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AGRICULTURAL RESEARCH
FOR DEVELOPMENT

Climate change and agriculture

A selection of CIRAD's expertise

February 2015

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Introduction

Changing our habits

The interactions between agriculture and climate change need to be analysed at all scales, from the microscopic to the macroscopic, from the genome through to international relations. Adapting to climate change while mitigating it is a complicated exercise and the scientific references available are incomplete. The best techniques will be ineffective without a supportive political, financial and institutional framework for creating resilience, not only in agricultural production processes, but in the entire food system.

> Maximum uncertainty

In developing countries, models for simulating future climate do not allow us to make sound hypotheses and numerous local climatic variations are likely. The prevailing poverty in these countries exacerbates the uncertainty facing researchers. By 2050, the majority of African countries will experience climates over at least half of their existing crop area that are currently unknown within the country. The ideal equation is 'adaptation + mitigation + food security' but finding the solution assumes that we have access to reliable climate information and proven expertise in order to minimise the risks posed by the vagaries of the climate. Agricultural know-how provides a range of options said to be 'sustainable' which can respond to the climate challenge. But we need to take into account that we are facing physical and biological disruption hitherto unknown in the history of mankind and that genuine innovations are required.

> Do not separate adaptation and mitigation

Quite legitimately, adaptation to climate change is the primary concern of the agricultural sector in developing countries. But we also now know that the land sector emits large amounts of greenhouse gases and we can reduce these emissions through changes in land use, livestock feed or management of rice fields. We also know that a resilience management approach to agricultural land adapted to climate hazards can store large amounts of carbon in soil and biomass and therefore offset emissions. This helps mitigate climate change while adapting to it. This synergy is even more virtuous when we devise innovations in heterogeneous landscapes in which it is easier to use nature's regulatory functions than at the plant or field scale. If adaptation and mitigation have until now remained separate in initiatives to combat climate change, this has been for institutional and political reasons, and is inconsistent with many agricultural practices.

> Ensuring proper diagnosis

Even though the tropics comprise around 134 countries, 80% of terrestrial biodiversity and 40% of the planet's surface and world population, our understanding of the physical mechanisms of climate change and its impact on biological and food systems in this region is imperfect. New, hitherto unseen combinations of different stresses may be seen, for example simultaneous increases in C02 and temperature with a disrupted rainfall pattern. Mathematical models capable of simulating such conditions for family agriculture in developing countries are not available. While we can find analogies in the temperate zone by using shifts in altitude or latitude, such analogies are much more difficult in the tropics. So we need to deepen our analysis of climate change and its impact in order to design innovations in line with societal realities in developing countries and valuing farmers' centuries-old experience. Our diagnosis should also include an evaluation of available public policies, institutions and agricultural funding measures in order to propose changes in these areas.

> Envisioning resilient agriculture

'Climate smart' agriculture combines food security, climate change adaptation and mitigation. To be resilient, it must be based on the ecological processes at work in the biological and ecosystem cycles observed in nature. This is the field of ecological intensification, which strongly differs from the artificial environment and economies of scale required by industrial agriculture. Conversely, it encourages diversity, respect for natural equilibriums and long-term protection of the planet's resources. Some major themes illustrate this approach, for example, the multifunctionality of agriculture, the association between adaptation and mitigation in multi-purpose landscapes, breeding and improvement based on resilience criteria, the study of the effects of climate change on pests and diseases, combatting the loss of agricultural water, the fight against food waste, and research on 'orphan' crops better adapted to their environment.

Agriculture is not only subject to climate change, but can also contribute to its solution. It is the only human activity which can reduce emissions and sequester carbon while contributing to lower carbon use in sectors such as energy and construction through the production of biomass. There is no doubt that man's use of rural land will be one of the major issues of the 21st century.

The information sheets in this brochure offer a selection of the expertise and results from CIRAD on the issue of climate change. They concern adaptation to climate stress, mitigation of greenhouse gas emissions and carbon capture, as well as various innovations in farming practices, public policies and regulations.

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Online dossier:

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See also: http://publications.cirad.fr

Adapting to heat

The example of rice

Anthesis of a rice panicle, IRRI, Philippines. © T. Lafarge/CIRAD

When growing rice, increased temperatures are a source of sterility. To maintain yields, it is vitally important to adapt flowering processes to heat. Researchers from CIRAD are contributing to develop varieties capable, at the time of flowering: of escaping the heat (anthesis occurs early in the day), avoiding it (the panicle is cooled through transpiration) or tolerating it (presence of genes of interest). Using models, they have shown that the main genetic improvement pathways relate to avoidance and tolerance, whereas ensuring escape would mean adjusting cropping practices, primarily sowing date. This integrative approach is a good example of the strategies adopted in ecophysiology.

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The risks of sterility: changes in the climate and cropping practices

In the Senegal River valley, high air temperatures during flowering can adversely affect plant fertility. As long ago as 1995, optimum sowing windows that minimized the climatic risks were determined using the RIDEV model developed by AfricaRice. However, a recent analysis of weather data showed that temperatures had increased and that the climate (2001-2012) was different from the reference period. The need to update recommendations meant revising the model. To this end, CIRAD has set up a trial network (in Senegal, the Philippines and Camargue) ensuring distinct combinations of climatic factors and contrasting types of planting material in terms of size, plant architecture and crop duration, level of tolerance and yield potential.

Survey in Seriballi, Office du Niger, Mali. © A-B. Baldé/AfricaRice

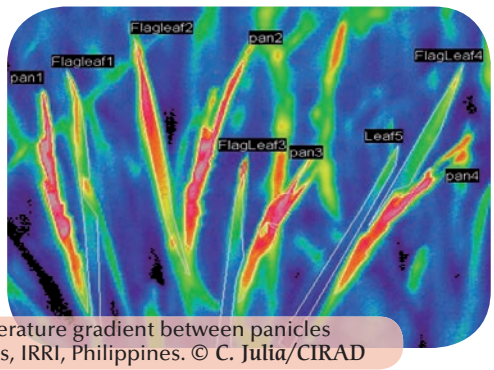
Adaptation through escape: anthesis early in the day

Anthesis is the development stage most sensitive to high temperatures. For a given spikelet, it occurs only in the morning and does not last more than two hours. Through their trial network, researchers have been able to show that anthesis is primarily correlated to the mean of two climate variables, calculated over the seven days that precede flowering: minimum ambient temperature and relative humidity. High air temperatures and relative humidity bring anthesis forward to the early hours of the morning. Conversely, anthesis occurs later in the event of cool, dry conditions. This behaviour is the result of adaptation through escape with respect to high temperatures.

Adaptation through avoidance: panicle cooling through transpiration

When the panicle transpires, it cools itself by consuming energy. At the same time, absorption of solar radiation heats it. The researchers measured panicle temperatures using infrared imaging, and showed that panicle temperature may be several degrees higher or lower than that of the air, depending on the climate conditions. An analysis over the trial network revealed that panicle temperature was primarily correlated to the relative humidity of the air. The rate of spikelet sterility is thus correlated to panicle temperature at the time of flowering, and not to that of the air. The relations established mean that it is possible to predict a degree of sterility once the temperature tops 30°C, with the sterility rate reaching 50% for temperatures of between 33 and 34°C.

Taking an infrared photo, IRRI, Philippines. © T. Lafarge/CIRAD



Temperature gradient between panicles and leaves, IRRI, Philippines. © C. Julia/CIRAD

Adaptation through tolerance: genes that maintain fertility despite the heat

The search for genes involved in heat tolerance at the time of flowering was conducted by studying the statistical correlations between the variations in the genotype and those in the phenotype of 167 traditional to modern varieties. A statistical analysis of the genetic determinism of the sterility rate of the varieties at 37°C detected 91 significant associations concentrated in 12 independent regions of eight chromosomes. The highest heat tolerance was found in two varieties, one originating from India, the other from Taiwan. The genome segments detected pave the way for cloning of the genes involved and implementation of a molecular marker-assisted breeding programme for heat tolerance.

