Climate change & agricultural and livestock production systems

The IPCC Fifth Assessment Report unequivocally concludes that global, ocean and surface warming has been under way since 1950 and states that is “extremely likely” that the human influence is the main cause of the observed warming. The different climate models used by IPCC, based on different greenhouse gas (GHG) emission scenarios, predict an amplification of this warming trend—if emissions continue to increase at the same pace as in previous years, it is estimated that the global average temperature will rise by between 2.6 and 4.8°C over the next century. In order to mitigate the disastrous impacts of such a scenario, the United Nations Framework Convention on Climate Change (UNFCCC) has set a goal to limit the global rise in temperature to less than +2°C relative to the preindustrial era. This requires a substantial and sustained GHG reduction.

World agriculture (crops and livestock) plays a dual role in this setting. First this activity accounts for almost 12% of global GHG emissions (around 70% of non-CO₂ GHG emissions, especially methane) which therefore have to be reduced, while at the same time it must adapt to climate change.

Several issues make this a particularly delicate adaptation. First, it should not take place at the expense of the production function. The growing world population, the persistence of malnourished people and the recent food riots in the most vulnerable countries, combined with agricultural price volatility, have pushed food and nutritional security to front stage. Secondly, crop varieties are the result of a long domestication process associated with human needs and with abiotic (climate, soil) and biotic (pollinators, symbiont microorganisms, pests and diseases) environmental constraints. The rapidly changing weather conditions, including water and thermal regimes could have a substantial effect on all of these constraints, leading to breakdowns and bridling the adaptation capacity. Finally, the resources that could be used to regulate the production capacity, e.g. water for irrigation or pesticides to stall the emergence of new diseases, are in turn affected, subject to competing uses or severely constrained by other issues such as environmental health and preservation.

Current and future research challenges regarding the adaptation of agriculture to climate change are thus considerable—to design with and for farmers, especially the poorest and most vulnerable, solutions that will help them adapt to climate change, reduce the percentage of agriculture-related GHG emissions, while maintaining or increasing production. These three pillars are pivotal to the climate-smart agriculture concept put forward by FAO since 2010.

The research presented hereafter partially illustrates the diverse scope of research carried out in this area by research units members of Agropolis International: genetic and evolutionary processes involved in the adaptation of crops and livestock to climate change; the impact of cropping and livestock production systems on GHG emissions; characterization of the impact of climate change on agricultural production in West Africa; analysis and development of the climate change adaptation capacity of different cropping and production systems, etc.

This chapter ‘Climate change & agricultural and livestock production systems’ has very close links with the other chapters in this Dossier, from the standpoint of resources and territorial development, plant and ecosystem adaptations, and the evolution of interactions between organisms triggered by climate change.

Global research, assembled in March 2015 in Montpellier within the framework of the international scientific Climate Smart Agriculture 2015 conference, will further contribute to this debate and outline scientific fronts that could help agriculture cope with the accelerating climate change process. The role of agriculture in international conventions, especially in the UNFCCC, could thus be strengthened and further enhanced at the 21st Conference of the Parties (COP21) of this Convention at Paris in late 2015.

Jean-Luc Chotte (UMR Eco&Sols) & Pascal Kosuth (Agropolis Fondation, LabEx Agro)
Climate change & agricultural and livestock production systems

Developing research on plants of agricultural interest, from genes to production systems, processing systems, and issues that link society and agriculture

LabEx Agro – Agronomy and sustainable development
(Programme Investissements d’Avenir 2011-2019), supported by Agropolis Fondation, pools a continuum of multidisciplinary expertise (biological science, engineering, humanities and social science). This expertise is internationally recognized regarding many different plant species—temperate, Mediterranean and tropical—and production systems and corresponding processing methods.

The aims are to understand:
- ecophysiological functioning of plants—genetic determinants in cells, tissues and organs; processes of adaptation to biotic and abiotic constraints
- processes of crop plant domestication, plant improvement and agrobiodiversity management
- functioning, evolution and adaptation of cropping systems and production systems according to climatic, environmental, societal, technical, economic and regulatory settings
- processes involved in food and nonfood product processing and the resulting quality
- social organization associated with agriculture, and product provisioning, food and health issues regarding communities, land and environmental management.

This knowledge is also mobilized to benefit society for:
- streamlining production; plant improvement and crop protection against diseases and pests
- improvement of agroecosystems under stress and management of their impact on resources, environments and biodiversity
- improvement of food and non-food product quality
- formulation of public agricultural and environmental policies.

LabEx Agro includes 37 research units, 1500 senior scientists, and 800 support staff working within 12 institutions (INRA, CIRAD, Montpellier SupAgro, IRD, Universities of Montpellier, Perpignan, Avignon and La Réunion, CNRS, IRSTEA, CIHEAM-IAMM, AgroParisTech). It hosts 800 PhD and postdoctoral students, and foreign scientists.

LabEx Agro is organized in five closely linked scientific fields: (1) Genetics and genomics, ecophysiology and plant improvement; (2) Plant/microorganism interactions, diseases and pests, population ecology and integrated pest management; (3) Agroecosystems, resource management, environmental impacts, agroenvironmental innovations; (4) Agrifood systems, processing and quality of food and nonfood products; (5) Agriculture/society interactions, innovation processes and social management of innovations.

It acts by:
- supporting management of its scientific community
- supporting research and higher education projects in all of its scientific fields (research fronts) or on cross-sectoral issues involving these different fields (future plant phenotype building; sustainability of crop and production systems; agroecological transition; integrated approaches to product quality; evolution, adaptation and sustainability of agricultural and food systems, etc.)
- supporting the transfer of research results to economic stakeholders, especially via public-private partnerships
- showcasing the LabEx community to enhance its international visibility and attractiveness.
Cultivated landscape engineering for sustainable water and soil resource management

The Laboratoire d’étude des Interactions entre Sol-Agrosystème-Hydrosystème (UMR LISAH – INRA, IRD, Montpellier SupAgro) generates knowledge for engineering cultivated landscapes for sustainable water and soil resource management. In response to global change (climate variations, new agricultural and food needs, etc.), the research unit contributes to the development of cultivated landscape management methods through streamlining of the spatial organization of agricultural activities (land use, soil and water conservation practices, crop rotations and treatment practices, etc.) and infrastructures (ditch networks, small dams, embankments, etc.).

