Managing pests and optimizing pesticide use
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 pests and diseases: risk analysis and control)
Managing pests and optimizing pesticide use

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...continued on page 32
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 non-diversified 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 non-host 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 *Cosmolopites 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 sanitation 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 corethurus* 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.
Managing pests and optimizing pesticide use

Effects of shade trees on pests and diseases of Arabica coffee

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 (Myctena 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 fulfill 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,
economic and social situations in tropical regions. This is contributing to the emergence of genuine ecologically intensive and sustainable 'ecohorticulture' 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**

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 under way on the predatory habits of codling moths and the rosy apple aphid (*Dysaphis plantaginea*), 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 enhancement 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 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

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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![Sahlbergella singularis adult and nymphs on a cocoa pod.](image1)

Inset - *Cocoa plantation.*

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![Sahlbergella singularis adult and nymphs on a cocoa pod.](image2)

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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 (H and deuterium) and polymorphism in microbial flora (bacteria, yeast) hosted by adult pests, determined using molecular markers, can facilitate study of long-distance migratory phenomena and determination of the geographical origins of these populations.

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

▲ Noctuid caterpillar feeding on a cotton boll.
▲ Peach-potato aphid (Myzus persicae) infestation on a peach tree branch.