Mature rice cover, Changsha, China. © T. Lafarge/CIRAD

A tool for predicting yields

CIRAD has developed a new version of the model, RIDEV_V2, in partnership with AfricaRice: it simulates the changes in the sterility rate of the cover depending on the sowing date, integrating the variables identified for escape and avoidance. This improved version allows for simulation exercises in order to develop better phenotypes with a high yield potential and high heat tolerance capacity. These steps forward will also make it possible to validate new sowing windows that would avoid climate periods that pose the greatest risk for the fertility of this major food crop.

Partners

Africa Rice (CGIAR), Benin; **IRRI,** International Rice Research Institute (CGIAR), Philippines; **CFR,** Centre français du riz, France. **CGIAR Research Programmes**: **CRP GRISP,** Global Rice Science Partnership; **CRP CCAFS,** Climate Change for Food Security.

› For further information

Lafarge T., Julia C., Baldé A., Ahmadi N., Muller B., Dingkuhn M., 2015. Rice adaptation strategies in response to heat stress at flowering. *In:* Torquebiau E. (ed.). Climate change and agriculture worldwide. Springer (in press)

See also: http://publications.cirad.fr

Tilapia resistance to increasing salinity

Salt-tolerant, fast-growing seventh-generation *Molobicus* hybrid
© H. D'Cotta/CIRAD

Rising sea levels and ever more frequent typhoons are increasing the salinity of certain aquatic and terrestrial ecosystems. This is one of the major current consequences of climate change. Preserving fresh water resources is thus a crucial food security issue. As regards farmed tilapia, this means being able to offer farmers species and strains adapted to future constraints.

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The tilapia group

Tilapia (sometimes called "aquatic chicken") is produced in more than 100 countries (4.3 million tonnes in 2013). It is the main group of farmed fish, after carp, produced and consumed in China. Tilapias originated in Africa, where they are primarily found in fresh water, and there are many species. The Nile tilapia, *Oreochromis niloticus,* which grows faster in fresh water, accounts for around 90% of total production, but is not very salt-tolerant. On the other hand, *O. mossambicus* (Mozambique tilapia) and *Sarotherodon melanotheron* (a lagoon tilapia) are highly tolerant of variations in salinity (euryhalinity), but are slow growing.

BFAR experimental installations in the Philippines for the Molobicus project. © H. D'Cotta/CIRAD

Combining high tolerance and high productivity

There are three types of approaches to breeding fast-growing, salt-tolerant strains in different salinity conditions: 1) using the high salt tolerance of naturally adapted species and implementing a selection programme to improve their growth in salt water; 2) using the fast growth of the Nile tilapia and improving its salt tolerance; and 3) combining the two traits by crossing the highly tolerant Mozambique tilapia with the highly productive Nile Tilapia. Researchers from the UMR ISEM Joint Research Unit and their partners in the South have adopted the third approach for the Molobicus project, supported by the French Embassy in the Philippines, which has allowed the production of two productive, salt-tolerant tilapia lines.

At the same time, using ecophysiology and genomics approaches, they are conducting research with a view to understanding the mechanisms by which fish adapt to salt stress.

The aim is to obtain genetic markers for salt tolerance, which will serve to identify species or populations of interest in their natural environment and to optimize breeding programmes. More specifically, this means:

- understanding the mechanisms of osmoregulation (role and ratios of the different ions involved, particularly Cl^- and Na^+) in the organs concerned;
- comparing the impact of salinity adaptation in different species, or hybrids, on reproduction and growth;
- analysing the feasibility and consequences of transferring the salinity tolerance trait from one species to another through hybridization;
- establishing molecular markers of salinity tolerance that will be used to identify species, populations and families for selective breeding.

The genomes of the Nile tilapia and of four other cichlid species (the family to which the tilapia belongs) have been sequenced by the Cichlid Genome Consortium (CGC), of which CIRAD is a member. Having access to the tilapia genome is vitally important for analysing and understanding what determines numerous traits of aquacultural interest. The Franco-Israeli Maïmonide project on salinity stress is working to identify markers of salt tolerance in two tilapia species *(O. niloticus* and *O. mossambicus)* and their hybrids

Energy cost, salinity and sex control

In fresh water, females, which have to build up substantial yolk reserves to ensure embryo development, grow more slowly than males. However, adaptation to salinity is based on osmoregulation mechanisms, which have a high metabolic cost for the fish. Since males have more energy available to adapt to salinity than females, controlling sex becomes doubly worthwhile when working with salt water.

Various methods are used to produce populations composed exclusively of males. As an alternative to using hormones, which raises several issues, CIRAD suggests two approaches: one environmental, based on the masculinizing effect of high temperatures, and the other genetic, involving the use of YY male breeders which give all-male progenies.

Molecular markers for early phenotypic sexing have been identified and tested as part of an ANR-Emergence project (SexTil) with a view to producing commercial kits.

In particular, these kits will serve to accelerate production of YY males and select parents that give thermosensitive progenies to enable hormone-free sex control.

Associating producers

However, the debate cannot focus solely on biology, and must take take account of economic and social criteria so as to ensure that human activity has as little impact on ecosystems as possible. Likewise, the innovations developed by research may mean rethinking animal and crop farming practices. It is therefore vital that users be closely associated with assessment of these new genotypes.

Female *Molobicus* incubating eggs. © H. D'Cotta/CIRAD

Hybrid red tilapias are often used for salt water farming (in this case in Bangkok). © H. D'Cotta/CIRAD

Partners

Agricultural Research Organization, Israel; **BFAR,** Bureau of Fisheries and Aquaculture Research, Philippines; Broad Institute Boston, **USA; IFREMER,** France; **INRA,** France; **IRD,** France; **UMR-MARBEC** and University of Montpellier II, France; University of Zürich, Switzerland; WorldFish Penang, Malaysia.

For further information

Ahmadi N., Baroiller J-F., D' Cotta H., Morillon R., 2015. Adaptation to salinity. *In:* Torquebiau E. (ed.). Climate change and agriculture worldwide. Springer (in press)

De Verdal H. *et al.,* 2014. Response to selection for growth in an interspecific hybrid between *Oreochromis mossambicus* and *O. niloticus* in two distinct environments. *Aquaculture,* 430: 159-165.

See also: http://publications.cirad.fr

Resisting increasing salinity

The case of citrus in the Mediterranean

Pollinating an orange tree, Morocco. © C. Rollin/CIRAD

Citrus fruits originated in tropical and subtropical Asia. They are grown in all the world's warm regions, generally under irrigation, as is the case all around the Mediterranean. On its southern shores, for instance, water resources are becoming increasingly limited, while higher demand for water due to human activity means that water tables are falling and soil salt levels are rising, which is already impacting agriculture. Scientists are investigating the mechanisms of adaptation to salt stress, in order to orientate breeding programmes and eventually offer farmers more adapted genotypes.

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Citrus trees are amongst the woody species most sensitive to salt stress. Ensuring better adaptation to salinity means 1) managing irrigation practices so as to prevent salt rising up through the soil towards the surface, 2) having rootstocks capable of limiting Na+ and Cl- ion uptake at root level, 3) having varieties for grafting onto the selected rootstocks that present physiological and molecular mechanisms that limit the impact of toxic ions.

CIRAD is combining ecophysiology and breeding with a view to:

- understanding the mechanisms leading to sensitivity and adaptation to salt (role and ratios of K+, Na+ and Cl- ions, osmotic adjustment, impact of plant morphology), triggering of oxidative stress, detoxification systems, etc
- analysing the mechanisms used by species to adapt to salinity;
- identifying candidate genes and genetic markers for selection;
- breeding varieties that are both tolerant and productive in different salinity conditions.

Creating tolerant varieties

The citrus group comprises three main botanical genera that are sexually compatible: *Citrus, Poncirus* and *Fortunella*. Most of the rootstocks in current use belong to the genera *Citrus* and *Poncirus*, or are hybrids obtained by crossing the two. Most citrus varieties (orange, mandarin, lemon, grapefruit and lime) all belong to the genus *Citrus*.

Citrus planting under netting . © Y. Froelicher/CIRAD

Rootstocks

Several CIRAD selections are currently being investigated and should serve to widen the range of possible rootstocks. As regards salt stress tolerance in rootstocks, three main groups have been identified: a tolerant group that comprises sour orange and "Cleopatra" mandarin, which are considered to be adapted to abiotic constraints; a sensitive group that comprises rough lemon and "Carrizo" citrange; and a highly sensitive group represented by *Poncirus* (*Poncirus trifoliata*).