LISAH’s specific research objectives are to:

- develop knowledge on mass transfers and on the ecodynamics of pollutants in soils and catchments, while considering their spatial and temporal organization (natural or anthropogenic)
- develop tools for the assessment and prevention of hazards caused by human activities, regarding changes in hydrological regimes or in water and soil resources in cultivated environments
- contribute to developing new sustainable management methods for cultivated landscapes
- train students on analysis and modelling concepts and tools regarding the spatial organization, soil and hydrology of cultivated environments.

LISAH manages the Mediterranean Observatory of Rural Environment and Water (OMERE) and is developing the OpenFLUID software platform to simulate flows in landscapes. In this setting, the research is primarily focused on Mediterranean cultivated landscapes, and secondarily on tropical cultivated landscapes. The laboratory is thus involved in North African countries with the support of a network of partners:

- in Tunisia: the Institut National Agronomique de Tunisie, the Institut National de Recherches en Génie Rural, Eaux et Forêts and the École Nationale d’Ingénieurs de Tunis
- in Morocco: the Institut Agronomique et Vétérinaire Hassan II (IAV), the Institut National de Recherche Agronomique and the École Nationale Forestière d’Ingénieurs.

See an example of a project conducted by UMR LISAH on page 11.
Impact of agroforestry development on greenhouse gas emissions

A study carried out by INRA in 2014 (on behalf of the French Environment and Energy Management Agency, the French Ministry of Agriculture, Agrifood and Forestry, and the French Ministry of Ecology, Sustainable Development and Energy) estimated the GHG mitigation potential of innovative agricultural practices in France. This included agroforestry (rows of trees planted in farm fields). A review of the relevant scientific literature revealed that, in 20 years, carbon storage in biomass and soil may reach 3.7 t of CO₂ equivalent/ha/year. This additional carbon sequestration is from storage in perennial plant biomass (which varies depending on the fate of the timber produced) and organic matter recycling in the soil. This study also accounted for other GHG emissions resulting from the introduction and management of trees in agricultural fields, as well as the cost of these operations and the so-called Maximum Technical Potential Applicability (MTPA), i.e. the potentially concerned agricultural area.

Two slow and limited dissemination hypotheses (between 4 and 10% of the MPTA by 2030) were considered regarding agroforestry, which represents a major innovation for farmers. The analysis highlighted that it is possible to introduce trees in crop fields and still maintain the French agricultural production level. Under these hypotheses, the study concluded that, in France, by 2030 agroforestry could allow “saving” carbon stocks by 1.5 million t CO₂e, for an approximate cost of €14/t of CO₂e. This cost is moderate in comparison to other initiatives considered in the study, indicating that agroforestry is a priority agricultural practice that should be politically promoted for the many environmental services it can provide.

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Agroecology for innovative sustainable tropical horticulture

The main aim of the research unit Agro-ecological Functioning and Performances of Horticultural Cropping Systems (UR HortSys – CIRAD) is to develop scientific bases for the agroecological transformation of horticultural systems (i.e. based on ecological intensification principles) and to contribute to designing innovative sustainable horticulture cropping systems.

Research on cropping systems applied to tropical horticultural production is a priority of HortSys. The aim is to substantially contribute to applied agroecological research and to the development of sustainable tropical horticulture. This specifically involves designing new systems that are adapted to climate change while also being ecologically innovative. The unit also provides support and training in this field for its partners in developing countries.

HortSys has formalized its research on cropping systems by focusing its scientific investigations in two distinct but complementary priority areas: (i) the agroecological functioning of horticultural systems, and (ii) the assessment and design of horticultural systems that address new economic, ecological and health challenges.

The unit is thus organized around two research teams:
- The disciplines studied by the ‘Agroecological Functioning, Interactions and Biological Regulations in Horticulture Systems’ team include agronomy, ecophysiology, ecology, entomology and phytopathology. The team uses representative model systems (shared with the other team) to study exemplary and contrasted situations from the standpoint of economic and scientific issues: mango orchards in West Africa and La Réunion; citrus orchards in West Africa and Martinique; vegetable cropping areas in Benin, Kenya, Senegal and Martinique.
- The key hypothesis underlying this research is that some conditions regarding the increase in plant biodiversity in agroecosystems could lead to natural regulation of pests (soilborne or above-ground). The team’s overall objective is to gain greater insight into the mechanisms involved in order to explain, predict and quantify the impacts of interactions between biodiversity and crop plants for enhanced pest control and to facilitate the provision of associated ecosystem services.

- The disciplines studied by the ‘Assessment and Design of Sustainable Horticultural Cropping Systems’ team are mainly systemic agronomy, but also environmental and economic assessment. Horticultural systems are complex and varied and have marked environmental (frequent pesticide use) and socioeconomic (high value-added activities) impacts. The team’s overall objective is to design and implement local and global methods for system assessment (life-cycle assessment–LCA), and methods to facilitate the design of ecologically innovative cropping systems (reduction of pesticide use, biological regulation, optimized biodiversity management). Ecodesign requires the assessment of agricultural, environmental, economic and social performances of the systems, so it is a methodological as well as scientific challenge.

See an example of a project conducted by UR HortSys on page 59.

▲ A flowering mango orchard in La Réunion.
© UR HortSys
Remote sensing to predict yields and analyse the impact of climate scenarios on agricultural production

A broad range of data, knowledge, tools and methods involving many scientific disciplines—meteorology, climatology (global and regional climate models), remote sensing, modelling and agricultural statistics—are required to characterize the impact of climate change and differentiate it from the effects of climate variability. The problem is that these different types of information concern very different spatiotemporal scales, e.g. plot to region, day to year, etc. However, at the operational scale, spatiotemporal variability and parametering have very substantial impacts on the predictive quality of climate models. For instance, in Senegal, mean interannual yields simulated by the SARRA-H (Système d’Analyse Régionale des Risques Agroclimatologiques, Version H) crop model, using data generated by nine regional climate models, showed significant bias (from 200 to 700 kg/ha).

