Family farming is highly diversified from many standpoints. These farms feature myriad techniques, a broad range of knowledge and know-how and also an intricate combination of species and varieties arranged in a deliberate spatiotemporal pattern depending on the soil, uses and cycles.

Pooling wild and cultivated biodiversity as well as natural resource management in the same chapter underscores the fact that in many family farming systems these constituents are not perceived separately, but rather as a whole in which social, economic, political and cultural factors interact with biological, agricultural and ecological factors. Whereas higher education and research institutions tend to reproduce, respect and comply with expertise specialization, better management of multidisciplinary approaches is the challenge that should be addressed by studies and management of wild and cultivated diversity in the family farming setting.

This chapter highlights several examples of the ingenuity of family farming regarding wild and cultivated biodiversity management. For instance, in Madagascar, plant diversity stems directly from the cropping practices and crop management sequences used. This diversity in turn promotes the diversity of birds from protected forests that take advantage of the agricultural landscape shaped by farmers to nest, feed and breed. Some so-called service plant species are also grown for the purpose of integrated pest management. In central Cameroon, around 100 plant species that have a wide variety of uses—producing fruit, oil, drinks, bark (used for medicinal purposes), timber and fuelwood—have been inventoried in cocoa farms. This multifunctional mosaic also helps preserve soil fertility by providing shade which enhances cocoa tree growth. The many interactions that characterize family farm functioning are promoted and ‘plant-microorganism’ combinations are proposed to ensure more efficient nitrogen and phosphorus sequestration in Tunisia, Morocco, France and Burkina Faso.

International issues concerning family farming are also showcased via studies on biodiversity and its management. Among some 7,000 known crop species, only a few ensure global food security from a quantitative perspective. Other species that are overlooked on an international scale represent a reservoir of genetic and functional diversity which remains unexploited, despite the demonstrated high potential of these crops. The adaptation capacity of traditional millet varieties to climatic variations is, for instance, being investigated in Niger; while decentralized management systems are tested in Oceania, Africa, South America and Asia. Locally cultivated clones and varieties are distributed in a diverse range of ecological and cultural environments. Each benefits from the adaptation potential of plants originally bred in other areas. Studies on the impact of introducing new varieties have led to the development of a participatory breeding process involving farmers in Mali and other countries to promote the appropriation of resources that best meet farmers’ needs.

At a more global level, water resource access and sharing generally represent another crucial international and development issue as it increases the interdependence of local, regional and international stakeholders.

Research is also focused on the inventory, collection and organization of genetic diversity of plants that have been propagated by generations of family farmers until today. As their diversity results from both natural and human-oriented processes, cultivated plants must be considered inherently hybrid entities to be studied by multidisciplinary approaches, as clearly illustrated in this chapter.

Challenges in the study and management of wild and cultivated diversity could not be addressed without the involvement of around 10 Agropolis institutions, bringing together nine laboratories and nearly 550 scientists specialized on over 20 Mediterranean and tropical species and involved in research on five continents.

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& Anne-Céline Thuillet (UMR DIADE)
How can the resilience of family farms that crop roots and tubers be facilitated?

Root and tuber crops (cassava, sweet potato, yam, taro) often have a very narrow genetic base in given countries, but the allelic diversity varies significantly between regions. Adaptation to global change could thus be enhanced by long-range distribution of this diversity. However, root and tuber crops do not benefit from seed sectors—smallholders have to manage their own plant material and few of them have access to improved varieties disseminated by research centres. A decentralized system was thus developed whereby farmers are supplied with varietal clones or hybrids with high allelic diversity. The principle is simple—avoid a concentration of resources required for genetic improvement and distribute genes for better preservation and, especially, use. The system is complex to implement because sets of varieties with high allelic diversity first have to be assembled and then large-scale screening is required using powerful tools.

In practice, selection of a representative sample (10% of varieties) of useful species diversity avoids duplication and maximizes the possibility of generating high variability. Introduced genotypes are then propagated and distributed directly to farmers, who in turn are responsible for the final selection and redistribution to neighbours. This approach was tested with taro (*Colocasia esculenta*) in Vanuatu, where farmers are widely dispersed and isolated on 80 islands. The material was distributed to many farmers with minimal monitoring and assistance. Field inventories revealed that the introduced varieties were preserved, that the best ones were propagated and distributed via exchange networks and that local varieties were not threatened. If the genotypes disappear—which is a common phenomenon in these regions—it is essential that the most relevant genes are consciously or unconsciously transmitted via networks. This FFEM-funded approach has now been tested in 19 countries in South America, Asia and Oceania (financed through the EU Food Security Thematic Programme).