Sensitivity is primarily due to Cl- ions. Leaf Cl- content is a good criterion for assessing the salt sensitivity of seedlings.

› Combined with *Poncirus*, the "Cleopatra" mandarin is used in breeding programmes to generate more tolerant diploid, double diploid and allotetraploid genotypes.

› Tetraploid rootstocks are more tolerant than the respective diploids, probably because of their greater ability to compartmentalize and detoxify Cl- and Na+ ions.

Scions

Another way of addressing the salinity issue is to assess the salt tolerance of newly created fruit varieties (scions).

› Several thousand triploid varieties are currently being assessed for fruit quality criteria with private partners. Evaluation of the pre-selected triploid varieties for their salt stress tolerance has been initiated.

Genetic diversity

› A recent analysis of the physiological response to salt stress of genotypes representative of the diversity suggested that it should be possible to find new sources of tolerance in rootstocks and also at variety level.

Associating end users

Substantial efforts are being made to be able to offer genotypes more adapted to high salinity. However, it is also necessary to take account of economic and social issues to ensure that human activity has little impact on ecosystems. Likewise, the new innovative genotypes developed by research may mean changing cropping practices. It is therefore vital that end-users be closely associated with the assessment of these new genotypes.

Effects of salt stress on various citrus fruits.
© F. Luro/INRA

1. Cleopatra mandarin: no symptoms – plant and fruit

2. Grapefruit: leaf fall and new shoots – plant and fruit

3. Citron: necrosis of leaves and branches – plant and fruit

Partners

INRA, Institut national de la recherche agronomique, France;
IVIA, Instituto Valenciano de Investigaciones Agrarias, Spain;
INAT, Institut national agronomique de Tunisie.
Private partners: Agromillora, Spain; Domaine Abbès Kabbage, Morocco.

Factsheet produced with the support of CTPS - AAP12 project no. 3 / C2012-01

› For further information

Nourollah A., Baroiller JF., D'Cotta H., Morillon R., 2015. Adaptation to salinity. *In:* Torquebiau E. (ed.). Climate change and agriculture worldwide. Springer (in press)

See also: http://publications.cirad.fr

Improving plant adaptation to drought in Africa

Examples of cotton, groundnut and sorghum

New plant growth in cracked soil.
© A. Rival/CIRAD

Producing varieties more resilient to adverse environmental conditions is a challenge for geneticists. Breeding is based on the one hand on exploring the broad genetic diversity that exists within cultivated species and wild relatives, and on the other hand on screening tests of adaptive traits. Multi-disciplinary approaches that associate ecophysiology, genetics and marker-assisted selection (MAS) serve to define varietal ideotypes that combine adaptive and productivity traits and can respond to the major issues for the future.

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Adapting crops to drought may use any of three strategies: escape, by adjusting the development cycle; avoidance of drying out, by controlling water losses and/or maintaining absorption; and tolerance, thanks to the plant's ability to overcome the deterioration of its water status. In plant improvement, marker-assisted selection (MAS), which consists in simultaneously characterizing the genotype, using DNA markers, and the plant's response to contrasting conditions (stressed versus unstressed) serves to identify the genome regions involved, or QTL (quantitative trait loci) and to select progenies indirectly.

Cotton, groundnut and sorghum, species that are of major importance in Africa and elsewhere, are a good illustration of the research being done by CIRAD and its partners.

Study of the cotton root system in a rhizotron.
© M. Giband/CIRAD

Diversity of wild and cultivated cotton varieties

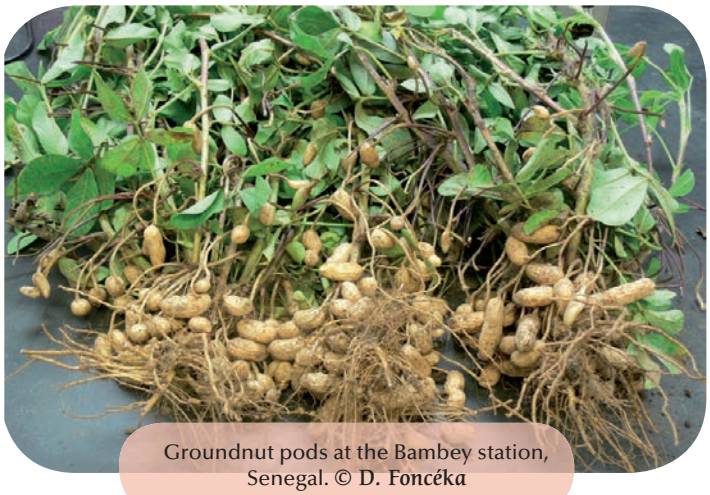
Perennial *Gossypium hirsutum* cotton plant populations from Mesoamerica and the Caribbean have been described and georeferenced: of 950 cotton populations, around a hundred are wild, tied to coastal environments with high constraints as regards water availability or salt stress. These wild populations represent a reservoir of environmental stress tolerance genes for improving cultivated cotton, *G. hirsutum*. Association genetics studies are under way at EMBRAPA in Brazil and at CIRAD, with the support of the Agropolis foundation, to determine the response to water deficits within the cultivated *G. hirsutum* pool. A panel of 250 varieties of various origins is undergoing morphological and physiological characterization under controlled conditions, on the one hand using rhizotrons (analysis of the root system) and on the other using a high-throughput measurement system developed by INRA in Montpellier (Phenoarch platform).

What the distant parents of groundnut can contribute

In Senegal, work by ISRA and CIRAD on groundnut drought tolerance led to the creation in 1989 of CERAAS, the *Centre d'études régional pour l'amélioration de l'adaptation à la sécheresse,* which federates research efforts on a regional level.

CIRAD, CERAAS, the CNRA (*Centre national de recherche agronomique,* Bambey) and EMBRAPA (Brazil) have established a programme to broaden the genetic base of cultivated groundnut through hybridization with wild species of the genus *Arachis,* for their adaptive traits (diseases, environmental stress). The Fleur11 variety and a tetraploid hybrid between two wild diploid species, *A. duranensis* and *A. ipaensis,* have been used for marker-assisted population construction to produce:

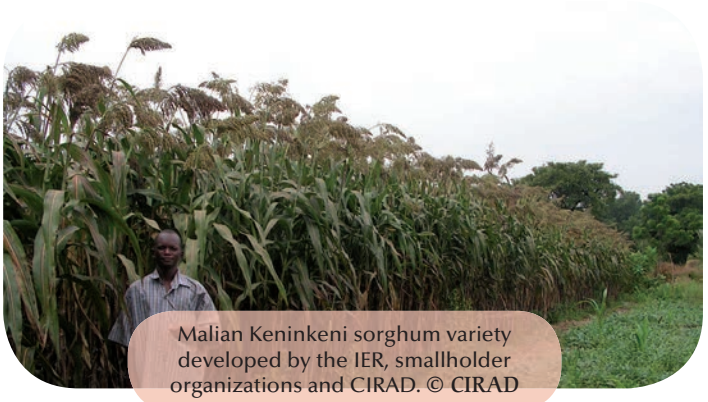
- an "AB-QTL" (Advanced Backcross-QTL) population used to map numerous QTL involved in morphology and yields under water stress conditions;
- a population of "CSSL" (chromosome segment substitution lines), comprising lines very closely related to the cultivated genome, each integrating a small chromosome segment of wild origin, used in several groundnut genetic improvement programmes (Senegal, Mali, Niger, Malawi, India and Brazil).



Groundnut pods at the Bambey station, Senegal. © D. Foncéka

Sorghum: sharing knowledge

African farmers have long experience of managing irregular rainfall patterns, the most spectacular aspect of which is making use of photoperiodism. In particular, photoperiodism serves to synchronize flowering with the end of the rainy season, independently of sowing date. This mitigates the effects of climate variability in the event of drought or excess water and avoids many biotic constraints (insects, birds and moulds). CIRAD's sorghum improvement programmes are using the broad genetic base of local varieties, or landraces, to combine the yield potential of modern varieties and the specific properties of local varieties. A molecular marker-assisted recurrent selection programme is under way in Mali and a broad experimental population including local and modern varieties has been built up. A major photoperiodism QTL was recently identified and could be used to develop varieties specifically adapted to the climatic variability of Sudano-Sahelian Africa.