These data may be compared to the mean 600 kg/ha yield obtained using data from the ground station network. However, the SARRA-H model clearly identified major trends concerning the impact of increased temperatures on crop yields. Regarding the Sudanian-Sahelian area, it thus seems that, beyond a 2°C increase in temperature, increased rainfall would not prevent a decline in crop yield, as photoperiodic varieties have a better capacity of adaptation to such change.

UMR TETIS (see page 21) researchers are striving to enhance documentation of these variabilities through a better combination of spatiotemporal scales by seeking consistencies between satellite imagery and modelling indicators. For instance, they are developing national and regional maps that characterize cropping systems and identify crop production anomalies associated with stresses affecting crops. Based on objective, repetitive and comprehensive satellite images, the aim of these studies is to characterize spatiotemporal variabilities (cultivated area, cropping system, phenology, biomass, etc.) in order to generate descriptors to parameter the models used for predicting yields, while analysing the impact of climate scenarios on agricultural production. These studies are supported by several projects (Programme National de Télédétection Spatiale; Analyse Multidisciplinaire de la Mousson Africaine; Agricultural Model Intercomparison and Improvement Project) along with many institutes and partners (CIRAD, CNRS, INRA, IRD, CNES, AGRHYMET, EMBRAPA, etc.).

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Satellite data providing large-scale information on land cover and temporal variations relative to reference periods.

Sustainable annual crop intensification in stressed tropical environments

The research unit Agro-ecology and Sustainable Intensification of Annual Crops (UR AIDA – CIRAD) conducts research on the sustainable intensification of annual crop production in tropical environments. Its research addresses effective uses of available resources for crop production. The focus is on optimising agro-ecological processes within agroecosystems through e.g. integrated management of trophic resources, integrated control of pests and diseases and sustainable use of genetic diversity of crops.

The unit develops a broad range of methods and tools (e.g. crop growth modelling and spatial information analysis) for assessment of crop production systems at different spatial and temporal scales.

In collaboration with producers and local stakeholders AIDA seeks to co-design innovative crop production systems and technologies that are tailored to the farming context and production orientations of smallholder farmers in developing countries (e.g. conservation agriculture based cropping systems, pest control techniques for cotton and sugarcane).

AIDA also aims to document major societal issues and fuel debates on global food security, trade-offs between agricultural production and environmental quality, reduction of greenhouse gas emissions, conservation of water resources and on interactions between agroecosystems, biodiversity and climate change.

See an example of a project conducted by UR AIDA on page 18.

A cotton producer in Burkina Faso.
K. Naudin © CIRAD
Ecological intensification of livestock systems

The joint research unit Mediterranean and Tropical Livestock Systems (UMR SELMET – CIRAD, INRA, Montpellier SupAgro) develops alternative management strategies that meet the challenges of ecological intensification of agroecosystems while maintaining, or even improving, their capacities to provide the ecosystem services that societies expect from livestock systems.

The unit has set three objectives to fulfil this mission:

- To analyse and understand changes in livestock agroecosystems and their settings—under the many and increasingly harsh constraints they are facing, these agroecosystems could show a capacity to adapt or, instead, decline and pave the way for other activities and livelihoods. The aim is thus to analyse their development trajectories, which may also be driven by certain, and usually economic, opportunities.
- To assess—in their biophysical and biotechnical environments—the production potential of livestock and crop resources, according to the prevailing opportunities and constraints, in order to assess the situations and develop innovations regarding livestock agroecosystems. These assessments are based on benchmarks.

Future of Mediterranean livestock systems

Livestock systems in the Mediterranean region must adapt to a broad range of complex changes linked with the region’s past and present history. The CLIMED project, conducted by UMR SELMET and involving CIRAD, INRA, IRD, the Agricultural Research Center (Egypt) and the Institut Agronomique et Vétérinaire Hassan II (Morocco), aims to gain insight into and assess the technical, economic and socioecological viability of integrated crop-livestock farming systems in the Mediterranean setting.

The challenge is twofold:

- to help farmers, local communities, researchers and policymakers better understand and predict future livestock farming trends in the Mediterranean region
- to set priorities, rules and policies that are better able to perceive socioenvironmental issues related to demographic and land pressure, in a setting of rising demand and changes in international competition.

The main objectives of the CLIMED project are thus:

1. identification and understanding of crop-livestock farming systems to enhance resource use (water, soil, crop residue, grassland fodder, etc.) and to achieve greater socioeconomic efficiency (increased production to meet the rising demand for top quality animal products)
2. assessment of the adaptation capacities of these systems and their extent of vulnerability and flexibility regarding current pressures and changes
3. assessment of the socioecological coviability and resilience of these systems with respect to population growth and from a historical perspective
4. development of future scenarios and formulation of priorities for the development of livestock farming in Mediterranean situations so as to enhance the adaptation capacities of these systems.

The project will also—via the sharing of research methods and databases—strengthen interdisciplinary collaboration between different teams from several Mediterranean countries.

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**LACCAVE project**

**Adaptation to climate change in viticulture and oenology**

The LACCAVE project aims to study the impacts of climate change on vines and wine and potential adaptation strategies for French wine regions. It is based on a systemic representation for the analysis of the wine sector in order to analyse both the impacts of climate change (advanced harvest dates, exacerbated water stress, wines with more alcohol and less acidity, etc.) and the diversity of levers for potential adaptation. This analysis is performed at several levels (plant, plot, farm, regional and wine sector) while focusing specifically on regional levels where climate impacts differ and adaptation strategies may be coordinated.

Coordinated by UMR Innovation in Montpellier and Écophysiologie et génomique fonctionnelle de la vigne en Bordeaux (EGFY – INRA, Bordeaux University, Bordeaux Sciences Agro), this project brings together 21 INRA research units, 8 of which are located in Montpellier. Many initiatives are under way: review of knowledge on climate change on a vineyard scale; studies on the physiological and genetic basis of vine responses to climate change parameters; analysis of innovations that could contribute to adaptation and conditions for their implementation on local scales; studies on the costs of adaptation to climate change impacts and on consumer willingness to pay for wines that reflect these costs, etc. These initiatives feed a foresight study, conducted in collaboration with FranceAgrimer that investigates adaptation strategies for different French wine regions.

