two major coffee regions of Kenya and Costa Rica *(WP2T1 Operations 2 and 3)*, the impact of tree cover and agricultural practices on production will be analysed, using existing data (many years of monitoring in Costa Rica) and newly acquired data from the plot network installed under this project (Kenya/Tanzania).

- In the zones of West Africa studied in the project, the effect of the distance from a tree or shrub on cereal crop yield will be studied, via an agronomic analysis of yield components in Senegal *(WP2T1 Operation 4)*, and by studying water interactions in Benin and Niger *(WP2T1 Operation 5)*.

Characterizing AFS impact on the other ecosystem services

The ecosystem services (and sometimes "disservices") provided by agro-ecosystems are of various types. Starting from the main topics identified by Power (2010), we shall adopt five categories, the first three being related to flows and stocks of matter (the physical components of the ecosystem), the following two being related to the biological diversity supported (players in the ecosystem) and its repercussion on their functioning.

Carbon flows and stocks: primary productivity, allocation and sequestration of C

AFS are often considered as carbon sinks, from the viewpoint of the biomass (stems, leaves and roots) they support, and of their contribution to increasing the organic stock of the soil. However, their efficiency in that respect (size and stability of the carbon sink) varies. This of course affects the GHG balance of the systems, but C stocks also play a central role in soils for their structural stability and fertility.

- In the coffee systems of Costa Rica *(WP2T1 Operation 2)* we shall be studying the interactions between C flow and stock constitution, based on the instrumented facility managed by Eco&Sols under SOERE F-ORE-T (flux tower) and the application of new complementary methods for the resolution of biomass increases (microdendrometry). These data, combined with the structural parameters of the ecosystems (WP1T1), will contribute to the mechanistic modelling of matter fluxes. C allocation (aboveground/belowground) will be monitored from the angles of production, of formation and of establishment of C stocks in the volcanic soils of the zone *(WP2T1 Operation 6)*.
- Biomass carbon acquisistion and allocation will also be monitored in Kenya. In these regions, AFS impact on aboveground biomass has already been studied in several contexts. The project proposes to take into account belowground carbon allocation (root biomass and C stocks in the soil) for a comprehensive understanding of the AFS effect on carbon flows and stocks *(WP2T1 Operation 3)*.

Ultimately, these two set-ups will lead to the acquisition of comparative data on agroforestry/primary production/C stock interrelations in two contrasting major coffee growing zones.

- Carbon flow and stock measurements will also be undertaken in the set-ups installed in the dry zone on the cereal systems in West Africa. Thus, the way shrub management methods affect the growth, and the aboveground and belowground biomass of the woody plants, and of the cereal crop, will be monitored through different trials conducted in the dry zone *(operations 2.4 and 2.5)*. Some analyses of shrub impact on C stocks in the soil and their dynamics will be carried out by sampling soil profiles in Senegal in the ISRA plots *(operation 2.4)*. Some targeted samples will then be taken at all the sites in the dry zone for comparisons, between sites and between systems, of the AFS impact on carbon stocks in the soil.
- Some measurements of C stocks in the soil will also be taken in the cacao AFS in Cameroon, to determine how the composition and age of the AFS affect C sequestration in the soils after different previous plant covers (forest or savannah) *(operation 2.4b)*.

Water flows and stocks, AFS impact on the water regime in the plots

In close correlation with carbon fixation and distribution, the presence of trees in the crop plot has considerable impacts on the water cycle: extension of the root exploration zone, impact on PET via shade and wind-break effects, potential competition with the crop or, on the contrary, facilitation via hydraulic lift or rainfall infiltration phenomena, etc.

- In the coffee growing zones, we shall be looking at how AFS affect the water balance on a plot scale in Costa Rica, paying particular attention to the effects of tree density on coffee tree hydraulic functioning *(operation 2.2)*, and on a watershed scale in Costa Rica and East Africa, notably by studying AFS impact on AET, drainage, run-off and erosion *(operations 2.2 and 2.7).*
- In the dry zones, the hydraulic functioning of the shrubs (*Guiera*) and trees (Shea), and their interactions with that of the associated crops, will be precisely studied with the support of the instrumented facilities managed by HSM and LTHE in Niger and Benin under ORE AMMA Catch *(operation 2.5)*. Some chemical tracing approaches will be used to quantify the shares of uptakes from rainwater and from water table in the shea systems. In addition, the occurrence of any hydraulic lift phenomena will be tested by setting up tensiometric profiles *(operation 2.5).* Some complementary water profile measurements carried out by Eco&Sols in Senegal and Burkina Faso in the *Piliostigma* and *Faidherbia* plots *(operation 2.4)* will enable some comparisons of the impact of these systems on the water regimes in slightly different agroclimatic contexts.