Malian Keninkeni sorghum variety developed by the IER, smallholder organizations and CIRAD. © CIRAD

Prospects

CIRAD's genetic improvement research highlights the importance of making use of as much of the diversity that exists within plant resources related to cultivated species as possible.

Partners

Cotton: EMBRAPA, IMAmt, Brazil; UMR CEFE, Agropolis Foundation, France; **Groundnut:** CERAAS, CNRA, Senegal; EMBRAPA, Brazil; ICRISAT (CGIAR); **Sorghum:** NARS (IER, ISRA, INERA, etc), ICRISAT, GCP, Syngenta Foundation, NGOs (AMEED, etc) CERAAS, Agropolis and Cariplo (BIOSORG) Foundations.

For further information

Lacape J-M. et *al.*, 2015. Enhanced drought adaptation in African savanna crops. *In:* Torquebiau E. (ed.). Climate change and agriculture worldwide. Springer (in press)

See also: http://publications.cirad.fr

Pests and diseases of tropical crops

New phenomena linked to climate change

Larva of *C. sacchariphagus*, the sugarcane stem borer. © R. Goebel/CIRAD

Climate change modifies pest behaviour and distribution. There is a real risk of increased phytosanitary pressure as a result of disruption of the environment and farming systems, which is a matter of concern for the whole range of agricultural stakeholders, particularly in temperate countries, where numerous new pests, diseases and weeds are likely to be introduced.

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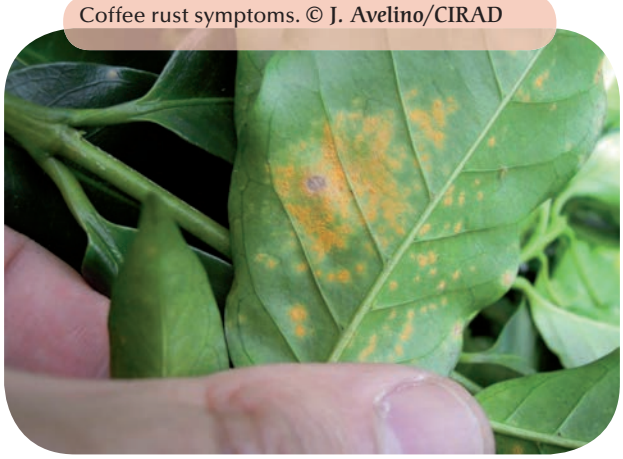
In tropical environments, the impact of climate change on pest populations and their natural enemies is more difficult to assess than in temperate zones, and more complex. There may be changes in pest status, introductions, the exponential development of certain pests and diseases and growth in their zones of distribution. The pests on which CIRAD is working have already provided some pointers in terms of adaptation to climate change, and new agro-ecological protection strategies are now available that foster the conservation of natural regulation services and enable a sustainable reduction in phytosanitary risks

Coffee berry borer. © CIRAD

Coffee rust symptoms. © J. Avelino/CIRAD



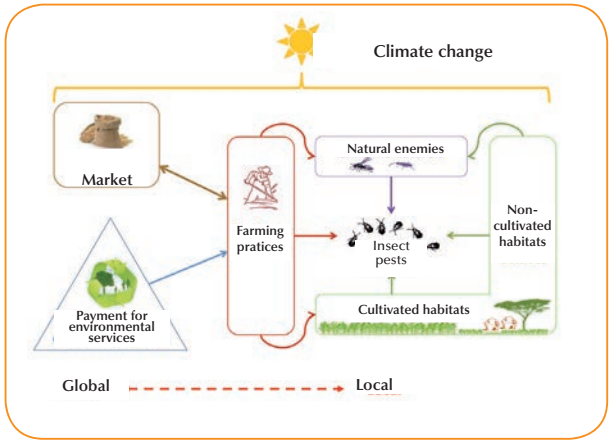
New phenomena that are gaining speed

- Changes in rainfall patterns can lead to variations in the level of infestation by the **coffee berry borer**. In the event of a marked dry season, coffee cherries all ripen simultaneously, and there is a food shortage after the harvest that is prejudicial to borers. If the dry season is not marked, coffee cherries are available all year round, which favours borers.
- On **sugarcane,** *Trichogramma* population levels are down. These tiny parasitoid wasps, which play a vital role in natural stem borer population regulation, are used in biological control strategies. However, the wasps, which live outside plants, are highly sensitive to temperature variations, whereas stem borers, which live inside the stem, are less sensitive.

› A severe epidemic of **coffee leaf rust,** one of the major fungal diseases of Arabica coffee, has been under way for several years in Latin America. It has now spread to highland regions, where temperatures are rising, whereas it was previously rarely seen in such areas.

› In West Africa, the explosion of **Cacao Swollen Shoot Virus,** an African virus that attacks cocoa plants, may be due to the more general changes caused by deforestation, which has modified the climate in the region.

› The biological cycle of the **cotton bollworm,** Helicoverpa armigera, in West Africa is closely linked to climate conditions. In tropical climates, there may be up to ten generations a year. In northern Benin, its abundance has been seen to be linked to the heterogeneity of the landscape in terms of host plants (cotton, maize, tomato and sorghum) around crop plots. That heterogeneity depends on the cropping calendar, which itself is closely linked to temperature and rainfall variations.



The range of relations to be taken into account in farming systems under pressure from climate change © CIRAD.

Some promising results

In a study in Madagascar, improving the water balance and reducing evapotranspiration through conservation agriculture helped reduce the impact of blast on upland rice crops. Installing a plant cover in rice plots also serves to cut losses due to pests and diseases, by enriching the local biodiversity (both above and below ground) and reducing the use of inputs with a large carbon footprint.

Managing coffee pests and diseases can be made easier by intercropping coffee with trees. This type of coffee-based agroforestry system has been adopted by most of the world's coffee smallholders, since trees provide the shade required to strike a balance between productivity and sustainability, without systematically resorting to irrigation or fertilizers.

It is thus possible to preserve ecological services while mitigating the effects of the climate on biodiversity, and we will need to be doubly ingenious and design cropping systems that ensure effective protection against pests and diseases by making use of the gamut of ecological processes. This is a priority for future research, which will call upon a wide range of disciplines.

H. armigera on a cotton plant. © A. Ratnadass/CIRAD

Minimizing the impact of pests and diseases: a systemic approach

It is necessary to adapt cropping systems to these disruptions by changing farming practices, taking account of landscape elements. Moreover, a veritable biosecurity plan needs to be adopted, to prevent new introductions into zones previously unaffected by the pests or diseases concerned.

CIRAD is concentrating on:

› local management of phytosanitary risks, which are being exacerbated by climate change, so as to adapt cropping systems in line with their effects

› adapting phytosanitary practices so as not to exacerbate the risks of climate change on a global scale;

› anticipating and preventing the introduction of tropical pests and diseases and their establishment in more temperate zones.

Partners

Research and training platforms in partnership
DIVECOSYS, Agro-ecological Pest Management in West Africa
SPAD, Farming Systems in the Highlands, Madagascar

Research centres
AfricaRice (CGIAR), Benin; **CATIE,** Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica; **CSIRO,** Commonwealth Scientific and Industrial Research Organisation, Australia; **FOFIFA,** Centre de recherche agronomique de Madagascar; **ICIPE,** International Centre for Insect Physiology and Ecology, Kenya; **IITA,** International Institute of Tropical Agriculture (CGIAR); **SASRI,** South African Sugarcane Research Center, South Africa.

› for further information

Cilas C., Goebel F-R., Babin R., Avelino J., 2015. Tropical crop pests and diseases in a climate change setting – a few examples. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide.* Springer (in press)

See also: http://publications.cirad.fr

Emergence or re-emergence of vector-borne diseases

Is climate one of many factors?