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**Changes in agricultural and agrifood practices and innovations**

The joint research unit **Innovation and Development in Agriculture and the Agrifoods Sector** (UMR Innovation – INRA, CIRAD, Montpellier SupAgro) conducts multidisciplinary research in France and abroad on agricultural and agrifood innovation processes to address agroecological transition and climate change adaptation issues.

This research concerns all processes related to adaptation initiatives, ranging from the analysis of stakeholders’ motivations and aims regarding innovation, to concrete measures to implement the changes, and the development effects induced by these changes. The studies are focused mainly on changes in practices and innovations ‘in the making’—they are potential levers for adaptation to climate change in the future. This work specifically stresses the role of research and the importance of building the capacities of farmers to cope with these issues.

The unit has expertise in agronomy and social science, with perennial crops (vines, cocoa, coffee, lavender, etc.) and annual cropping systems (rice, cereals, cotton, etc.) as topics of study.

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**Co-design of climate-smart farming systems**

Research on climate-smart agriculture aims to investigate institutional changes (new support services, novel arrangements between stakeholders, etc.), innovative practices (use of agroclimatic information, precision irrigation, etc.) or long-promoted agroecological practices (use of compost, crop associations, etc.), while assessing them according to food security, adaptation and GHG mitigation criteria. These studies are carried out by UMR Innovation in collaboration with CIAT (International Center for Tropical Agriculture, Colombia) in different countries (Burkina Faso, Colombia, France) and include participative approaches involving farmers. They aim to co-design innovative strategies while simulating their short- and long-term effects according to climate-smart agriculture criteria.

These simulations are combined with on farm experiments that facilitate farmers’ appropriation of available solutions and their implementation methods.

This research contributes to the development of new farmer decision support tools. They help train public and private extension services on current short- and long-term uncertainties, and assessment of possible future scenarios via simulation tools.

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MACACC: on-farm testing of adaptive management scenarios

The overall aim of the MACACC project (Modelling to Accompany Stakeholders Towards Adaptation of Forestry and Agroforestry Systems to Global Changes) is to define different adaptive management scenarios and estimate farmers’ willingness to adopt them. Three perennial crop plantations were selected for the case studies on the basis of their economic importance, origin (tropical or temperate area) and structure (single- or multi-layer, main crop in upper- or under-storey): eucalyptus in Brazil, coffee in Costa Rica and maritime pine in France.

Many published articles have dealt with the impacts of climate change on agriculture, but there has been little coverage of other agricultural economics issues. This is the case regarding an assessment of the adaptation capacity of an agricultural system to climate change. Economists are involved in a project of UMR LAMETA (see page 25) and MOISA (Markets, Organisations, Institutions and Stakeholders Strategies – CIRAD, INRA, CIHEAM-IAMM, Montpellier SupAgro) in which these issues are studied using recent experimental economics and microeconometric advances. The evaluation of adaptation strategy sustainability should take interactions and feedbacks between crop growth, resource availability and economic factors on the farm scale into account. Models that simulate farmers’ decision rules are thus required to explore potential strategies for adaptation to environmental change.

In many cases the production of ecosystem services is beneficial for adaptation. For instance, shaded coffee plantations provide various ecological services, such as high biodiversity, soil protection, erosion control, and carbon sequestration. This production of public goods legitimates the use of external financial incentives to promote the adoption of adaptation practices.

Ecological processes in soil—the role of plants and soil organisms regarding carbon and nutrient flows

The joint research unit Functional Ecology & Bio-geochemistry of Soils & Agro-ecosystems (UMR Eco&Sols – INRA, CIRAD, IRD, Montpellier SupAgro) conducts research in Europe (Montpellier, France), Africa (Senegal, Burkina Faso, Congo, Kenya, Madagascar), South America (Costa Rica, Brazil) and Southeast Asia (Thailand).

Eco&Sols conducts research involving a functional ecology approach and addresses the question of the role of plants and soil organisms (roots, soil fauna and microorganisms) on coupled carbon and nutrient (mainly nitrogen and phosphorus) flows in soils and agroecosystems. Research carried out in Mediterranean and tropical areas can involve agroecosystems, perennial tree plantations, agroforestry areas or annual crops. Different agricultural practices are tested, such as crop associations (grasses/legumes, genotype mixtures, mixed plantations), low-input crops or organic farming.

This approach is developed in the framework of land-use and climate changes. The aim of Eco&Sols research is to develop practices geared towards maintaining and improving the agricultural and environmental functions of agroecosystems in a changing environment (climate, land-use changes).

Enhanced knowledge on the biological functioning of soil is required in order to develop agricultural practices able to promote ecological processes, this concerns:
- the role of organisms (bacteria, fungi, rhizosphere microorganisms, microfauna, macrofauna), the impacts of their trophic or non-trophic interactions on nutrient (N, P) dynamics in soil and on the bioavailability of these nutrients for plants
- biogeochemical processes that determine the nutrient (N, P) acquisition, use and recycling efficiency in low-input agroecosystems
- major factors and processes regarding carbon production and sequestration in agroecosystems.

Several types of land-use and management methods are thus assessed and modelled in terms of their productivity, the ecosystem services they provide and their vulnerability to global change.

See an example of a project conducted by UMR Eco&Sols on page 38.
Genetic improvement of Mediterranean and tropical plants

The joint research unit Genetic Improvement and Adaptation of Mediterranean and Tropical Plants (UMR AGAP – CIRAD, INRA, Montpellier SupAgro) brings together a broad range of expertise to form a major research cluster for biology, ecophysiology and targeted plant genetics research, including agents from its supervisory bodies, as well as from the Institut français de la vigne et du vin and the Conservatoire botanique national méditerranéen de Porquerolles.

In a rapidly changing global environment, the ability to produce plant material adapted to a range of different changing agricultural conditions, and to new needs, is a key priority. Genomics, informatics and mathematical modelling open new avenues for studying relationships between genetic diversity, agronomic behaviour and selection responses. AGAP is working towards developing plant material adapted to production systems while taking climate change factors into account.