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Characterization and development of cultivated biodiversity

The aim of the joint research unit *Genetic Improvement and Adaptation of Mediterranean and Tropical Plants* (UMR AGAP, CIRAD/INRA/Montpellier SupAgro) is to contribute to boosting knowledge and breeding varieties adapted to a range of environments and uses, while also participating in training and education in the areas mentioned.

The unit focuses on developing family farming through field initiatives involving the management, characterization and development of cultivated biodiversity. The diverse range of projects under way illustrates the diversity of multidisciplinary and complementary approaches in over 20 countries in South America, Africa, Asia and Oceania.

With its 13 research teams and five technology platforms, UMR AGAP implements quantitative genetics, ecophysiology, developmental biology and biomathematical approaches aimed at gaining insight into the genetic and functional bases of agronomic traits in around 20 Mediterranean and tropical crop species. The team’s main activities concern genetic resource analysis and development through studies on diversity structuring and plant adaptation to abiotic and biotic constraints using the latest genomics and functional analysis tools.

This research sheds light on the practices and roles of farming societies in the structuring and management (including conservation) of the genetic resources of major or underutilized food crops. For instance, participatory selection is applied to breed varieties tailored to users’ needs and applications, seed systems are improved to adapt them to different settings, and combined analyses of genetic resources and traditional knowledge are conducted.

The unit is based in Montpellier (France) and French overseas departments and regions. Its research is carried out in collaboration with public and private partners in France and abroad—Africa, Latin America, Asia, Europe and Oceania—thus forming a broad global network.
Fonio—a keystone for food security in West Africa

Over 7,000 plants are cropped worldwide but from a quantitative standpoint food security is based on just a few major species. Wheat, maize and rice account for over 50% of the world’s food energy intake of plant origin. Underutilized species still represent an unexplored reservoir of diversity and potential despite incentives to foster sustainable agriculture and consumption via crop diversification. Could these species be tomorrow’s crops?

Fonio is promising in this respect. This small-grain cereal is cultivated and consumed in sub-Saharan regions of West Africa, from Senegal to Lake Chad. Two fonio species are generally cropped, i.e. mainly white fonio (Digitaria exilis Stapf), as well as black fonio (D. iburua Stapf), which is primarily grown in northern Togo. Fonio is usually only grown on family farms. Farmers tend to differentiate varieties according to the length of their growth cycle. Seeds of short-cycle varieties ripen before the end of the rainy season and therefore serve to fill the hunger gap. Fonio is grown on small plots, often in women’s fields, and harvested every day for daily consumption. Seeds of varieties with a longer cycle, which tend to have higher yields, can generally be consumed and marketed. Fonio cropping thus depends on families’ specific needs and uses, and thus on the social organization.

A workshop attended by different stakeholders was held to draw up a concerted list of needs regarding the assessment of available diversity (in a broad sense), improving cultivation procedures, marketing channels and postharvest procedures, including the development of specific equipment. These aspects are being dealt with through different projects involving multidisciplinary approaches. UMR AGAP, DIADE and QUALISUD and African partners are focusing research on diversity with respect to agrosystems, species, know-how and associated techniques. Comprehensive approaches that do not dissociate the crop from its physical and social environment are applied in these projects. Methods and tools inspired from those used for major crop species are developed, along with new technological and methodological tools, particularly on the basis of preservation, marketing and processing strategies.

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▲ Bundling fonio after sickle harvesting and stacking.
▼ Early fonio harvested in Upper Guinea and stacked in the field before threshing and consumption.
Evolution of millet varieties in Niger in response to climatic variations

Millet is a rainfed crop in Niger, in an economic setting dominated by family farming. The cropping area is bounded in the north by the 350 mm isohyet, while south of this line the climatic gradient extends towards less arid conditions. The flowering dates of the varieties grown in this area are variable and correlated with the rainfall gradient—with millet flowering earlier as the climatic conditions get drier.

A series of heavy droughts occurred in the Sahel between 1970 and 2000. A comparison of millet samples collected in 1976 and 2003 in the same villages in Niger revealed that the varieties, their ranges and neutral genetic diversity (where diversity has no impact on organisms’ adaptation capacity) were similar. Conversely, trials conducted under controlled conditions over a 3-year period indicated a shift towards a more compact morphology and earlier flowering in these varieties.