The blue tit, a potential West Nile virus reservoir in Europe.
G. Balança/CIRAD

Diseases transmitted by insect vectors have a major impact on human and animal health, and on the economy of societies. Because of the way in which they are transmitted, these diseases, whether or not they are zoonotic, are particularly sensitive to climate change. The biological processes involved are complex. CIRAD and its partners have been working for several years to develop models that enable a clearer understanding of these phenomena and can identify the periods and/or zones most at risk.

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Understanding the mechanisms and environmental conditions that are behind the emergence of vector-borne zoonoses is a major issue for improving control and prevention methods. The two examples below illustrate the major progress made through work by CIRAD and its partners.

Rift Valley fever

Rift Valley fever (RVF) is a "climate-sensitive" disease that is a major threat in most of Africa. It is caused by a Phlebovirus and transmitted to ruminants and man by mosquitoes (primarily *Aedes* and *Culex*). It has a dramatic sanitary and economic impact: in ruminants, mass abortions among gestating females and high mortality/morbidity in young animals; in man, there are several serious forms (notably encephalitis and a haemorrhagic form); and it can bring animal trading to a complete standstill. Senegal is currently one of the most severely affected countries in Africa. In this world region, no correlation has yet been established between extreme rainfall episodes and the occurrence of epizootics, unlike what has been observed in Kenya. However, CIRAD and

Temporary pond where the main mosquitoes that carry RVF in Senegal proliferate: in the dry season (top) © A. Tran/CIRAD; in the rainy season (bottom). © V. Chevalier/CIRAD

its partners have observed that major RVF epidemics were seen in years with simultaneous population peaks of the main two vector species, *Culex poicilipes* and *Aedes vexans,* those peaks being a direct consequence of specific, now well-described rainfall patterns. This work (entomological and serological studies, modelling) is being continued under the Vmerge project.

West Nile fever

West Nile fever (WNF), which is also transmitted by mosquitoes of the genus *Culex,* is caused by a Flavivirus. The reservoir hosts are wild birds, primarily passerines. Humans and horses can be infected, but are considered to be "epidemiological dead-ends". In Europe, the virus has been seen in the Mediterranean since the 1960s, without any marked impact on human or animal health. However, the incidence of neurological cases in humans and horses increased sharply in the 2000s, particularly from 2010 onwards. A recent study by CIRAD and its partners showed that abnormally high temperatures, particularly in the month prior to epidemics, helped to trigger them by increasing vectorial competence and reducing the length of the gonotrophic cycle (the time between sucking blood and laying eggs). The statistical model developed can be used to generate predictive maps of the risk of transmission, which are already being used to optimize surveillance and target the most at-risk zones.

The starling, a potential West Nile virus reservoir in Europe. © G. Balança/Cirad

The climate is not the only culprit

Although it often plays a role, the climate and its variations have very seldom been the only factor in the emergence of vector-borne diseases in recent decades. The concurrence in time and space of hosts – birds or ruminants – and vectors, and their ability to pass on or harbour pathogens are crucial. Reservoir distribution and density, the seasonality and geography of migration, landscape structure and the trophic preferences of the vectors present will have to be taken into account in future in order to fine-tune forecasts and reduce the impact of these diseases on health and the economy.

Culex mosquito, a West Nile fever vector. © CIRAD

Partners

Europe: ANSES, Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail, France; **ECDC,** European Centre for Diseases Prevention and Control, Sweden; **IRD,** Institut de recherche pour le développement, France.

Africa and Middle East: ISRA, Institut sénégalais de recherches agricoles, Senegal; **University of Haifa,** Department of Geography and Environmental Studies, Israel.

Vmerge project: http://www.vmerge.eu

› For further information

Véronique Chevalier *et al.,* 2015. Climate change and vector-borne livestock diseases. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide.* Springer (in press)

See also: http://publications.cirad.fr

Annual cropping systems and climate change

Weeding millet in a parkland of *Faidherbia albida* in Senegal. Acacia plays an essential role in the management of soil fertility.
© T. Brévault/CIRAD

In the tropics, annual crops on family farms are very sensitive to climate. Between the positive, negative and poorly predicted effects, changes in biotic stress and the different interactions possible, too many uncertainties still exist to enable us to forecast yield changes resulting from climate change. Cropping systems (conservation agriculture, agroforestry, direct seeding using the Zai technique) and decision support (risk management, weather insurance) are being studied, with the dual objective of reducing greenhouse gas emissions and reducing the impacts of climate change on the standard of living of agricultural households.

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Mitigating the causes of climate change

Agriculture could and should contribute to global efforts to reduce emissions of both CO_2 and methane (CH_4):

Limiting consumption of inputs: Research is focusing on improving the efficiency of fertilisers, rather than on their substitution or reduction.

Increasing carbon sequestration: Different agricultural practices are recognised for their sequestration potential (agroforestry, conservation agriculture etc.). However, sequestration rates are still hotly debated. Once very expensive, soil carbon measurements are now feasible in situ and at lower cost (infrared spectrometry).

Limiting CH_4 emissions: It is estimated that irrigated rice fields produce more than 50% of CH_4 emissions (due to methanogenic bacteria in the soil). Yet rice production will have to increase still further to meet population growth. Temporary drying out of rice fields can greatly reduce CH_4 emissions. Moreover, this seems to control some rice diseases and predators, in addition to vectors of human diseases.

Planting out rice in Laos. © F. Ribeyre, CIRAD

Mitigating the effects of climate change

Predicting the effects: Forecasting is necessary because it allows research and development policies to be steered towards mitigating the effects of climate change on crops (extreme weather events, water stress etc.). Crop modelling uses several tools, depending on the scale being studied. At the territorial or catchment area scale, statistical tools based on historical data can predict the harvest according to one or more climate variables. At the crop or plant scale, simulation models for growth and development are the most appropriate for taking into account the effects of practices and climate. CIRAD and its partners are working to improve these models which, for the moment, do not take into account important factors such as biotic communities, soil biology, soil erosion, extreme temperatures etc.

Adapting cropping systems: Many local techniques exist to address, in particular, hazards posed by water: management of surface water, mixed localised inputs of organic and mineral fertilisers, physical (stone rows or barriers, maybe walls) and biological (ground cover, hedges, mulches) anti-erosion measures.

Conservation agriculture: directly sown cotton grown with a mulch of sorghum and weeds.
© K. Naudin/CIRAD

Millet sown using the Zai method in Benin.
© P. Sylvie/IRD-CIRAD

Insuring against risks

As in other sectors, insurance can mitigate (through the compensation paid) the consequences of production losses suffered as a result of problems (drought, flood, frost, mass locust attacks). Since the early 2000s, experiments with innovative systems have been conducted in various countries (India, China, Mexico, Kenya, Senegal, Mali etc.). It remains to be shown whether this will be economically feasible on a large scale in the South and pertinent when compared with other agricultural aids.

A challenge for family farms

In developing countries, where many biotic and abiotic stresses are combined in producers' fields, the shortcomings of predictive models are considerable. To cope with the changes forecast, ecological intensification of agriculture will, of necessity, also be 'climate smart'.

The development of risk prediction systems is a promising way to help farmers in the 'tactical' management of the cultivated ecosystem. But technical choices at the field scale need to be supported by policies to promote farmers' room for manoeuvre in constantly adapting their cropping systems or to cushion the effects of the hazards they face.

Partners

Networks and projects

- **IntensAfrica project** (European Union, FARA)
- **ASAP,** Agro-Silvo-Pastoral Systems in West Africa
- **F&B,** Forests and Biodiversity, Madagascar
http://www. forets-biodiv.org
- **SPAD,** Farming Systems Sustainability in the Highlands, Madagascar
- **Agroforesterie Cameroun,** Agroforestry systems in Central Africa
- **CANSEA,** Conservation Agriculture Network in South-East Asia
http://cansea.org.vn
- **AFS-PC,** Agroforestry Systems with Perennial Crops in Mesoamerica
http://www.pcp-agroforestry.org

› For further information

Gérardeaux E. *et al.*, Relationships between tropical annual cropping systems and climate change. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide*. Springer (in press).