The unit’s research is focused on around 20 tropical and Mediterranean plant species, with four scientific objectives:

- understanding factors concerning plant development and adaptation to environmental constraints
- characterization and understanding of genome organization and diversity
- study and management of agrobiodiversity and related data while taking different biological, ecogeographical, spatiotemporal and societal scales into account
- acquisition and mobilization of knowledge to define ideotypes and create innovative plant material.

The unit is structured in three thematic areas:

- Diversity and genomes, domestication, environments, societies: studying population responses to environmental constraints and understanding the evolutionary dynamics of agrobiodiversity from a spatiotemporal standpoint enhances the development of diversity management strategies; understanding genome organization and diversity in turn enables assessment of their impact on the transmission and expression of genes and traits of interest.
- Functioning of plants and stands: in a climate change and environmental constraint setting, the aim is to highlight and analyse the physiological, molecular, genetic, epigenetic and environmental control of traits of interest, especially mechanisms of adaptation to abiotic and biotic constraints.
- Integrative approaches for varietal innovation: advances in integrative biology, the increased availability of ‘high-speed’ data and simulation tools offers new opportunities for defining ideotypes and optimising plant improvement schemes to obtain innovative plant material, combining stress resistance and product quality.

Plant adaptation to climate change—study of genetic and evolutionary mechanisms involved in phenological changes

It is now clear that climate change affects many biological and ecological processes, with consequences ranging from major phenological changes to modifications in species’ ranges. Gaining insight into and predicting the impact of climate change on the genetic and phenotypic diversity of crop plants and related wild forms are major challenges, especially for developing countries where human communities rely primarily on conventional rainfed cropping systems.

In order to progress on these issues, it is essential to have a clear understanding of the genetic architecture of adaptive traits as well as the adaptive trajectories of natural and artificial plant populations subjected to changing environmental conditions.

To meet these objectives, UMR AGAP uses high throughput methods for the analysis of nucleotide polymorphism and study genotype/phenotype and genotype/climate interactions of the original populations so as to detect genomic regions involved in plant responses to climatic heterogeneity. This research, developed in close collaboration with UMR DIADE, involves methodological studies in population genomics and experimental approaches focused on four species: two rice species (Oryza sativa and Oryza glaberrima), millet (Pennisetum glaucum) and Medicago truncatula, a model species for legumes genetics and genomics. The flowering date is the target adaptive trait studied because it is a key plant fitness and seed yield character.

The diversity studied encompasses spatial (species range) and temporal (monitoring and sampling over time at the same site) climatic gradients. This research is conducted under the ARCAD project.

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Adaptation of millet to drought

Millet and sorghum are two cereal crops that are widely grown in Sahelian dryland regions. These regions have, however, experienced a series of droughts since the 1970s. How have these crop varieties adapted and what genes are associated with these adaptations? The Agropolis Resource Center for Crop Conservation and Adaptation (ARCAD) project is addressing these two questions as part of a collaboration between UMR DIADE, AGAP and the Université Abdou Moumouni in Niamey (Niger). It is supported by funding from ANR and Agropolis Fondation.

These studies highlighted the evolution of millet varieties in Niger between 1976 and 2003 on the basis of field sampling experiments carried out during these two periods. At these two times, spontaneous selection of an allele of the phytochrome C gene was found to have occurred—this is one of the genes that mediates variation in the millet cycle. These results provide direct solutions that are especially relevant now since current forecasts indicate that the rainy season in the Sahel could be reduced by 10-20% in the future. Gaining insight into natural mechanisms of genetic adaptation could thus help identify strategies of adaptation to future climatic conditions.

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Genomics for enhanced adaptation of crops to their environment

Research conducted by the joint research unit Crop Diversity, Adaptation and Development (UMR DIADE – IRD, UM) aims to gain insight into the nature and role of structural and functional diversification mechanisms: (i) of the genome of tropical plants, and (ii) of their populations, during speciation and adaptation to natural environmental variations or human-induced changes.

The research relies primarily on expertise in genetics, epigenetics, development biology, physiology, systematics and evolution. Other approaches such as modelling, remote sensing and ecology are also integrated in some collaborative projects.

The unit’s studies are generally based on comparisons of model plants (rice, Arabidopsis, tomato, poplar) and species of agricultural or ecological interest (coffee, cassuarina, yam, maize, palm, millet). Analyses are focused on different levels, ranging from the cell to the species complex.

UMR DIADE thus studies:
1. fine regulation of key genes of development
2. control of developmental transitions
3. evolutionary history of gene families
4. molecular determinants (genes or gene networks) of phenotypic variations in traits of agricultural or ecological interest
5. genome dynamics and plasticity and population dynamics and diversity in response to ecological, human (genetic diversity structuring, adaptation to environmental change, domestication) or biological (genomic shocks) factors.

This functional and evolutionary biology research integrates tools and concepts of modern genomics. These have radically altered the scientific understanding of how genomes and heredity mechanisms function, and also the way genotype and phenotype contributions are now assessed.
Models for tailoring crop management to climate change

Hard to overcome experimental problems may arise when analysing crop management methods and developing climate change adaptation strategies, especially for crops with complex and highly developed canopies. This is the case for vines, where many conventional management methods could be gradually replaced by systems that are better adapted to future climatic conditions. The concepts underlying current practices thus require reassessment by incorporating the impacts of thermal and hydric constraints when designing the systems.

A LEPSE team combined several models to address this issue—one reconstructs the vine canopy structure, another distributes radiation in this architecture, while the last predicts the adaptation in the photosynthetic capacity of leaves according to the light microenvironment. This calculation chain dynamically simulates carbon assimilation and leaf transpiration according to the local microclimate perceived by the leaves.

Physiological responses of plants to drought and high temperatures—identifying varieties adapted to climate change

The Laboratoire d’Ecophysiologie des Plantes sous Stress Environnementaux (UMR LEPSE – INRA, Montpellier SupAgro) primarily aims to help find the most stress-tolerant, efficient and economic varieties for tomorrow’s agriculture. It analyses and models genetic variability in plant responses to a range of environmental conditions, especially drought and high temperatures. Knowledge gained through this research is injected into models incorporating genetic and environmental variability to predict the behaviour of genotypes and species under current or future climate conditions.