AFS impact on soil preservation: organomineral richness and erosion mitigation

AFS are often described as helping to maintain or improve soil fertility characteristics, by promoting the mobilization of nutrients over large depths, notably via microbial or mycorrhizal associations, and by stabilizing the texture and organic richness of soils. However, precise studies on the balances, dynamics and synchronization between nutrients and cropping cycles in AFS need to be developed, for a clearer understanding of the benefits (or not) that can be expected from them. In this project, we shall more particularly be looking at:

- The nitrogen cycle in the coffee/*Erythrina* system in Costa Rica.
  One of the combinations currently practised in Costa Rica is coffee under the shade of a nitrogen fixing tree (*Erythrina poeppigiana*). Using isotopic tracing, we shall explore the effect of that combination on the N balance in the plot, the nitrogen redistributions operating between the shade tree and the coffee tree, and the potential impact in terms of external input savings. This study will be based on an experiment combining nitrogen fertilization and tree density *(operation 2.8).*
- N and P dynamics in connection with the presence of shrubs in the Sahel zone
  In Senegal, the impact of the woody species on nutrient dynamics (N and P) will be studied in a network of ISRA plots according to the distance from the tree *(operation 2.4)*. The sampling and analysis methodologies developed for this work will then be transferred to the other AFS in the dry zone.
- Interactions between AFS pedoclimatic regimes and erosion in Kenya and Costa Rica
  Preserving soil quality not only concerns their ability to sustain a nutrient cycle in phase with crop requirements, but also, first and foremost, their integrity. Particularly in wet zones, run-off and erosion can be mitigated by the presence of cover trees. These phenomena will be studied in Costa Rica *(operation 2.7)* and Kenya *(operation 2.3).*
- Changes in soil fertility in relation with the composition and age of cacao-based AFS

In Cameroon, changes in the organomineral characteristics of the soil and the nutritional status of the cacao tree will be analysed in the AFS set up on savannah, in relation with a study of the functional traits of shade species *(operation 2.4b).*

AFS effect on the diversity and dynamics of pests and diseases and of beneficial species

The existence of trees in the plot, or in the landscape, may have repercussions on the health status of the crop. The effects vary depending on the species, pests and diseases, or beneficial species, their life traits and physical environments (Ratnadass et al. 2012). These effects may be complex with some antagonistic effects depending on stages within the life cycle of certain pests and diseases (some processes favoured, others not), contrary effects on different species (one species favoured, another not), or even interactions with the environment (an effect regulating a pest or disease in one situation, but with the opposite effect in another). The general outcome of these effects is therefore difficult to define a priori.

- In the cacao growing zones of Cameroon, we shall be studying (on a plot scale) the impact of the density (degree of shade) and plant biodiversity of AFS on the dynamics of two major pests: *Sahlbergella singularis*, a pest of the mirid family, and the pathogen *Phytophthora megakarya*. Particular emphasis will be placed on the spatial structure of plant biodiversity and its effects on attack levels and on the spatial distribution of the pests. The action pathways studied will be the microclimate and natural enemies *(operations 2.9 and 2.10).*
- The arabica coffee tree in Cameroon is particularly susceptible to coffee berry disease. Disease propagation depends on the coffee tree's own architecture and on the structure of the shade tree cover. In order to more effectively characterize these interactions, the spatio-temporal dispersal of coffee berry disease will be analysed on a plant scale, along with the effect of "genotype x shade level" interactions on disease development *(operation 2.11.)*
- In Kenya, the main three Arabica coffee pests and diseases will be studied: coffee berry disease (*C. kahawae*), the coffee berry borer (*Hypothenemus hampei*) and leaf rust (*Hemileia vastatrix*). All the factors known to affect the pests and diseases will be considered on a plot scale. A survey in farm situations will also be undertaken *(operation 2.3).*
- In Costa Rica, factorial approaches will be taken to study the effects of shade on coffee and cacao pests and diseases on a plot scale: (i) antagonistic effects on the dispersal and germination of coffee leaf rust propagules (*H. vastatrix*) and cacao frosty pod rot (*Moniliopthora roreri*) (ii) effects of shade x topography interaction on American Leaf Spot of coffee (*Mycena citricolor*) (iii) contrary effects on the different coffee pests and diseases *(operation 2.12).* Lastly, as has been proposed for Cameroon, the effect of the spatial structure of the associated plant biodiversity on cacao frosty pod rot and its spatial distribution will be studied *(operation 2.10).*
- In the Sudano-Sahelien agroforestry zones, we shall be looking at the effects of trees on the arthropod communities (pests and natural enemies) in the cereal-based systems, on a plot and landscape scale. Surveys will be undertaken to study the effects of the organization and the nature of the landscape. It is hoped to identify landscape contexts and practices that would ensure connectivity for the species involved in biological control, and limit the movements of harmful organisms *(operation 2.13).*

AFS effect on the biodiversity of the fauna in the agro-ecosystem

Plant biodiversity is already beings studied in the stand structure (see WP1).

Here, we shall be looking at how AFS affect the functional biodiversity of the soil (and more particularly the fauna) in the coffee systems of Costa Rica. It will involve using an isotopic analysis of inventoried species to position their respective roles in the trophic networks of the ecosystem. This study will constitute a reference for perceiving the pedobiological component of AFS *(operation 2.14)*.

WP2T2 (Task 2): Biophysical and socio-economic meta-analyses: Dynamics, interactions and trade-offs between Provisioning Services and Ecosystem Services
Olivier Roupsard (CIRAD - UMR Eco&Sols)

The tropical AFS chosen by this project offer the advantage of encompassing large pedoclimatic, intensification, productivity and socio-economic gradients. However, the hypotheses, questions and research topics, along with the methodologies, are relatively common to the sites. This situation is appropriate for trying to discover some broad outlines or broad laws in the dynamics and challenges of AFS, particularly regarding trade-offs between services, using this diversity of situations that is offered. To that end, we propose to carry out multi-site comparisons, or even meta-analyses for the issues that the databases enable us to treat through a sufficient number of sites.