Genetically, in the 1976 and 2003 samples, UMR DIADE identified polymorphism associated with flowering variation in the PgPHYC gene. The frequency of this gene’s earliness allele increased between the two sampling years. These results suggest that there has been selection on this gene over time. These studies are currently being extended within the ARCAD project* under way in a collaboration involving INRA, INRA and CIRAD. These findings demonstrate the adaptation capacity of millet to climatic variations in agricultural systems predominated by family farms in which the crop varieties grown feature high genetic diversity.

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Functional and evolutionary biology of plants of agricultural or ecological interest

Research conducted by the joint research unit Crop Diversity, Adaptation and Development (UMR DIADE, CIRAD/IRD/UM2) is closely linked with the challenges facing family farming in coping with environmental changes. UMR DIADE pays close attention to processes involved in the adaptation of tropical plants to natural and human-induced changes in the environment. Studies are focused on different biological scales: structural and functional genome diversification mechanisms, and evolution in the genetic diversity of plant populations.

It is currently possible to conduct cutting edge research on a broad range of different crop plants, some of which are little known. This research can benefit from the transfer of advanced knowledge on the biology of so-called model plants (rice, Arabidopsis, tomato, poplar). Plant species of agricultural or ecological interest (coffee, casuarinas, yam, maize, palm, millet) are investigated by the unit. These species are generally grown in family farming based systems.

The unit’s field studies are often focused on these latter systems. The research activities are carried out with local partners in West and North Africa (Senegal, Niger, Cameroon, Benin, Morocco), South America (Peru, Colombia, Argentina) and Asia (Vietnam).

Many crop plants are native to developing countries. Smallholders have shaped the diversity of these plants and contributed to their adaptation to various environments via their cropping and seed selection practices. Understanding how crop plants evolve and adapt is necessary to identify practices beneficial to this adaptation. In-depth knowledge of the biological mechanisms of adaptation contributes to the development of strategies for the conservation, management and effective use of crop plant biodiversity—a food security pillar for communities in developing countries. • • •
Soil-plant interactions—the basis of production systems

The aim of research conducted by the joint research unit Functional Ecology & Bio-geochemistry of Soils & Agro-ecosystems (UMR Eco&Sols, Montpellier SupAgro/INRA/CIRAD/IRD) is to develop ecological engineering approaches for the management and improvement of the agricultural and environmental functions of Mediterranean and tropical agroecosystems.

Low-input agricultural systems are particularly targeted, which generally involves smallholdings, especially in developing countries. UMR Eco&Sols aims to develop knowledge bases concerning joint changes in plant and soil functioning under the impact of global change and agricultural practices.

The unit conducts research to describe ecological processes involved in primary production and regulation of carbon and nutrient fluxes in agrosystems, particularly: major nutrient cycles (nitrogen, phosphorus), ecosystem regulation services and, specifically, carbon sequestration—carbon storage and greenhouse gas emission—and the ecological dynamics of biological contaminants. The stability and resilience of these functional communities to climate and land use changes are studied in different Mediterranean and tropical soil-climate conditions in collaborations with national agricultural research centres and universities in developing countries. These experimental approaches are closely associated with a modelling approach dedicated to the formalization of biological and biogeochemical processes that determine soil-plant interactions as well as to the prediction of flows within agroecosystems.

UMR Eco&Sols is located in France (Montpellier) and in several tropical countries of West (Senegal, Burkina Faso) and Central (Congo) Africa, Madagascar, Southeast Asia (Thailand) and Latin America (Brazil, Costa Rica). The main agroecosystems studied range from cereal crop systems to tree crop plantation systems, in association or rotation with legumes.

Other teams focused on this topic

- UMR ART-Dev: Actors, Resources and Territories in Development (CNRS/UM3/CIRAD/UPVD/UM1) 70 scientists
- UMR GRED: Governance, Risk, Environment and Development (IRD/UM3) 45 scientists
- UMR QUALISUD: Integrated Approach to Food Quality (CIRAD/Montpellier SupAgro/UM1/UM2) 66 scientists
- UPR AIDA: Agroecology and Sustainable Intensification of Annual Crops (CIRAD) 56 scientists
- UPR B&SEF: Goods and Services of Tropical Forest Ecosystems (CIRAD) 45 scientists

Legumes in Mediterranean and tropical production systems

The demand for plant protein for food and feed uses has increased considerably in recent decades. As legumes produce high protein seeds, they are prime candidates for meeting the growing demand. However, there is high variability in legume yields due to often limited water and nutrient supplies. It is also now essential to reduce the reliance on chemical inputs in research on new agricultural practices.