The LEPSE environmental ‘Stress and Processes Involved in the Control of Growth’ research team conducts studies to identify the factors determining plant capacities for adaptation to drought and heat stress. It tests hypotheses on the model species *Arabidopsis thaliana*—which shows high natural or artificial genetic variability, as characterized using molecular techniques—combining ecophysiology, quantitative genetics, physiology and molecular biology approaches along with modelling.

The ‘Efficiency of Transpiration and Adaptation of Plants to Dry Climates’ research team aims to identify genetic and agronomic levers for improving water-use efficiency in vineyard systems subject to abiotic constraints. Genetic variability in tolerance to drought and high temperatures is then assessed via the development and use of models simulating plant transpiration and water status, as well as photosynthetic activity from the leaf to the canopy scale.

Studies on cereals carried out by the ‘Modelling and Analysing Genotype by Environment Interactions’ research team aim to identify the effects of gene alleles on important plant functions (leaf growth, reproductive development, transpiration) according to environmental conditions. The aim is to develop tools (models) that can be used to determining combinations of favourable alleles within a given climate scenario. The researchers thus model the studied functions, analyse genetic variability in the model parameters and incorporate everything in crop models that are then tested in the field.

LEPSE is a pioneer in the development of automated phenotyping platforms, which are effective in exposing large collections of genotypes (varieties, lines, accessions) to controlled environmental stress, while measuring (often through imaging) their growth or development. These platforms are also used to study gene expression and functions at different organizational levels—from the cell to the whole plant—under controlled environmental conditions.
Adaptation of plants to environmental constraints— from perception to molecular and physiological responses

The joint research unit Biochemistry and Plant Molecular Physiology (UMR B&PMP – INRA, CNRS, Montpellier SupAgro, UM) focuses on studying mechanisms that govern the hydromineral status of plants under different abiotic conditions. This research includes disciplines such as biochemistry, molecular and cell biology, physiology, biophysics and genetics, while relying primarily on studies of the Arabidopsis plant model. The laboratory has recently participated in systems biology programmes involving mathematical modelling approaches.

The B&PMP research unit is recognized worldwide for its studies on plant cell transport activities (membrane transport proteins and channels) and its physiological analyses on mineral nutrition. In addition, the laboratory’s research programmes are focused on perception and signalling mechanisms that enable plants to adapt to environmental constraints (water stress, salt stress, mineral deficiencies, metal toxicity). Root system development processes and morphological adaptation of this system in response to abiotic constraints are also studied, along with metabolic aspects associated with mineral applications, their assimilation or toxicity.

Several research themes of B&PMP are focused directly on climate change impacts. Overall fresh water shortages and repeated droughts are two of the most serious threats associated with climate change, even in temperate areas. Moreover, the excessive levels of CO₂ which cause these changes reduce the capacity of plants to take up nitrate or use certain micronutrients like iron or zinc. These phenomena could significantly reduce yields of crops and their nutritional qualities.

B&PMP has all of the scientific and technical expertise required to analyse physiological and genetic mechanisms involved in plant responses to these new environmental constraints. The unit’s studies will help develop unique phenotype screening procedures for crop improvement or for new cropping practices so as to offset the negative impacts of climate change on crops.

See an example of a project conducted by UMR B&PMP on page 18.

Microbiology of Agroecosystems: Translational Research from Pathogen Life Histories (MISTRAL) is the name of a research project and the team that conducts it in the Plant Pathology research unit (see page 59).

The MISTRAL team conducts studies on the ecology of phytopathogenic microorganisms that disseminate in air and water, while also managing an interdisciplinary international network on adaptation to climate change.

Via the MISTRAL project, the presence of high diversity in genetic strains (pathogenic and nonpathogenic) was highlighted for several phytopathogens, especially for the bacterium Pseudomonas syringae. This bacterial species, which is also known for its ice nucleation properties and ability to disseminate in the troposphere and within the cloud layer, is an interesting focus of study because of its link to the hydrological cycle—it is involved in key atmospheric rain-making processes.

This team is striving to enhance insight into the bioprecipitation cycle in which ice nucleation microorganisms such as P. syringae are at the interface of plant cover/atmosphere exchanges.

Impact of agricultural practices on the local microclimate and on plant diseases

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Genetic basis of adaptation of local cattle breeds in the Mediterranean region

This project will enhance knowledge on local cattle breeds in the Mediterranean region so as to come up with conservation solutions and determine ways to cope with the impacts of global climate change.

This project is based on three types of collected data regarding local Mediterranean breeds:
1. genotypes obtained using a bovine 50K SNP (single nucleotide polymorphism) chip
2. soil-climate data
3. information obtained through several surveys and questionnaires on breeding systems and on breeders’ views regarding climate adaptation in livestock.

The 19 cattle populations in the study were all sampled, genotyped and genetically characterized (e.g. through a principal component analysis and unsupervised hierarchical clustering). Previously obtained genotypes of 20 cattle breeds representative of the three main bovine groups, i.e. European taurine breeds, African taurine breeds and zebus, were used. This exploratory analysis identified the genetic proximity between breeds in the Mediterranean Basin.

Furthermore, climatic data for the study areas and information on the different breeding systems were also collected. Four in-depth surveys focused on Moroccan, Corsican, Italian and Egyptian breeds are currently under way. A joint analysis of genetic and environmental data will represent the main outcome of this project.

The GALIMED project is supported by the joint research unit Génétique Animale et Biologie Intégrative (INRA, AgroParisTech), in collaboration with UMR InterTryp (see page 65) and SELMET and 12 other partners in the Mediterranean region. This project is funded by the INRA metaprogramme ‘Adaptation of Agriculture and Forests to Climate Change’.

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Helping farmers in East African highlands to adapt to climate change

The 4-year R&D project ‘Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa’ (CHIESA) focuses research on agriculture, hydrology, ecology and geomatics. This project aims to overcome the lack of knowledge on the impacts of climate change on food security, livelihoods and on the economic development of communities living in highland East African ecosystem hotspots.