The bulk of the work will be to identify the research issues, then recompile the existing data (bibliography, data mining), combine them in a coherent joint database whose structure will be mutually defined when the project is launched and, lastly, analyse and model them. The data arising from this project will be added as it progresses.

Trade-offs between Provisioning Services and Ecosystem Services

In an initial set of analyses, we shall seek to test the hypotheses on the biophysical parameters that are decisive in establishing trade-offs. For example, by cross-comparing experimental data and modelling data, we shall be looking at how plant cover density can be optimized in line with production and preservation objectives. We shall also be examining how the biodiversity of these ecosystem players significantly affect, or not, agrosystem functioning, depending on the service considered and the situations analysed. This is given as an example, but more generally, meta-analyses will allow addressing several of the hypotheses put forward during the numerous functional agroecology approaches developed in this project.

Dynamics of Provisioning Services and Ecosystem Services

In a second set of analyses, we shall attempt to test how the socio-economic contexts and strategies of stakeholders contribute to AFS modelling and, ultimately, govern the services they provide. For instance, market trends, socio-economic regulations and physical environments, which obey different logics and temporalities, which also impact on different scales, will help to condition AFS efficiencies and, over the long term, will govern whether or not they are adopted. Meta-analyses can thus be used to decipher levers that lead to AFS being established in agrarian landscapes, and to the emergence of innovations for their management.

Depending on the issues covered, the different hypotheses will be delegated to specialists from the project, who will supervise the work of the students involved in these analyses and in constructing the database. In addition to joint transversal publications between the parties in the project, their work will culminate in a far-reaching database, which will be one of the exploitable deliverables of the project.

<u>WP3: Analysis of the possibilities for improving AFS (through technical and institutional innovations)</u>

Leader: Bruno Rapidel (CIRAD - UMR System); Isabelle Droy (IRD – UMI Résiliences); Eduardo Somarriba (CATIE – Costa Rica)

Issues

In connection with task T2 of WP1 and T3 of WP2, WP3 will seek to help stakeholders to take on board the project's scientific results. Possible improvements to AFS include the analysis of possible responses to the issues raised in WP1 regarding current AFS functioning, and the results of WP2 regarding trade-offs between ecosystem services. These improvements are of an agronomic, socio-economic and institutional nature, and their combinations will be the subject of scenarios analysed with the stakeholders (participatory approach) and converted into proposals for agronomic practices, but also for monetary incentive systems (prices, taxes, subsidies, bonuses, etc.) and non-monetary incentives (standards, obligations, etc.).

Objectives

The general objectives of WP3 are to analyse possibilities for improving AFS and to construct and assess, on a participatory basis, the scenarios that integrate them, partly depending on the diversity of products, of the different services provided and of the uses made of them by the stakeholders in the territory, and partly depending on AFS dynamics.

Methodology, operations

The fields for improvement proposed for assessment will take into account:

- environmental services and the trade-offs arising from WP2
- the diversity of products arising from WP1/WP2
- different time steps in the assessment, including an analysis of the reversibility of choices (e.g. very obvious in the case of cacao)

To do this, we shall bring into play knowledge arising from the study of practices on different continents and in different contexts on two levels (farm/plot scale and territory scale) corresponding to the two tasks in this WP:

- ***WP3T1 (Task 1)*****:** on the level of all agroforestry producers, considering any changes in management practices; this task amounts to a **comparative analysis of possible improvements to AFS on a plot and farm scale**. Manager: *Bruno Rapidel (CIRAD - UMR System)*

- ***WP3T2 (Task 2)*****:** on the level of all stakeholders in the territory, by assessing the different intervention and environmental management strategies; this task involves a **comparative analysis of incentive systems (institutions) on a farmer and a territory scale to promote greater production of ecosystem services by AFS**. Manager: *Jean-François Le Coq (CIRAD - UMR ART Dev)*

The stakeholders include producer representatives, but also NGOs, firms in the supply chain, users of environmental services, public administrators, political decision-makers, etc., in Costa Rica and Nicaragua for the coffee supply chain.

These two tasks will be divided into three operations (described in the annex) of which the first cuts across the two tasks:

- Operation 1 *(WP3 Operation 1)* on cropping system design in coordination with stakeholders on a plot and a watershed scale. On a plot scale (Task 1), in consultation with producers based on an explanation of trade-offs, and assisted by the models, it will be a matter of drawing up proposals for modifying shade management systems in the coffee plantations at El Cuá, in Nicaragua. On a watershed scale (Task 2), some modelling and field results on a landscape scale will be combined to bring out the basis for establishing a system of payments for environmental services in the LLano Bonito watershed in Costa Rica, in relation with ICE and FONAFIFO.
- Operation 2 *(WP3 Operation 2)* concerns the identification and participatory assessment of technical innovations for improving the cacao-based AFS of central Cameroon at Ngomedzap, exclusively on a plot and a farm scale (Task 1).
- Operation 3 *(WP3 Operation 3)* involves simulating the implementation of local instruments in the territories (Task 2) in order to test different new rules for the adoption of practices and changes in coffee plantations in Costa Rica at Llano Bonito and in Nicaragua at El Cuá.

Expected results

For task 1:

- Scenarios on changes in agroforestry producer practices
- Criteria for assessing those scenarios
- Recommendations for reducing obstacles to improving practices in AFS, and for ensuring learning mechanisms in the face of uncertainties as and when progress is made (learning-by-doing).