See also: http://publications.cirad.fr

Livestock sustainability and climate change

Cattle grazing on *Brachiaria humidicola* in the Amazon. © V. Blanfort/CIRAD

Supporting adaptation

The relationship between livestock farming and climate change is complex. On the one hand, rearing livestock is a major contributor to the phenomenon through its emissions of greenhouse gases (GHG). On the other hand, the significant and growing contribution of animal products in food systems and agriculture in Southern countries (manure, transport, savings, income) makes it essential that it is maintained, especially as major demographic, environmental and consumption changes are underway. CIRAD and its partners are contributing to the adaptation of livestock systems and to the sustainability of their multiple functions.

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Producing references for livestock systems

Few local references on the contribution of livestock systems in Southern countries to global warming are available. As part of the EPAD and Animal Change projects, CIRAD and its partners have built many references on fossil energy consumption and GHG emissions from pastoral and agro-pastoral livestock systems, as well as systems undergoing intensification, in various parts of world (Brazil, Burkina Faso, Costa Rica, Egypt, Guadeloupe, French Guiana, Reunion, Kenya, Mali, Mayotte, Democratic Republic of Congo, Senegal and Vietnam).

Assessing the impact of climate change on livestock farming

Rising temperatures, changing rainfall patterns and extreme weather events affect the various components of the system. CIRAD is evaluating all the impacts on animals resulting from thermal stress (decreases in production or reproduction, livestock mortality), changes in local feed resources due to increased temperatures and $C0_2$ levels, and the reduction in available grazing land in some territories, particularly in sub-Saharan Africa.

Conversion of natural grassland into *Brachiaria* pasture, DRC. © A. Duclos/CIRAD

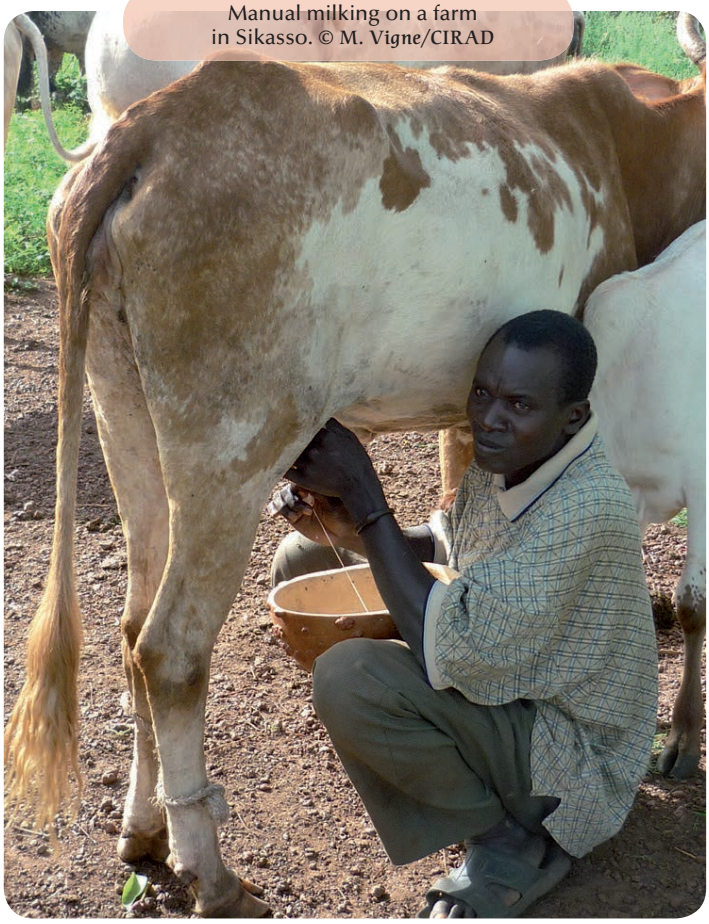
Understanding and supporting adaptation

Beyond the impacts on livestock, it is important to assess the capacity for adaptation to changes and to support them. Demographic models such as Dynmod make it possible, for example, to simulate the impact of successive droughts on the dynamics and productivity of a herd. In Egypt, the Elvulmed project has made it possible to understand how Bedouin livestock farmers, faced with recurrent drought from 1995 to 2010, lived through this period of profound change by adapting under different forms of production systems and supply chains.

Exploring ways of mitigating GHG emissions

The great diversity of livestock systems around the world allows us to consider many options for mitigating GHG emissions. In particular, CIRAD and its partners are studying:

- Feed resources with reduced methanogenic potential and to improve animal productivity (crop by-products in particular).
- The conservation and recycling of nitrogen on the farm (for example, the construction of manure pits in Burkina Faso).
- Carbon storage in pastures (CARPAGG and Animal Change projects).



Manual milking on a farm in Sikasso. © M. Vigne/CIRAD

Making the right decisions

This work supports decision making, at the farmer level (changes in practice, anticipating weather events) and at the policy maker level (public policies). In the short term, it means adapting to more frequent and more intense crises and, in the longer term, anticipating developments and proposing measures which make adaptation possible without social costs. For example, the information and early warning system in the Sahel (SIPSA) makes it possible to understand the current dynamics and support decision-making when dealing with the various crises experienced by the region.

A manure pit on a family farm, Burkina Faso. © M. Blanchard/CIRAD

Partners

Africa: FIFAMANOR, Centre de Développement Rural et de Recherche Appliquée, Madagascar; **FOFIFA**, National Institute of Agricultural Research, Madagascar; **IER,** Institut d'Economie Rurale, Mali; **ISRA,** Institut Sénégalais de Recherches Agricoles, Senegal; **Ranch de Kolo,** DRC; **UCAD,** Cheick Anta Diop University, Senegal.

Latin America: CATIE, Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica; **EMBRAPA,** Empresa Brasileira de Pesquisa Agropecuária, Brazil.

Asia: NIAS, National Institute of Animal Science, Vietnam.

France: Chambre d'Agriculture de Bretagne; **CERPAM,** Centre d'Etudes et de Réalisations Pastorales Alpes Méditerranée; **IE,** Institut de l'Elevage; **INRA,** Institut National de la Recherche Agronomique; **Montpellier SupAgro.**

European Union: FEDER projects.

French overseas regions: Producers' cooperatives: SicaLait and SicaRevia, Réunion; French Guiana and Réunion Regions.

International: FAO, Food and Agriculture Organization of the United Nations; **CIRDES,** Centre International de Recherche-Développement sur l'Elevage en zone Sub-humide, Burkina Faso; **ICARDA,** International Center for Agricultural Research in the Dry Areas, Egypt; **ILRI,** International Livestock Research Institute.

For further information

Mathieu Vigne et *al.*, 2015. Livestock farming constraints in developing countries – from adaptation to mitigation in ruminant production systems. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide.* Springer (in press)

See also: http://publications.cirad.fr

Management of hydrosystems

A global challenge for research in partnership

Infrastructure for water management in Mali. © E. Daou

The water cycle is influenced by global dynamics (socio-economic, institutional, political, etc.). It will also be progressively affected by climate change, which induces modifications - sometimes substantial - in hydrosystems and natural hydrological processes. Water users and stakeholders try to adapt in order to control their relationships with water. However, current scenarios show an acceleration in the intensity of changes. CIRAD's research is often conducted on site, following principles of stakeholder participation - from rural producers through to policy makers and managers - and aiming at the co-construction of possible solutions.