CHIESA’s activities are focused especially on three ecosystems: Mount Kilimanjaro in Tanzania, Taita Hills in Kenya and Jimma Highlands in Ethiopia. In these three hotspots, the teams monitor the meteorological conditions and detect changes in vegetation and those associated with land use. They also study pest pressure, ecosystem services, the food security concept, along with biophysical and socioeconomic factors that impact crop yield.

The research and training initiatives strengthen the capacities of research organizations, extension agents and decision makers involved regarding environmental research and climate change adaptation strategies.

By getting local communities to participate in their research, the project stakeholders will thus develop, test and disseminate climate change adaptation tools and propose options and production strategies that are relevant at the farm level. The project is thus improving existing monitoring and forecasting systems by installing automatic weather stations and it disseminates the scientific results to all stakeholders—from farmers to decision makers.

UR B-AMR (see page 58) manages the ‘coffee’ component of the CHIESA project, while the overall project is coordinated by the International Centre for Insect Physiology and Ecology (ICIPE) based in Nairobi (Kenya) and it is funded by the Finnish Ministry of Foreign Affairs.

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A global agricultural research partnership for a future without hunger

CGIAR, a Consortium of 15 international agricultural research centers, is dedicated to reducing rural poverty, increasing food security, improving human health and nutrition, and ensuring sustainable management of natural resources. CGIAR centers conduct research in close collaboration with hundreds of public and private organizations, including national and regional research institutes, organizations of civil society, academic institutions and the private sector.

These centers generate and share demand-driven knowledge and approaches for agricultural development through multipartner research programmes, known as CRPs (CGIAR Research Programs). Based in Montpellier (France), the CGIAR Consortium Office maintains close relations with members of the Agropolis community and beyond with French and European partners. The multidonor CGIAR Fund supports research conducted by these centers through research programmes. As a cross-cutting issue, climate change finds relevance across all the work of CGIAR.

Coordinating research efforts on climate change adaptation among CGIAR centers and partners is one of the key responsibilities of the CRP on Climate Change, Agriculture and Food Security (CCAFS), while also collaborating with other CRPs. CCAFS structures its coordination effort around four interlinked global research flagships, all of which have a climate change adaptation component:

- Climate-smart practices—to test and scale up technologies and practices that are needed to build adaptive capacity and food security with mitigation co-benefits.
- Climate information services and climate-informed safety nets—to deliver improved farmer advisories, better management of safety nets and enhanced design of weather-indexed insurance.
- Low-emissions agricultural development—to develop and test incentive mechanisms, policies and metrics for low-emissions pathways that benefit both mitigation and adaptation.
- Policies and institutions for climate-resilient food systems—to address adaptation and food security policies, largely at the national level but also up to the global level, including modelling, scenario assessment and governance work.

Coordinated research to foster the adaptation of global farming systems to climate change

Coordination work carried out under the CCAFS program has stimulated cooperation and generated positive results. For example, the program has brought together scientists to collaborate with the national meteorological services of several African countries to produce and disseminate climate information at a scale that is relevant to rural communities. In Senegal, for instance, seasonal and 10-day forecasts are broadcasted on community radio stations in 14 local languages throughout the rainy season. The advisory bulletin, which initially started as a small pilot project, is now estimated to reach over two million people.

On another continent, the International Maize and Wheat Improvement Center (CIMMYT) recently launched the ‘Dissemination of climate-smart agro-advisories to farmers in CCAFS benchmark sites of India’ in four villages in the north of the country. Farmers thus receive information on their mobile phones that helps them adopt climate-smart technologies that could mitigate risks associated with climate change.

In another area, the International Rice Research Institute (IRRI), in collaboration with other global partners, leads the ‘Climate Change Affecting Land Use in the Mekong Delta: Adaptation of Rice-based Cropping Systems’ (CLUES) project. The aim of the work is to alleviate constraints on farmers’ ability to adapt to an altered Mekong hydrological regime resulting from climate change.

Improved practices are also being promoted, such as alternate wetting and drying (AWD)—a water management technique that reduces water use by 15-30%, lowers GHG emissions, whilst maintaining yields. Other initiatives include the development and dissemination of varieties adapted to local environmental conditions—rice cultivars with improved tolerance to submergence and salinity are, for instance, developed at IRRI. At the International Institute for Tropical Agriculture (IITA), a cowpea germplasm catalog has been collated to strengthen the genetic diversity and support the development of more resistant germplasm that can better cope with drought, pests and diseases stresses.

Furthermore, outputs from CGIAR research centres also demonstrate the progress being made in affecting wider policy change. The work of the International Center for Tropical Agriculture (CIAT) on climate change impacts on small-scale coffee production has aided the Nicaraguan government in the creation of a National Adaptation Plan for Agriculture. This plan includes measures for adapting smallholder coffee farmers’ livelihoods to climate change and diversifying coffee-based incomes. The plan attracted major investment from the International Fund for Agricultural Development (IFAD)—some US$24 million—to help coffee and cocoa farmers adapt to climate change.

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Field work under the Roots, Tubers & Bananas CRP in East Africa.
Promoting agriculture with a low carbon footprint in Brazil

EMBRAPA LABEX – External Laboratory Without Walls of EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), based in Montpellier on the Agropolis campus for over 10 years, is a gateway to European research for Brazilian researchers.

Knowledge-based natural resource management is a prerequisite for sustainable efficient agriculture, providing a unique opportunity for development in harmony with environmental conservation.

Agriculture thus becomes a solution—not a problem—when biodiversity and environmental conservation are taken in to full account. Over the last 40 years, crop yields and agricultural areas have increased by 4% per year (200% overall!) and 30%, respectively.

Agricultural technology development has increased intensive agricultural land use, thus preserving 60% of all land in Brazil, which is now classified as biology reserves, natural parks and indigenous land. The Low-carbon Agriculture Program that has been under way for 4 years in Brazil has provided the necessary funding and incentives for farmers to adopt sustainable agricultural practices and technologies. The Brazilian agricultural research system, coordinated by EMBRAPA and including over 70 universities and agricultural research institutions, is developing agricultural intensification practices, which are sustainable from technological and political standpoints, to boost productivity while generating environmental services. Research has thus contributed to the development of alternative forest protection policies and practices, leading to a reduction in deforestation in the Amazon region.