From task 2:

- A relation between decision-making by players in AFS and monetary incentive systems (prices, taxes, subsidies, bonuses, etc.) and non-monetary incentive systems (rules, standards, obligations, banning, etc.)
- An assessment of methods making it possible to explore possible changes in the performance of AFS linked to institutional changes
- Institutional innovations acceptable to stakeholders with a view to optimizing the services provided by AFS.

5. Results expected on a project scale and the beneficiaries

The project will endeavour to produce knowledge and know-how on AFS functioning, along with tools and methods for designing and assessing such systems. It will contribute to capitalizing on, making optimum use of, and structuring the know-how, achievements and practices of the CIRAD and IRD teams and of their partners, whilst producing new knowledge. It will set in place a forum for exchanging thoughts and discussions on developing common concepts, approaches and tools giving credibility to the added value derived from the association between CIRAD and IRD for development in the countries of the South through training, research and innovation, in compliance with the missions of AIRD. The project beneficiaries will therefore be the researchers themselves (from CIRAD, IRD and the partner institutions), trained and qualified students, development organizations and farmers in developing countries.

Without returning to the specific results expected in the different WPs, a reminder is given below of the unifying aspects that the project will endeavour to construct:

- Interdisciplinary and inter-team dynamics for CIRAD, IRD and their partners from the South for the characterization of structures-services and for an analysis, through scenarios, of the trade-off space between production and other AFS services.
- A network of experimental sites and agroforest territories that can be used as a support for longer-term studies and comparative analyses.
- A novel approach for studying trade-offs between AFS services, tested at a few sites and usable in other projects.
- Production of validated tools and methods (experimental designs and analysis methods, indicators, modelling, databases, specific tools), also promoted through publications.
- Training, mostly at Master's level but also thesis level for students from developing and developed countries.
- Quality replies to future calls for proposals.

6. Human resources provided by the project (students)

In all, 63 training periods, mostly at Master's 2 level, but also engineering and year-off internship, will be funded by the project. They will be divided up as follows: 20 for WP1 (10 for each of the two tasks on AFS structure and dynamics respectively), 38 for WP 2 (34 for task 1 concerning services, 4 for task 2 concerning the meta-analyses). The project will also ensure or contribute to the functioning of 9 on-going theses, at a rate of 7 for task 1 in WP2 and 2 for WP3.

7. Assessment indicators

- Derived research projects submitted and/or accepted for funding,
- Scientific publications, communication at scientific events,
- Master's and Engineer diplomas and theses obtained in the North and South,
- Training modules and courses given; participation on thesis committees and panels,
- What becomes of the trainees from the North and the South supervised under the project.

8. Considerations on project risks

The purpose of the project is precisely to seek AFS management trade-offs that reduce environmental risks and increase the food security of farmers, either directly (reduced pollution, preservation and optimization of diversified production) or indirectly (reduced erosion, fertility maintenance, drought risk control). In so doing, under this project, there are no plans to introduce organisms, potentially invasive plant species or genetically modified plants.

In socio-economic terms, production diversification is a direct strategy for reducing famine risks. Its purpose is to increase incomes, but also add further value to products and better sharing of resources, whilst providing land tenure security, i.e. a reduction in social risks.

On the other hand, given the major challenges facing tropical countries (poverty, food insecurity, climate change, loss of biodiversity) there may be a major economic risk to break with traditional agroforestry techniques, without assessing it beforehand. It is precisely this evaluation that the project proposes to carry out. There also exists a social risk linked to the worsening vulnerability of the communities involved, should they be obliged to adopt monoculture techniques, for either food or cash crops, based exclusively on increasing their short-term profitability. Given the limitations due to the time available, the budget and the human resources, it will not be possible to cover these aspects during the project, which will remain focused on the assumed more secure alternative represented by AFS, but some accompanying comparative studies may possibly be considered at a later date, or at the same time as part of replies to other calls for proposals.

Lastly, as regards the risk inherent to project management, this arises from the great diversity of situations – particularly the contrasts between the humid tropical zones and the dry tropical zones – and of the services dealt with, but also that of the disciplines and teams involved. The very challenge of project coordination and leadership (WP0) will therefore be to succeed in unifying all those involved around interdisciplinary scientific dynamics, by switching from partial analyses to an integrated analysis within a shared conceptual framework.

9. Ethical implications

- The outcomes of the SAFSÉ project will be “public goods”.
- The research issues will be jointly established with the partners from the South.

10.Bibliography

Avelino, J., Cabut, S., Barboza, B., Barquero, M., Alfaro, R., Esquivel, C., Durand, J.-F., Cilas, C., 2007. Topography and crop management are key factors for the development of american leaf spot epidemics on coffee in Costa Rica. Phytopathology 97, 1532-1542.

Asare A., Tetteh D.A. (2010) The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southeastern Ghana. Agroforestry Systems 79: 355-368.

Asse R. & Lassoie J. P. (2011) Household decision-making in agroforestry parklands of Sudano- Sahelian Mali. Agroforestry Systems 82: 247–261.

Barradas VL, Fanjul L. 1986. Microclimatic characterization of shaded and open-grown coffee (Coffea arabica) plantations in Mexico. Agric For Meteorol 38:101–112

Bayala J. , Teklehaimanot Z. & Ouedraogo S. J. (2002) Millet production under pruned tree crowns in a parkland system in Burkina Faso. Agroforestry Systems 54: 203–214.