The aim of the FABATROPIMED project (2010-2015), entitled ‘Ecological services of legumes for nitrogen and phosphorus biogeochemical cycles and carbon sequestration in cereal cropping systems of Africa and the Mediterranean Basin’, is to increase the role played by legumes in conventional cropping systems in West and North Africa, and Madagascar. The unique feature of this UMR Eco&Sols coordinated project is that it proposes the co-construction, with farmers, of technological innovations that influence interactions between soil microorganisms and plants in order to achieve more efficient nitrogen and phosphorus acquisition.

This multi-location participatory research is geared towards organizing selection processes for efficient plant-microorganism combinations adapted to local conditions. These studies are focused on crop plants such as Phaseolus vulgaris (green bean), Vicia faba (faba bean) and Vigna unguiculata (cowpea), grown in rotations or association with cereals such as wheat in Tunisia, Morocco, Algeria and southern France, maize in Algeria and Madagascar, and sorghum in Burkina Faso.

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Agroforestry systems—dynamics and management of ecosystem services benefiting rural households

Many global agricultural systems are based on multispecies cropping systems, which provide food and income for millions of rural families. These systems currently seem to offer a credible alternative to fulfil the Millennium Development Goals regarding the eradication of hunger and the fight against poverty worldwide. They could also serve as models for the development of new ecologically intensive and multifunctional cropping systems.

The research plan of the joint research unit Tropical and Mediterranean Cropping System Functioning and Management (UMR SYSTEM, CIRAD/INRA/Montpellier SupAgro) is aimed at investigating the properties of these systems in temperate and tropical areas, while determining the management leeway for efficient and sustainable production of different ecosystem services that rural households expect from agriculture. Research conducted by UMR SYSTEM is focused on studying the properties of annual-perennial and herbaceous-woody species mixtures that smallholders combine in the same area. These species meet different needs of farming families, but compete for light and soil resources. Gaining insight into the terms of this competition could help identify conditions required to achieve greater overall productivity.

The different environmental services offered by these systems have also been characterized: soil protection and water dynamics, biodiversity preservation, regulation of pathogen communities, pests and beneficial organisms. Finally, the evolutionary dynamics of these systems—which farmers are instrumental in changing over time—are analysed along with the impact of plant diversity on the stability of their performances and resilience to climate hazards. The many services that rural households expect from multispecies systems also prompted UMR SYSTEM to design new cropping systems by studying evolution scenarios based on crop diversification.

These scenarios are the focus of a multicriteria assessment based on experiments and/or simulations of prototypes in collaboration with farmers. In order to support the planned technical changes, greater attention is paid to the evolution of biophysical and technical constituents of systems in transition, while developing strategies to manage these transitions so as to be able to cope with hazards. On the farm scale, the unit studies how strategic choices and the cropping systems involved change and are able to maintain their performances when changes are under way with respect to the climate, regulations, the economy and technical specifications. •••
Cocoa agroforestry systems in Central America—biodiversity management for a better trade-off between ecosystem services

In Central America, UMR SYSTEM is working in partnership with the Tropical Agricultural Research and Higher Education Centre (CATIE) and other members of the ‘Tree crop-based agroforestry’ Research and Training Platform in Partnership (PP) to quantify ecosystem services provided by cocoa-based agroforestry systems*. These systems, which are managed by farmers and their families on small areas (0.25-4 ha), have long been neglected by agricultural research. Since the 1990s, agroforests have been spotlighted for their extraordinarily high wild and cultivated biodiversity and role in supplying many ecosystem services. The multifunctionality of these systems, their structural similarities with tropical forests, the spatial and functional transition between forests and cropping systems that they facilitate, and their various productions makes them a relevant focus of ecological intensification research.

A network of 229 smallholder cocoa agroforest plots was monitored in Central America (Panama, Costa Rica, Nicaragua, Guatemala, Honduras), to:
- measure the productivity of the main crop (cocoa) and the system (supply services)
- gain insight into the relationships between the botanical composition, the spatial structure of the vegetation and the productivity of cocoa trees and the system
- seek trade-offs between the main crop and system performances
- seek levers to adjust the balance between ecosystem supply services (crop productivity), regulation (pollination, pest regulation, carbon sequestration) and support (primary production, wildlife habitat, etc.) provided by these systems.

By integrating forestry and community ecology concepts and tools with those of agronomy to characterize the composition and structure of complex agroforests and quantify the studied ecosystem services, UMR SYSTEM is firmly positioned in the field of the agroecology of agroforestry cropping systems regarding the ecological intensification of their productivity.

Research conducted by UMR SYSTEM and partners is ongoing in this georeferenced plot network under the PP-PCP ‘Central America’.