Promoted by the Brazilian government, this program is the target of the approval of the World Bank and leads to the authorization of the mounting of multipurpose microcatchments that may be adopted in a similar way to Chaco’s case study.

Agriculture thus becomes a solution. This is well illustrated by the Brazilian case, where the Brazilian government is not only promoting the use of agricultural technology, but also supporting the development of alternative forest protection policies and practices, which are sustainable from both technological and political standpoints. The Brazilian agricultural research system, coordinated by EMBRAPA and including over 70 universities and agricultural research institutions, is developing agricultural intensification practices, which are sustainable from technological and political standpoints, to boost productivity while generating environmental services. Research has thus contributed to the development of alternative forest protection policies and practices, leading to a reduction in deforestation in the Amazon region.

Through EMBRAPA LABEX, three Brazilian researchers have been hosted by Agropolis research units, contributing to the sustainable natural resource management theme:

- Dr. José Madeira joined the Laboratoire d’étude des Interactions Sol, Agrosystème et Hydrosystème (UMR LISAH) to study the hydrology of cultivated environments. His work involved modelling interactions between agricultural practices and environmental indices through model development and validation and the development of vegetation indices for crops with a discontinuous canopy (vineyards, orchards, etc.). Image analysis data, obtained in collaboration with UMR TETIS, were used in this research. The developed models describe water flows and the impact of management practices in microcatchments where intensive agricultural land use is under way.

- Dr. Geraldo Stachetti Rodrigues was hosted by the Performance of Tree Crop-Based Systems research unit (CIRAD) to carry out an impact study and develop integrated system indicators for environmental management of rural activities. The team used an integrated approach to assess palm oil according to international environmental certification standards and sensu strictu sustainability criteria. This research was aimed at developing indicators for tree crop-based systems: ecological integrity, economic vitality, social equity of rural production activities geared towards promoting local sustainable development. This work consolidated the partners’ scientific advance with respect to agricultural sustainability.

- Remote sensing and image analysis methods are now essential tools for agricultural and land-use monitoring. Dr. Margareth Simões integrated the joint research unit Spatial Information and Analysis for Territories and Ecosystems (UMR TETIS) to study land use and land cover dynamics assessment for a sustainable agriculture. The results will generate reliable tools to support public policymaking during the crucial transition from extensive agriculture to an ecologically intensive model.

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Strengthened collaborations with Brazil through EMBRAPA LABEX
Reducing greenhouse gas emissions by livestock farming in Argentina

LABINTEX is currently developing, in collaboration with UMR Herbivores (INRA, VetAgroSup) at Clermont-Ferrand (France) and Scotland’s Rural College (SRUC) at Edinburgh (Scotland, UK), a joint research project (JRP) on the theme ‘Environmental sustainability of intensified grazing livestock systems’. These units contribute to training INTA technicians on methods for measuring enteric methane emissions in grazing livestock. The aims of this JRP are to evaluate these enteric methane emissions, develop technology for GHG mitigation and study a systemic approach, at the rural farm level, regarding the GHG mitigation technologies applied.

In accordance with the JRP recommendations, assessments of enteric methane emissions were carried out in different agroecological regions of Argentina. Hence, in 2014, SRUC provided Argentina with instruments and technical equipment for the measurement of these emissions, and advised INTA on the installation of two gas exchange chambers at experimental stations located in temperate and subtropical regions of the country. As a member of the Global Research Alliance, Argentina also participates—via INTA within the Livestock Research Group—in the FONTAGRO project, which aims to adjust inventoried GHG estimates regarding livestock in Latin America.

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Promoting the environmental sustainability of livestock farming systems in Argentina

LABINTEX External Laboratory Without Walls of INTA (Instituto Nacional de Tecnología Agropecuaria/Argentinian National Institute of Agricultural Technology), based in Montpellier on the Agropolis campus for 3 years, is a gateway to European research for Argentinian researchers. One of its four priority themes concerns technologies for environmental conservation and sustainable management. More generally, INTA focuses primarily on natural resource conservation and the environmental, economic and social sustainability of agriculture.

The agricultural sector is the backbone of the Argentine economy, providing 9.5% of the national GDP. Globally, Argentina is the top exporter of soybean flour, the 2nd exporter of maize, sorghum, sunflower oil and honey, the 3rd exporter of soybeans, the 4th exporter of lemons and the 5th exporter of beef. In a setting of increased global demand for food (especially animal products), population growth, urbanization and increased overall revenues, and taking the necessary adaptation of the agricultural sector to climate change into account, it is essential for the country to sustainably boost its food production capacity. In order to take up the economic opportunity offered by the international market, Argentina especially needs to boost its beef and veal production capacity.

In addition, growing demand for cereals and oilseed products over the last two decades has led to a marked increase in the area devoted to these crops. This phenomenon, combined with constraints imposed by national deforestation policies, caused a 15 million ha reduction in the livestock farming area over the last 15 years. Production has thus been intensified so as to maintain a consistent supply of beef, with a switch from 100% pastoral systems to systems supplemented by cereal and fodder inputs and, in some cases the animals are even enclosed in fattening pens prior to slaughter.

As a result of these changes, the reproductive performance of cattle herds have improved, the weaning rate has increased and the proportion of non-performing animals has decreased. The more digestible livestock feed has increased productivity, thus indirectly leading to a reduction in the intensity of enteric methane emissions.

In collaboration with Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA, Brazil) and the Instituto Nacional de Investigación Agropecuaria (INIA, Uruguay), INTA is studying issues regarding the adaptation of livestock farming to climate change and GHG mitigation in pastoral livestock systems. Beef exports represent a major component of the economies of these three countries as well as that of Paraguay—together these four countries produce a fifth of all bovine livestock in the world—a figure that clearly indicates how important it is to mitigate GHG emissions from livestock worldwide.

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