Beer J, 1987. Advantages, disadvantages and desirable characteristics of shade trees for coffee, cocoa and tea. Agrofor Syst 5:3–13

Beer J, Muschler RG, Kass D, Somarriba E 1998. Shade management in coffee and cacao plantations. Agrofor Syst 38:139–164

Bellefontaine R. (1997) Synthèse des espèces des domaines sahélien et soudanien qui se multiplient naturellement par voie végétative, pp. 95-104. Dans : d’Herbès, Ambouta, Peltier (eds.), Actes de l’Atelier « Fonctionnement et gestion des écosystèmes forestiers contractés sahéliens, Niamey, nov. 1995 », John Libbey Eurotext.

Bisseleua D.H., Vidal B.S. (2008) Plant biodiversity and vegetation structure in traditional cocoa forest gardens in southern Cameroon under different management. Biodiversity and Conservation 17 : 1821-1835.

Boffa J-M., Taonda S. J-B., Dickey J.B. & Knudson D.M. (2000) Field-scale influence of karité (Vitellaria paradoxa) on sorghum production in the Sudan zone of Burkina Faso. Agroforestry Systems 49: 153–175.

Bonnassieux A. (2007) Dynamiques migratoires et transgressions des frontières urbain-rural au Niger, pp. 159-169. Dans : Bouquet C. (ed.), Regards géopolitiques sur les frontières. Harmattan.

Bosselmann, A.S., Dons, K., Oberthur, T., Olsen, C.S., Ræbild, A., Usma, H., 2009. The influence of shade trees on coffee quality in small holder coffee agroforestry systems in Southern Colombia. Agriculture, Ecosystems & Environment 129, 253-260.

Cannavo P, Sansoulet J, Harmand JM, Siles P, Dreyer E, Vaast P, 2011. Agroforestry associating coffee and Inga densiflora results in complementarity for water uptake and decreases deep drainage in Costa Rica. Agriculture, Ecosystems and Environment 140: 1-13.

Dawoe E.K., Isaac M., Quashie-Sam J. (2010) Litterfall and litter nutrient dynamics under cocoa ecosystems in lowland humid Ghana. Plant Soil 330: 55-64.

DeClerck, F., Vaast, P., Escalante, M., Philpott, S., Soto Pinto, L., Sinclair,F. 2006. Report on data available on tree cover in coffee plantations along the MBC and its impact on productivity and biodiversity, pp. 54.

Dia A. H., Becerra S., Gangneron F. (2008) Crises climatiques et ruptures politiques dans les transformations de l'action publique environnementale au Mali. Vertigo, Revue électronique canadienne des sciences de l'environnement, 8, 1 (art 7).

Doré, T., Clermont-Dauphin,C., Crozat, Y., David, C., Jeuffroy, M.H., Loyce, C., Makowski, D., Malézieux, E., Meynard, J.M., Morison, M. (2008) Methodological progress in regional agronomic diagnosis. Agron Sustain dev. Doi: 10.1051/agro: 2007031.

Dossa, E.L., Diedhiou, S., Compton, J.E., Assigbetse, K.B., Dick, R.P. (2010) Spatial patterns of P fractions and chemical properties in soils of two native shrubs communities in Senegal. Plant and Soil 327: 185–198.

Dugué P. (1999) Utilisation de la biomasse végétale et de la fumure animale : impacts sur l'évolution de la fertilité des terres en zone de savanes. Étude de cas au Nord-Cameroun, et essai de généralisation, Montpellier, France, Cirad-Tera.

Garrity D.P., Akinnifesi F. K., Ajayi O. C., Weldesemayat S. G., Mowo J. G., Kalinganire A., Larwanou M., Bayala J. (2010) Evergreen Agriculture: a robust approach to sustainable food security in Africa. Food Security 2: 197–214.

Gaze, S.R., Brouwer, J., Simmonds, L.P., Bromley, J. (1998) Dry season water use pat- terns under *Guiera senegalensis* L. shrubs in a tropical savanna. Journal of Arid Environment 40: 53–67.

Gbemavo, DSJC., Glèlè Kakaï, R., Assogbadjo, A., Katary, A., Gnanglè, C. (2010) Effet de l'ombrage du karité sur le rendement capsulaire du coton dans les agroécosystèmes coton karité du Nord Bénin. Tropicultura 28: 193-199.

Glèglè Kakaï R., Akpona T. J. D., Assogbadjo A. E., Gaoué O.G., Chakeredza S., Gnangle P.C., Mensah G. A. & Sinsin B. (2011) Ecological adaptation of the shea butter tree (Vitellaria paradoxa C.F. Gaertn.) along climatic gradient in Benin, West Africa. African Journal of Ecology 49: 440–449.

Gómez Delgado F, Roupsard O, Le Maire G, Taugourdeau S, Pérez A, van Oijen M, Vaast P, Rapidel B, Harmand JM, Voltz M, Bonnefond JM, Imbach P, Moussa R, 2011. Modelling the hydrological behaviour of a coffee agroforestry basin in Costa Rica. Hydrology and Earth System Sciences 15: 369–392.

Guengant J.-P., Banoin M., Quesnel A. (2002) Dynamique des populations, disponibilité en terres et adaptation des régimes fonciers : le cas du Niger. FAO, Rome.

Harmand, J.M., Avila, H., Dambrine, E., Skiba, U., De Miguel, S., Renderos Duran, R.V., Oliver, R., Jimenez, F., Beer, J. 2007. Nitrogen dynamics and soil nitrate retention in a Coffea arabica - Eucalyptus deglupta agroforestry system in southern Costa Rica. Biogeochemistry. 85, 2:125-139.