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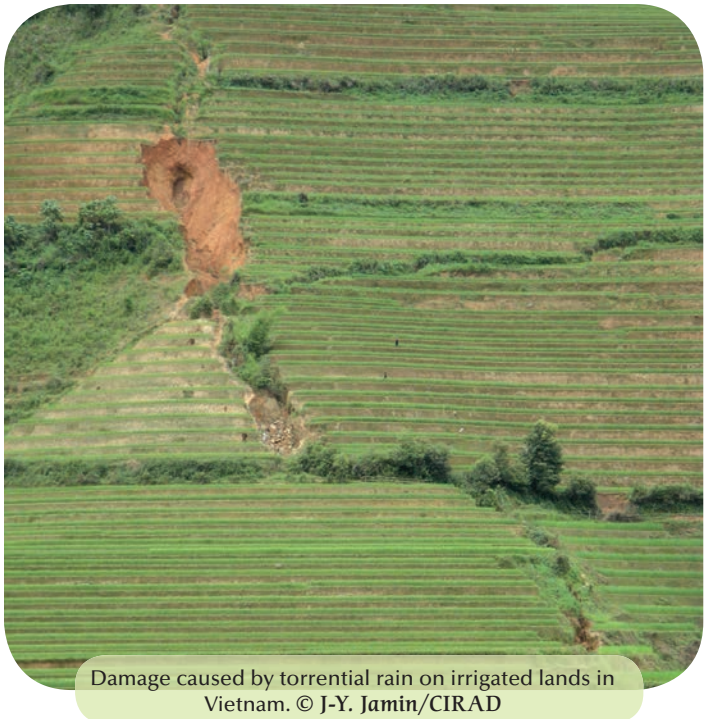
Three major issues drive the research actions on water resource management conducted by CIRAD and its partners:

- **Characterising changes in order to better understand the dynamics induced by climate change,** as well as other global changes, on both natural and social systems; modelling the effects and short and long-term risks; representing the interweaving of climate change with other dynamics at work (socio-economic, institutional and political).
- **Proposing technical solutions,** to support stakeholders in the adaptation of their practices.
- **Adapting governance to deal with changes,** taking into account emerging issues on water management and water use in the territory.



Damage caused by torrential rain on irrigated lands in Vietnam. © J-Y. Jamin/CIRAD

Characterising changes

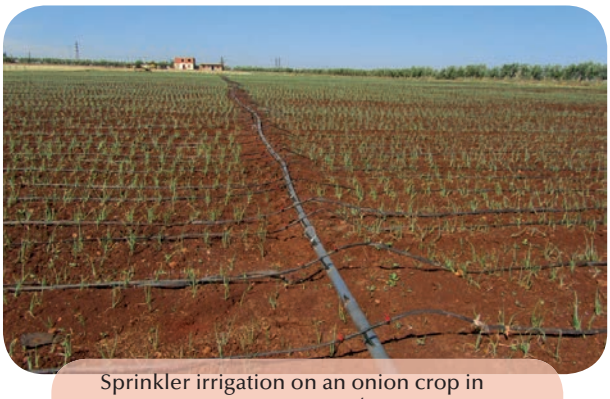
The first major issue relates to the characterisation of the changes at work through:

- Monitoring the dynamics and availability of water resources by systematic measurement and through the development of statistical climate and hydrological models.
- Adapting to these dynamics.
- Studying farmers' perceptions of the importance of climate change and other global changes, and of the need to adapt.

Proposing technical solutions

Three types of solutions are explored and their effects on different uses and on environmental sustainability are analysed:

- Technological innovations in water use, particularly in terms of irrigation; the use of more water-efficient irrigation methods (such as drip irrigation) are studied and issues of appropriation by stakeholders are addressed.
- Solutions for regulating the resource availability, for example through the use of reservoirs.
- Solutions relating to the use of alternative resources: slightly saline water, wastewater, groundwater, etc.



Sprinkler irrigation on an onion crop in Tunisia. © J-Y. Jamin/CIRAD

Adapting governance to deal with change

The governance of hydrological territories includes forms of non-technical adaptation (increased migration, alternative scenarios for allocating water resources, etc.). Consequently, researchers, in partnership with stakeholders in water management, develop and propose methods and tools to facilitate the integration of diverse views in selecting adaptation options.

For instance, in the Mediterranean region, studies on the participatory management of aquifers suggests an approach based on collective governance and action to ensure the sustainability of hydrosystems.

In many areas, in Africa and elsewhere, the kit for participatory modelling and simulation, Wat-A-Game (WAG), accompanies stakeholders at various levels towards negotiation platforms for the management and the use of water. It gives a voice to disadvantaged actors having their own perceptions on change and proposals for adaptation. Its use makes it possible to bring together both village communities and government officials in the development of their collective development strategies.

Building a continuum of knowledge

The research conducted by CIRAD and its partners aims to better involve the different actors engaged in the process of adapting hydrosystems to climate change and other global changes. The objective of this applied and participatory research is to form a continuum of popular and scientific knowledge, know-how, local practices, exogenous technologies and information to feed the decision-making channels used in the adaptation process for rural populations, farms and public policies.

Participatory seminar within the Aquimed project in Morocco. © N. Faysse/CIRAD

Partners

AFD, Agence Française de Développement, France
AIT, Asian Institute of Technology, Thailand
IAV, Institut Agronomique et Vétérinaire Hassan II, Morroco
ICID, International Commission on Irrigation & Drainage
INAT, Institut National Agronomique de Tunis, Tunisia
IWMI, International Water Management Institute (CGIAR)
NEPAD, African Western and Southern Networks of Centres of Excellence in Water Sciences
UNESCO Chair in Water Economics and Transboundary Water Governance
UNESCO IHE, Institute for Water Education
University Cheick Anta Diop, Senegal
University Eduardo Mondlane, Mozambique
University of Pretoria, South Africa

For further information

Barreteau O., Farolfi S., Perret S., 2015. Management of collective water resources in response to climate change disruptions. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide*. Springer (in press)

See also: http://publications.cirad.fr

Recycling of organic waste

To reduce greenhouse gas emissions

Livestock on Réunion island.
© E. Tillard/CIRAD

In agriculture, simply recycling organic waste can replace mineral fertilisers and make nutrient cycles more efficient, thereby reducing sources of GHG. In accordance with the principles of the bioeconomy, a more comprehensive recovery integrating biotransformation will reduce still further, both directly and indirectly, these emissions through stable carbon storage and savings in fossil fuels. CIRAD's research is contributing to a more rational approach for the exchange, biotransformation and use of organic waste in various agricultural production contexts in the tropics.

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Integrated recycling of agricultural, agro-industrial and urban waste

Over the past 25 years, the surge in development of the livestock sector on Réunion island led to the creation of supply chains which are exemplary for their integration and production capacity. However, this intensification has led to a significant increase in their carbon footprint.

There are multiple links between organic waste, its production, its final destination and GHG emissions. By simulating the operation of livestock farms, CIRAD has developed technical improvements that allow producers to reduce their climate impact. But the potential for improvement is much greater if it is conceived at the territorial scale. Thus, the search for sustainable solutions leads to establishing synergies between different types of waste and achieving economies of scale, making it possible to implement biotransformations such as methanization.

Spreading pig manure on an experimental sugarcane plot on Réunion island. © F. Feder/CIRAD

Such solutions have been developed in the GIROVAR research and development project, which involved a local community in Réunion and ran from 2011 to 2014.

A suitable method: methanization

Methanization of organic waste is recognised as one of the major solutions for reducing GHG emissions in agriculture and agro-industry. It is of particular interest in the tropics, where high temperatures boost output and where electrical power is not yet fully distributed. In Africa there is a major potential for the recycling of organic waste, from the farm scale through to the territorial scale, and also in agro-industrial sites. Since the 1990s, CIRAD has more often been concerned with the methanization of agro-industrial waste, produced in large quantities and in one place.

In the Sahel, where livestock production remains predominantly extensive, the slaughterhouse is the only place where animals are concentrated and in which it is possible to envisage a genuine recycling of waste. CIRAD was involved in two projects, in Senegal and Egypt, to demonstrate the technical and economic feasibility of the methanization of slaughterhouse waste. Continuing this approach, since 2014 CIRAD has coordinated the WABEF project, which aims to promote methanization in West Africa through the provision of decision making tools and initial and professional training.

Another example concerns the palm oil supply chain. Palm oil mill effluent (POME) generated from palm oil milling activities has a high polluting strength. Conventionally this effluent is treated in huge open-air ponds, emitting up to 38kg of CH_4 per tonne of oil produced. Since 2011, CIRAD has been working with a private company in Gabon, Ghana and Nigeria to implement methanization of these effluents in covered ponds, a technique which is particularly suitable for local conditions. The biogas produced will, by 2020, generate savings of more than 4 million litres of diesel per year. Coupled with the reduction of greenhouse gas emissions compared with the previous method, emissions of 73,700 tonnes of CO_2 equivalent will be avoided annually.