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* Studies carried out under the ‘Cocoa Central America’ project in which UMR SYSTEM coordinated the Research component from 2008 to 2012.

Cocoa farms in central Cameroon—complex systems that meet farmers’ needs

Within the framework of the ‘Agroforestry Cameroon’ Research and Training Platform in Partnership, UMR SYSTEM is conducting research on cocoa agroforestry systems in collaboration with the Institut de recherche agricole pour le développement (IRAD, Cameroon) and other CIRAD research units (including UPR Performance of Tree Crop-Based Systems). To analyse the performances of these systems—which are hard to assess as a whole—a participatory assessment of 50 cocoa agroforests was carried out based on a use value attributed by farmers for each species in the system. Farmers thus revealed that 80% of the 122 species inventoried in their cocoa stands had between one and seven different uses, thus confirming their multifunctionality. The highest use value was attributed to cocoa trees (24%), but other associated woody species were found to have an explicit value for farmers by meeting the vital needs of farm households, including the sale and consumption of various products (fruits, oil and palm wine), supplies of medicinal products (bark, leaves), timber and fuelwood, preserving soil fertility and generating shade for cocoa trees.

The frequency of these species was also significantly and positively correlated with their use value ($R^2 = 0.914$). This confirms that the multifunctionality of cocoa agroforestry systems is closely associated with their high agrobiodiversity level and that these complex systems are built and managed by farmers over time. Initiatives to improve cocoa cropping systems should thus take this intentional complexity into account so as to meet farmers’ needs and ensure better adoption of proposed technical innovations. Designs of new systems should follow the lead of these agroforestry systems so that cocoa production will hereafter be more in line with farmers’ strategies while also providing ecosystem services.

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Average use values attributed by Cameroonian farmers to different woody species growing in their cocoa agroforests (study carried out in 2009 on 50 cocoa farms in the central region).
Large-scale agricultural investment and water resource sharing for irrigated rice cropping in Mali

As pressure on agricultural and food markets increases, vast areas of arable land in Africa are attracting a growing number of international investors in a phenomenon often referred to as ‘land grabbing’.

In the irrigation area administered by the Office du Niger (Mali), in addition to competition for land, the arrival of investors has prompted a redefinition of the terms of access to water, an essential resource for irrigated rice production. 600,000 ha of land is currently being allocated to investors, i.e. sixfold the currently developed area, while more than 80% of the Niger River flow is already being used for irrigation purposes during some periods of the dry season. This leaves very little leeway to meet future water needs.

Sharing of water supplies between different stakeholders is both a technical and social issue. Family farmers, who have made this rice-growing area a success, see their future becoming increasingly precarious due to the lack of access to information and of leverage in resource allocation negotiations.

In this setting, UMR G-EAU is conducting action research with the following objectives:

- to analyse and compare land management practices of family farmers and investors
- to assist stakeholders in identifying the long-term challenges and foreseeing the impacts of new land allocations on the functioning of the irrigated system.

UMR G-EAU and the Institut d’Économie Rurale du Mali conducted a participatory prospective awareness initiative. Different stakeholder groups participated in scenario-building workshops and role playing games. Family farmers, who had until then not been substantially involved in any long-term thinking, were able to exchange information and views on the future. This ultimately enabled them to imagine possible development scenarios for the next 20 years and debate guidelines to move towards the future in the most suitable way, while ensuring the sustainability of the family farming model and preserving the resources.

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Irrigated agriculture—adaptation to global changes and impacts on water resources in North and Sub-Saharan Africa

The joint research unit Water Resource Management, Actors and Uses (UMR G-EAU, AgroParisTech/CIHEAM-IAMM/CIRAD/IRD/IRSTEA/Montpellier SupAgro) conducts research on water resource management arrangements at different scales (catchment basin to irrigated plot). The aim is to test levers to balance water resource preservation and sustainable development. Research carried out at the interface between water resources and uses is multidisciplinary, ranging from earth sciences (hydrology, hydrogeology, engineering (automation, fluid mechanics), life sciences (agronomy, hydrobiology), human and social sciences (economics, sociology, political science). The social dimension of agricultural water use has led the unit to focus on differentiating types of production and their scope for water access and management.

The unit conducts research along three lines, two of which concern the quantitative dynamics of water resources and their strategic and operational management. The third line deals with irrigated agricultural systems, their adaptations to global changes, impacts on water resources and ways to enhance their performances via technical or organizational innovations. Forms of social organization of agricultural production are also taken into account, while focusing on how family farms change to cope with modernization in order to intensify their production, and the increase in more capital-intensive, and potentially competing, production structures.