Hergoualc'h K, Blanchart E, Skiba U, Hénault C, Harmand JM, 2012. Changes in carbon stock and greenhouse gas balance in a coffee (Coffea arabica) monoculture versus a coffee agroforestry system with Inga densiflora in Costa Rica. Agriculture, Ecosystems and Environment 148: 102-110.

Huxley P.A. (1999) Tropical Agroforestry. Londres, Grande Bretagne, Blackwell Science.

Juhrbandt J., Duwe T., Barkmann J., Gerold G., Marggraf R. (2010) Structure and management of cocoa agroforestry systems in Central Sulawesi across an intensification gradient. In : Tropical rainforests and agroforests under global change. Ecological and socio-economic valuations. Tscharntke T., Leuschner C., Veldkamp E., Faust H., Guhardja E., Bidin A. (eds). Dordrecht, Pays-Bas, Springer: 115-140.

Kater L.J., Kanté S. & Budelman A. (1992) Karité (Vitellaria paradoxa) and néré (Parkia biglobosa) associated with crops in South-Mali. Agroforestry Systems 18: 89–105.

Kessler J.J. (1992) The influence of karité (Vitellaria paradoxa) and néré (Parkia biglobosa) trees on sorghum production in Burkina Faso. Agroforestry Systems 17: 97–118.

Kizito, F., Draglia, M., Sene, M., Lufafa, A., Diedhiou, I., Dick, R.P., Selker, J.S., Diack, M., Dossa, E., Khouma, M., Badiane, A.N., Ndiaye, S. (2006) Seasonal soil water variation and root patters between two semi-arid shrubs co-existing with pearl millet in Senegal, West Africa. Journal of Arid Environment 67: 436–455.

Kizito, F., Sene, M., Draglia, M., Lufafa, A., Diedhiou, I., Dossa, E., Cuenca, R., Selker, J.S., Dick, R.P. (2007) Soil water balance of annual crop-native shrub systems in Senegal's Peannut Basin: the missing link. Agricultural Water Management 90: 137– 148.

Laird S.A., Awung G.L., Lysinge R.J. (2007) Cocoa farms in the Mount Cameroon region: biological and cultural diversity in local livelihoods. Biodiversity and Conservation 16: 2401-2427.

Louppe, D. (1991) Guiera senegalensis: espèce agroforestière? Micro-jachère dérobée de saison sèche et approvisionnement énergétique d'un village du centre nord du Bassin Arachidier sénégalais. Revue Bois et Forêts des Tropiques 228: 41–47.

Milleville P. (2007) Une agronomie à l'oeuvre : Pratiques paysannes dans les campagnes du Sud. Versailles, Paris, Editions Quae, Editions Arguments, 243 p.

Mouen Bedimo, J.A., Bieyesse, D., Nyassé, S., Nottéghem, J.L., Cilas, C., 2010. Role of rainfall in the development of coffee berry disease in Coffea arabica caused by Colletotrichum kahawae in Cameroon. Plant Pathology, 59: 324-329.

Nair P.K.R. (1993) An introduction to agroforestry. Dordrecht, Pays-Bas, Kluwer Academic Publishers, 499 p.

Oke D.O., Odebiyi K.A. (2007) Traditional cocoa-based agroforestry and forest species conservation in Ondo State, Nigeria. Agriculture, Ecosystems § Environment 122: 305-311.

Ong K. & Leakey R. R. B. (1999) Why tree-crop interactions in agroforestry appear at odds with tree-grass interactions in tropical savannahs . Agroforestry Systems 45: 109–129 .

Ouédraogo S.J., Devineau J-L. (1996) Rôle de la jachère dans la reconstitution du parc à karité (Butyrospermum paradoxum Gaertn. F. Hepper) dans l'Ouest du Burkina Faso. pp. 81–87, Dans: Actes de l'atelier « La jachère lieu de production, Bobo-Dioulasso 2–4 octobre 1996 ». Projet CEE « Amélioration et gestion de la jachère en Afrique de l'Ouest », Projet 7 ACP RPR 269. Publication CORAF.

Pelissier P. (1980) L'arbre dans les paysages agraires de l'Afrique noire. Dans : Pelissier P. « L'arbre en Afrique tropicale : la fonction et le signe ». Cahiers O.R.S.T.O.M, série Sciences Humaines, vol. XVII, n° 3-4:131-136.

Pelissier P. (2001) Les interactions rurales – urbaines en Afrique de l'Ouest et Centrale. Le bulletin de l'APAD n°19, Les interactions rural – urbain. Circulations et mobilisations des ressources.

Peltier R. (1996) Les parcs à Faidherbia. Cahiers Scientifiques n°12, édition du CIRAD-Forêt.

Power, A.G. (2010) Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society B: Biological Sciences 365, 2959–2971.

Ratnadass, A., P. Fernandes, J. Avelino, and R. Habib. (2012) Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. Agronomy for Sustainable Development 32:273–303.

Ruf F., Schroth G. (1995) Chocolate Forests and Monocultures : A Historical Review of Cocoa Growing and Its Conflicting Role in Tropical Deforestation and Forest Conservation. In : Agroforestry and Biodiversity Conservation in Tropical Landscapes. Schroth G., Da Fonseca G.A.B., Harvey C.A., Gascon C., Vasconcelos H.L., Izac A.M.N. (eds). Washington, Etats-Unis, Island Press : 107-133.

Schroth G., Harvey C. (2007) Biodiversity conservation in cocoa production landscapes: an overwiew. Biodiversity and Conservation 16: 2237-2244.

Siles, P., Harmand, J-M., Vaast, P., 2010. Effects of Inga densiflora on the microclimate of coffee (Coffea arabica, L.) and overall biomass under optimal growing conditions in Costa Rica. Agroforestry Systems, 78 : 269-286.

Snoeck D., Abolo D., Jagoret P.(2010) Temporal changes in VAM fungi in the cocoa agroforestry systems of central Cameroon. Agroforestry Systems 78: 323-328.

Somarriba, E., Harvey, C.A., Samper, M., Anthony, F., Gonzalez, J., Staver, C., Rice, R.A. 2004. Biodiversity conservation in neotropical coffee (Coffea arabica) plantations, in: Schroth,G., Fonseca, G.A.B, Harvey, C.A., Gascon, C., Vasconcelos, H.L., Izac A.M.N. (Eds.). Agroforestry and biodiversity conservation in tropical landscapes, Island Press, Washington, 198-226.

Sonwa D.J., Nkongmeneck A.B., Weise S.F., Tchatat M., Adesina A.A., Janssens M.J. (2007) Diversity of plants in cocoa agroforests in the humid forest zone of Southern Cameroon. Biodiversity and Conservation 16: 2385-2400.

Soto-Pinto, L., Perfecto, I., Castillo-Hernandes, J., Caballero-Nieto, J., 2000. Shade effect on coffee production at the northern Tzeltal zone of the state of Chiapas, Mexico. Agriculture, Ecosystems and Environment, 80 : 61-69.

Teklehaimanot Z. (2004) Exploiting the potential of indigenous agroforestry trees: Parkia biglobosa and Vitellaria paradoxa in sub-Saharan Africa. Agroforestry Systems 61: 207–220.

Vaast P., Bertrand B., Perriot J.J., Guyot B., Génard M. 2006. Fruit thinning and shade improve bean characteristics and beverage quality of coffee (Coffea arabica L.) under optimal conditions. Journal of the science of food and agriculture, 86 (2) : 197-204.

Vaast P, Harmand JM, 2002. Importance des systèmes agroforestiers dans la production de café en Amérique centrale et au Mexique. In : Recherche et caféiculture, Plantations, Recherche, Développement, pp: 35-40.

Vaast P, van Kanten R, Siles P, Angrand J, Aguilar A., 2007. Chapter 9. Biophysical interactions between timber trees and Arabica coffee in suboptimal conditions of Central America. In: Jose´ S, Gordon AM (eds) Towards agroforesty design: an ecological approach. Springer, Berlin, pp 135–148 Wezel, A., Rajot, J.L., Herbig, C. (2000) Influence of shrubs on soil characteristics and their function in Sahelian agro-ecosystems in semi-arid Niger. Journal of Arid Environment 44: 383–398.

Wood G.A.R., Lass R.A. (1985) Cocoa. Fourth edition. Londres, Grande Bretagne, Longman, Tropical Agriculture Series, 620 p.

Zapfack L., Engwald S., Sonke B., Achoundong G., Birang A.M. (2002) The impact of land conversion on plant biodiversity in the forest zone of Cameroon. Biodiversity and Conservation 2 : 2047-2061. Asse R. & Lassoie J. P. (2011) Household decision-making in agroforestry parklands of Sudano- Sahelian Mali. Agroforestry Systems 82: 247–261.

11.Funding requested

Summary of the budget by year and item of expenditures (see the annexes for detailed information)

Project budget	**2012**	**2013**	**2014**	**2015**	**Total**
Student course allowances	400	72697	39914	15420	128431
Trainee travel	0	19350	6600	1200	27150
Course operations	700	12043	12346	1150	26239
Airline tickets for researcher missions	16600	31200	12600	6300	66700
Mission expenses	19300	36400	12100	11300	79100
Operation	32130	98065	71835	29900	231930
- Salaries + local travel	*13270*	*69010*	*50300*	*13450*	*146030*
- Analyses	*0*	*16000*	*11500*	*7000*	*34500*
- Satellite images	*4800*	*350*	*2700*	*2100*	*9950*
- Consumables and small items of equipment	*10560*	*9205*	*2275*	*1050*	*190480*
- Meeting expenses + publications	*3500*	*3500*	*5060*	*6300*	*18360*
Equipment	35150	5300	0	0	40450
Total	**104280**	**275055**	**155395**	**65270**	**600000**

Description of equipment

Organization	**Research unit (UMR)**	**Equipment**
IRD	LTHE	1 weather station
	HSM	Water measurement systems 10 Tensiometers: Watermark + thermistor 3 CAMPBELL data loggers 3 50-Wc solar panels 4 10-A solar regulators 4 12-V / 110 Ah batteries 4 Campbell multiplexers 9 Dynamax 50 mm sap flow sensors 4 heat regulators 9 25-m sensor cable extensions 3 storage cabinets
	Eco&Sols	8 1-volt dendrometers with Wifi system PAR and SPAD sensors