In irrigated agriculture, as in the entire agricultural sector, ‘family farming’ structures—based on family control of farm production and management—still prevail worldwide. By mobilizing costly water development projects, irrigated agriculture implies intensification and high added value crops. The current pressure on cereal markets due to growing global demand has questioned the capacity of family farms to modernize in order to make effective use of these development projects. UMR G-EAU addresses these issues of changes in production structures and tension over land and water access in North Africa, Sub-Saharan Africa, and Asia.

The research is focused on agrarian dynamics and associated social and economic challenges, supporting the design and dissemination of innovations in irrigated cropping systems adapted to small family farms, participatory and prospective approaches to integrate smallholders in water resource sharing negotiation and coordination processes.
Modelling interactions between ecological and social dynamics

The internal research unit Management of Renewable Resources and Environment (UPR GREEN, CIRAD) uses systematic and interdisciplinary approaches to address the issue of the co-viability of ecosystems and the livelihoods they support. Interactions between ecological and social dynamics are the main focus. The aim is to understand how these interactions question collective decisionmaking processes and how nature is appropriated in a sustainable development setting. Studies carried out since its founding in 1994 have highlighted the construction of an interdisciplinary approach to study topics—social, agronomic and ecological sciences, and informatics—where modelling is an intermediation process between different types of knowledge.

With a ‘management of common resources and the environment’ entry, the unit focuses on a broad range of different resources (water, forests, land, fisheries, etc.) on various scales (village to region, sometimes even country). It conducts cross-sectoral analyses on biodiversity, land-use changes and conservation/usage arbitration, natural and renewable resource access and modes of appropriation. This Montpellier-based research unit is also involved in research in West Africa, the Indian Ocean, Southeast Asia, Central and South America.

UPR GREEN was a pioneer in the development of participatory modelling approaches (ComMod, Companion Modeling) to support local stakeholders (farmers, managers, politicians, etc.) on renewable natural resource management, based on its own modelling platforms’. The researchers are thus highly involved in institutional arrangements that accompany public decisionmaking processes on local, national and even international scales (Madagascar and Senegal on land, Bhutan, Burkina Faso and Ghana on water, Latin America and West Africa on agrobiodiversity).

Enhanced production and seed access for family farmers

Access to a variety of high quality seeds for a broad range of species is a major challenge for African family farms, from the food security and climate change adaptation standpoint. Seed dissemination in Africa is generally managed through farmers’ seed systems based on traditional trade, which means that all farmers have access to high varietal diversity that exists in situ according to practices that are dependent on the sociocultural context. These open and dynamic systems constantly integrate new cultivated varieties/species and changes in seed trade rules. Currently, 80% of food crop seeds are traded through these systems in Africa, whereas the capacity of improved variety dissemination through formal systems is limited.

The ‘Sustainable management of agricultural biodiversity in Mali’ (FFEM, 2010-2013) and ‘Impact of seed access arrangements on genetic diversity dynamics in agriculture’ (ANR, 2008-2012) projects conducted by UPR GREEN and UMR AGAP were aimed at supporting family farming stakeholders in a participatory improved variety selection and seed dissemination process, and at studying the impact of introducing new varieties on the biodiversity dynamics of studied species.

Innovative tools were used to develop a participatory modelling approach applied to seed systems. Multi-agent models incorporate stakeholders’ viewpoints and simulate scenarios involving changes in practices to analyse their impacts on biodiversity dynamics, with the ultimate aim of collectively designing new agrobiodiversity management strategies. The characterization of varietal diversity in local cropping systems is discussed to be able to assess system changes according to different scenarios. These scenarios are useful to, for instance, discuss the location of certain minor sorghum varieties (in terms of cropping area and number of farmers that use them) according to the type of farm and risk of genetic diversity loss. Workshops conducted in Mali led to the registration of plant varieties in the national catalogue to enable the extension of sorghum varieties collectively obtained by participatory selection.

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Wild and cultivated biodiversity and natural resource management

Sociosystem and agrosystem diversification in North African oases—the status of family farming and date palm cropping

Over the centuries, Tunisian oases have adapted to many economic, political and environmental crises. Families were organized around oasis agriculture, with date palms being the traditional core crop. Oasis agrosystems were bio-diversified (three cropping levels, a diverse range of palm varieties), in interaction with livestock farming, often associated with rainfed crops grown outside of irrigated areas. These agrosystems were based on know-how and technical skills passed down from father to son.