12.Participants

List of participants from the North

Organization	Research unit	Forename, surname
CIRAD	UR Systèmes Bananiers Plantains	S. Dépigny
	UR Systèmes Bananiers Plantains	Thierry Lescot
	UMR AMAP	Hervé Rey
	UMR AMAP	Jean Dauzat
	UMR ART DEV	Sandrine Fréguin-Gresh
	UMR ART DEV	Jean François Le Coq
	UR Bioagresseurs	Jacques Avelino
	UR Bioagresseurs	Régis Babin
	UR Bioagresseurs	Leila Bagny Beilhe
	UR Bioagresseurs	Daniel Bieysse
	UR Bioagresseurs	Christian Cilas
	UR Bioagresseurs	Natacha Motisi
	UR Bioagresseurs	Philippe Lachenaud
	UR Bioagresseurs	Fabrice Pinard
	UR Bioagresseurs	Olivier Sounigo
	UR Bioagresseurs	Martijn ten Hoopen
	UMR Eco&Sols	Jean-Michel Harmand
	UMR Eco&Sols	Christophe Jourdan
	UMR Eco&Sols	Guerric le Maire
	UMR Eco&Sols	Olivier Roupsard
	UMR Eco&Sols	Philippe Vaast
	UMR Eco&Sols	Karel Van Den Meersche
	UMR Innovation	Nicole Sibelet
	UMR Innovation	Philippe Pedelahore
	UR SCA	Thierry Brévault
	UR SCA	Rabah Lahmar
	UR SCA	Valérie Soti
	UMR System	Clémentine Allinne
	UMR SYSTEM	O. Deheuvels
	UMR System	Patrick Jagoret
	UMR System	Nathalie Lamanda
	UMR System	Marie-Ange Ngo-Bieng
	UMR System	Bruno Rapidel

	UMR System	Stéphane Saj
	UMR Tetis	Camille Lelong
IRD	UMI Résiliences	Isabelle Droy
	UMR AMAP	N Barbier
	UMR AMAP	Hubert De Foresta
	UMR CEREGE	Pierre Ethienne Mathé
	UMR Eco&Sols	Eric Blanchart
	UMR Eco&Sols	Marc Pansu
	UMR Eco&Sols	Alain Albrecht
	UMR Eco&Sols	Tiphaine Chevallier
	UMR Eco&Sols	Dominique Masse
	UMR Eco&Sols	Lydie Lardy
	UMR Eco&Sols	Cathy Clermont-Dauphin
	UMR Eco&Sols	Laurent Cournac
	UMR Eco&Sols	Frederic Do
	UMR GRED	Stéphanie Carrière
	UMR GRED	Patrice Levang
	UMR HSM	Julie Carreau
	UMR HSM	Jérome Demarty
	UMR HSM	Bernard Cappelaere
	UMR HSM	Christophe Peugeot
	UMR HSM	Luc Séguis
	UMR HSM	Josiane Seghieri
	UMR LTHE	Jean-Martial Cohard
	UMR LTHE	Sylvie Galle
	UMR IDES-Univ Paris Sud	Laurent Bergonzini
	UMR LOCEAN	David Williamson
INRA	UR BEF	Bernd Zeller
	UMR LisaH	Y. Le Bissonnais
Ohio State University	NSF/PIRE project	R. Dick
Montpellier SupAgro	UMR Innovation	Isabelle Michel
	UMR System	Jacques Wéry
Bordeauw University	UMR - ADES	Jean Etienne Bidou

List of participants from the South

Country	Organization	Forename, surname
Benin	INRAB	Césaire P Gnanglé
Benin	DG-Eau (Directorate General for Water)	Dr. Arnaud Zannou
Benin	Abomey Calavi University, Agricultural Sciences Faculty	Prof. Kossi Euloge Agbossou
Cameroon	IRAD	Joseph Mouen Bedimo
Cameroon	IRAD	Hervé Todem
Cameroon	IRAD	Virginie Mfegue
Cameroon	IRAD	Nérée Onguéné
Cameroon	IRAD	Bidzanga Nomo
Cameroon	IRAD	Hervé Ngnogué Todem
Cameroon	Dschang University	Marie-Louise Avana
Costa Rica	CATIE	Isabel Gutiérrez
Costa Rica	CATIE	Wilbert Phillips Mora
Costa Rica	CATIE	Gabriela Soto
Costa Rica	CATIE	Eduardo Somarriba
Costa Rica	CATIE	Elias de Melo
Costa Rica	CINPE	Fernando Saenz
Costa Rica	Universidad de Costa Rica, CITA	M. Villatoro, ;
Costa Rica	Universidad de Costa Rica, CITA	María del Milagro Granados
Kenya	University of Nairobi	Prof. G. Ong'ama
Kenya	University of Nairobi	Prof. D. Olago
Kenya	CRF Nairobi	J. Kimemia
Kenya	ICRAF	E. Barrios
Kenya	ICRAF	C. Mathuri
Nicaragua	Nitlapan	Francisco Pérez
Niger	Abdou Moumouni University, Faculty of Sciences	Yahaya Nazoumou
Niger	Maradi Univ., ex-Abdou Moumouni University, Niamey	Prof. Mahamane Saadou
Niger	Maradi Univ., ex-Abdou Moumouni University, Niamey	Dr. Ali Mahamane
Senegal	ISRA	Y. Ndour
Senegal	ISRA	NH. Diallo
Tanzania	Agronomy office, Rungwe District	Hadda MATUNDA

Tanzania	IRA, Univ. Dar es Salaam	B Mwakisunga
Tanzania	IRA, Univ. Dar es Salaam	S. Kajula
Tanzania	IRA, Univ. Dar es Salaam	J. Lyimo
Tanzania	IRA, Univ. Dar es Salaam	Prof. A Majule