In recent decades, political and economic support for Deglet Nour dates (an exported variety) has been underpinned by subsidies for the development of new irrigated areas and the expansion of cropping areas. The oases are open to the public (e.g. tourism). They have, however, been impacted by increased desertification, poverty and outmigration, which is common in dryland regions. All of these globalization-related dynamics have given rise to new patterns regarding society/environment relationships. Agricultural artificialization thus continues through large-scale initiatives (earthworks, deep drilling). Date palm is less bio-diversified and increasingly at risk with respect to diseases and environmental conditions. In some oases, agrosystems are no longer the only economic resources—tourism is developing, urban areas are taking over irrigated areas. Palms are sometimes no longer grown to produce dates but rather to be decorative or even recreational (tree climbing). Palm stands are sometimes even replaced by recreational activities (golf, etc.) in irrigation areas. Finally, some other oases are geared towards promoting ‘a traditional system’.

A collective† has been set up to update long-standing systemic knowledge and relatively monothematic current research. The aim is to gain insight into the different oasis systems that prevail in Tunisia and other North African areas, the status of date palm and family farming, and the viability of new systems and their environment/society co-viability. This means seeking ways to observe and monitor changes via remote sensing, while also extending the observations to other North African areas (GEOSUD programme). The ultimate goal is to mobilize (in observatories) all knowledge on these systems and their spatial footprints in order to help oasis inhabitants develop more efficient sustainable systems and foresee risks.

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† Collective consisting of UMR ESPACE-DEV in France, the Institut des Régions Arides at Médenine, the Institut Supérieur agronomique de Chott-Mariem and the Centre Régional de Recherche en Agriculture Oasisienne de Degueche (OAS); Integrated approach to oasis agrosystems (OSE); Integrated approach to oasis agrosystems (SOC). The UMR ESPACE-DEV develops its research activities through a multi-site system with headquarters in Montpellier. Secondary stations are located in the French overseas areas (French Guiana, Réunion, Martinique, New Caledonia) and in Gabon.

Environmental monitoring, renewable resource management and complex agrosystems

Founded in 2011, the joint research unit ESPACE-DEV (IRD/UM2/UR/UAG) conducts baseline, technological and applied research integrating data, knowledge and methods to benefit scientific communities and decisionmakers within the framework of projects for the sustainable development of territories in developing countries on local, regional and global scales.

Based on priority issues concerning environmental monitoring and renewable resource management, the research unit hinges research, training, expertise and services on questions regarding the spatialization of environmental knowledge for decision support in peripheral tropical regions vulnerable to global change.

The research is carried out by three teams in synergy: Spatial observation of the environment (OSE): Integrated approach to environments and societies (AIMS) and Information and knowledge systems (SIC). Studies are conducted in various environments (islands, coastal areas, forests, mountains, drylands, etc.), which all have environments that have been fragilized and/or altered under the constraints of global change. The aim is to provide answers for local people and development managers by boosting awareness on the co-viability of their systems (sociosystems, agrosystems, ecosystems) and the viability of their territories.

The illustrative examples presented by the UMR are in line with the complex systems with an agricultural component theme and are focused on the role that could be played by family farming. In both cases, they involve a native species (babassu palm in the Amazon region, and date palm in North Africa). The first so-called ‘native’ species grows in post-deforestation agrosystems managed by local communities, while the second is planted in traditional or changing intensive agrosystems (oasis). These two examples involve system modelling, with fields being monitored by satellite imaging, direct environmental observations and via surveys of stakeholders. Both have basic and targeted research objectives at the society/environment interface, with the aim of enhancing the sustainability of the monitoring system dynamics.

UMR ESPACE-DEV develops its research activities through a multi-site system with headquarters in Montpellier. Secondary stations are located in the French overseas areas (French Guiana, Réunion, Martinique, New Caledonia), Brazil and Gabon.
Ecological intensification adapted to small family farming—a case study of babassu palms

Babassu palm (*Attalea speciosa* Mart. ex Spreng.) is a useful species that is native to dense rainforest areas in the Brazilian Amazon and preserved in agrosystems. In Brazil, babassu palm grows over an area of around 200,000 km² and may be promoted for ecological intensification. It is the focus of extractivism, mainly for its oil-bearing kernels, and is an economic asset in some States. Babassu extractivists are mainly low-income rural workers, often farming or landless women. They belong to an association, i.e. the **Movimento Interestadual das Quebradeiras de Coco Babaçu** (MIQCB), founded in the 1980s and have been fighting to obtain recognition for their work and associated rights, such as prohibiting the felling of babassu palm trees, and authorization to harvest babassu nuts on large private farms. Moreover, various other stakeholders who use or eliminate this palm could have a swift and irreversible impact on the future of this species.

Knowledge required for setting up management plans for this species is currently being acquired by a multidisciplinary (ecology, remote sensing, socioeconomics, modelling) and interinstitutional (mainly IRD, UM1, UM2, INRA, Federal Rural University of the Amazon, Belém, Brazil) team.

Several projects* are focused on analysing the population dynamics of this palm, its spatial distribution and factors related to the adult population occurrence and density. The impact of babassu nut harvesting (carried out by various categories of stakeholders) on the reproducibility of the resource is being studied so as to be able to perform evolution simulations that could subsequently be used in management plans.

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* Projects:
- CNES/TOSCA_CIC-TOOB project: Remote sensing sensor integration chain for monitoring land-use patterns and automatic extraction of resource objects—a case study of babassu palm in the Amazon.
- CNPQ/IRD/UFRJ-Relais project: Regional Epidemiological Landscape Amazon Information System
- Agropolis ‘Open Science’ project: Methods and tools for decision support related to sustainable management of babassu palms in Brazilian grasslands.
- Project A IRD-PPR-AMAZ ECOTEL-B: Ecology and remote sensing for local communities—a case study of babassu palms

▼ Manual extraction of kernels from babassu nuts by two generations of *quebradeiras de coco* (mother and daughter).

D. Mitja © IRD
Biodiversity is pivotal to the ecological intensification concept, to ensure optimal natural resource management and serve as a guarantor of the resilience of family farming production systems. These systems are increasingly hampered by natural and socioeconomic turbulence.

In Madagascar, in the CIRAD priority research platform ‘Highland production systems and sustainability’, UPR AIDA conducts research and development activities on different scales—plot to terroir—with the aim of enhancing the sustainability of upland rice cropping in highland regions, while providing food security and generating new income to overcome the problem of land saturation in irrigated areas.

An iterative participatory approach, involving analysis, monitoring of reference farms and controlled experiments under real field conditions, enables innovation in a step-by-step production system design process, combining local know-how and external scientific and technical knowledge to meet current and future needs.

In the short term, the main challenge is integrated management of upland rice pests. This crop is hampered by many constraints due to fungal diseases, white grub infestations and parasitism (Striga asiatica). The genetic diversity of upland rice (selection and breeding) associated with the introduction of service plants in the crop sequence and crop diversification are being studied on a cropping system scale. Innovation adaptation, adoption and dissemination will follow this learning phase.

In the medium and long term, biodiversity generated by the introduction of service plants will provide fodder opportunities for dairy farmers and generate, via soil-livestock plant resource sharing, synergies between these two main constituents of production systems.

The genetic biodiversity and multifunctional service plants introduced in upland rice cropping systems are gradually being appropriated in the highland and middle western regions of Madagascar. This has given rise to agrobiological models that could be applicable in other settings.

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Family farming landscapes as guarantors of biodiversity in Madagascar

In Madagascar, a description and analysis of periforest landscapes generated by family farming activities highlighted assets that should be promoted for biodiversity conservation. Land development strategies derived from family farmers’ practices, beliefs and strategies have, since ancient times, contributed to shaping heterogeneous landscapes with complex and intricate overlapping of many ecological habitats that are favourable for biodiversity. These agroecosystems, which are the very image of diversity, enable farmers to produce a high variety of crops, fruit trees or timber species, while also enabling local inhabitants to gather a broad range of resources (medicinal plants, fuelwood, fibres, game, etc.). Cropping areas, consisting of a multitude of small plots with different histories and crops, are interspersed with hedgerows, groves and isolated trees (pine, eucalyptus fig, other sacred tree species, etc.), fallows of different ages, grasslands for livestock grazing, patches of natural forest protected by farmers, and fruit tree orchards.

UMR GRED researchers, in collaboration with the Université d’Antananarivo, showed that the intra- and inter-plot plant diversity in these fallows is closely linked with the diversity of practices, crop management sequences and strategies implemented by farming families (cropping and fallowing times, land savings, fires, etc.). It was also shown that landscapes resulting from family farming promote movements of birds from protected forests to these agroecosystems to nest, feed and breed. Forest, grassland and ubiquitous bird species all gather in these landscapes, so they have greater avian biodiversity than in the forests. The research findings revealed that these landscapes have protective qualities and serve as buffer zones for forest biodiversity. Current research aims to highlight the extent of their connectivity in order to characterize elements that promote biodiversity.

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▼ Bétisleo women farmers, Androy municipality, Ambendrana, southern highland region of Madagascar.