Construction of a methanization pond in Ghana. © Biotec

Outlook

Recycling organic waste requires a better understanding of the behaviour of metals, pathogens and certain organic compounds in different environmental compartments (water, soil, plant, air). Therefore, CIRAD has implemented long-term trials on meadows in Réunion and has just set up a highly instrumented experimental site on sugarcane as part of a national system dedicated to long-term observation and experimentation for environmental research on the impact of organic waste recycling in agriculture (SOERE-PRO). Measurements taken on these sites, as well as the modelling of composting and methanization, will provide valuable references and will be used to establish links between 'potential' measures in the laboratory and field data.

Measuring N_2O emissions using accumulation boxes in an altitude meadow on Réunion island. © M. Miralles-Bruneau/CIRAD

Partners

Réunion: SIAAM programming system, Services et Impacts des Activités Agricoles en Milieu tropical.

Senegal: IESOL mixed international laboratory, Intensification Ecologique des Sols cultivés en Afrique de l'Ouest.

Mainland France: CEREGE, Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement; INRA, Institut National de la Recherche Agronomique; UMR SAS, Sol, Agro et hydrosystème, Spatialisation; UMR Ecosys, Ecologie fonctionnelle et écotoxicologie des agroécosystèmes.

Projects
GIROVAR: http://www.tco.re/nos-competences/developpementeconomique/projet-girovar

WABEF: http://wabef.cirad.fr

› For further information

Tom Wassenaar *et al.*, 2015. Agricultural organic waste recycling to reduce greenhouse gas emissions. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide.* Springer (in press).

See also: http://publications.cirad.fr

Tropical rainforests

How can they resist climate change?

Forest after a fire, in Costa Rica..
© B. Locatelli/CIRAD

Water deficits are the main climate-induced threat for tropical rainforests. CIRAD is working with its partners in the main forests of the humid Tropics, to understand the physiology of the various tree species in order to assess their vulnerability, develop models so as to understand how the floristic composition of stands evolves, and measure the effects of their use by man. This will allow the development of management methods that minimize the increasing risks.

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Projections to be taken into account

Over the course of history, the species found in tropical rainforests have experienced many types of climate change. Tree species have had to adapt, either by changing how they function physiologically, or by migrating to find optimum climatic conditions. Nowadays, migration is no longer possible, since it would run up against the growing human occupation of tropical landscapes. Experts estimate that as a result of the many different types of pressure to come, 55 to 82% of the area currently under tropical forest could be degraded by 2100.

Climate projections suggest a change in the water balance, with two types of modifications: lower rainfall volumes and the accentuation of seasonal cycles. Trees can function for a few weeks or months under water deficit: they halt their growth. However, if the deficit lasts too long, forest dynamics may be affected and floristic composition modified.

Sensors on the Guyaflux tower (INRA) above the Paracou forest (CIRAD site), French Guiana. © CIRAD

Assessing the vulnerability of species

One of the major issues is finding measurable indicators of tree vulnerability, notably that of commercial species, to water deficit. CIRAD and its partners have opted for ecophysiological approaches based on:

- the hydraulic properties of wood: a water deficit in the soil creates sap tension in the tree's sap vessels; above a certain threshold, air bubbles appear in the xylem and the water column is broken. This is known as cavitation. Upward sap circulation is reduced and the tree's metabolism is affected, resulting in a growth deficit and even the death of the tree;
- the capacity of the leaf cells to respond to water stress: in living cells, internal adjustments such as raising the concentration of osmoticum (molecules that modulate osmotic pressure) or increasing cell elasticity serve to reduce tissue dehydration.

Tree growth sensors connected to the micro-weather station data logger.© CIRAD

The micro-weather station and the researchers' huts at la Trinité, French Guiana. © CIRAD

Adapting production and management methods

Half the area under tropical forest is currently used for wood production. In future, it will be necessary not only to boost productivity, but also to take account of the vulnerability of these forests.

There are various ways of making logged forests more resilient:

- in productive forests, reducing competition regularly by selective thinning. Such forests are more resistant and resilient in the event of water deficits. However, this positive effect is only temporary: it subsequently fades and indeed becomes negative, since this technique encourages the growth of very tall trees, which are susceptible to drought;
- in zones seen as more fragile, such as forests growing on poor soils, keeping silvicultural intervention to a minimum so as not to cause additional stress;
- in what are seen as the most favourable zones, intensifying production and renewing species of major commercial value: thinning, leaving space around valuable young trees, and enrichment, to compensate for the drop in production elsewhere.

Logging also makes forests more susceptible to fire, due to the larger quantities of dry dead wood on the ground and greater penetration of human activity into the forests. The area of forest affected by forest fires in the Amazon each year is growing exponentially. Striking compromises between reduced competition to ensure that stands are less susceptible to water deficits and the resulting greater fire risk is a major issue.

Gaps in the canopy foster tree growth and regeneration. © S. Gourlet-Fleury/CIRAD

Prospects

CIRAD has large quantities of data gathered through long-term monitoring of forests in French Guiana and central Africa, but full-size experiments have yet to be carried out. For instance, the models developed will make it possible, based on the different climate scenarios, to predict changes in wood production, a crucial factor in forest sustainability in many intertropical zones. This issue masks another, which is even more of a challenge: finding an economic model that will make it possible to fund these new production and management methods.

Partners

Research and training platforms in partnership
Research and training platforms in partnership FAC, Forests of Central Africa; F&B, Forests and Biodiversity in Madagascar; Paracou site, French Guiana; M'Baïki site, Central African Republic; Tropical Managed Forest Observatory

Projects

Coforchange: www.coforchange.eu
Cofortips: http://ur-bsef.cirad.fr/principaux-projets/cofortips
DynAfFor: http://www.dynaffor.org

For further information

Hérault B., Gourlet-Fleury S., 2015. Will tropical forests survive climate change? *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide*. Springer (in press)

See also: http://publications.cirad.fr

Functional ecology

Characterizing the services provided by planted forests

© Y. Nouvellon/CIRAD

How can we preserve native tropical forests, control climate change and satisfy the increasing demand for wood and energy all at the same time? In addition to their economic role, planted forests can fulfil some of these functions. In particular, they play a major role in soil fertility, atmospheric carbon sequestration and the water cycle. Functional ecology sets out to understand the biological and physical laws that ensure the sustainability of these systems, and serves to strengthen their environmental functions through improved crop practices.

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Characterizing matter and energy flows

Climate change and pressures on land are likely to increase the degradation and fragmentation of natural forests, leading to a loss of major ecosystem services. In light of these threats, planted forests and agroforestry systems are set to play a bigger role, provided they are sustainably managed.
The aim of UMR Eco&Sols' work is to strengthen the positive impacts of planted forest ecosystems on the environment, whilst minimizing their negative impacts:

› **Positive impacts:** planted forests, which are often set up on impoverished soils, contribute to the needs of populations and the market (eg they account for 5% of forest areas, but for 35% of exploited woody production). They reduce the pressure on natural forests for wood production. They can improve soils and biodiversity in degraded zones, filter/purify drainage water, play a role in climatic balances by sequestering carbon and regulating rainfall, etc.

› **Main risks:** planted forests are more susceptible than natural forests to phytosanitary problems. Intensive production can lead to an eventual drop in certain natural resources (groundwater and water tables, soil nutrients), biodiversity loss if logged natural forests are replaced by plantations, and impacts on the landscape if large plantations are set up.

Coffee trees under *Erythrina poeppigiana* (legume) shade, Costa Rica. © O. Roupsard/CIRAD

Functional ecology studies the functions of organisms in interaction with their environment. This discipline is implemented by CIRAD to characterize the functioning of planted forests and agroforestry systems, and the associated environmental impacts. An ecosystem approach, backed up by a specific methodology and tools, enables a dynamic study of water, carbon and mineral nutrient flows in agro-ecosystems.

A network of experimental sites in the main tropical planted forest areas

CIRAD's expertise includes a unique network of experimental sites where it studies with its partners the key processes of functioning: eucalyptus and savannah in Congo, eucalyptus monocultures and multi-species plantations in Brazil, rubber in Thailand, coffee-based agroforestry systems in Costa Rica. The studies focus on:

- factors affecting the water, carbon and greenhouse gas emission cycles (susceptibility of primary production and of soil respiration to climate change, impact of cropping practices on organic matter in the soil, etc)
- factors affecting nutrient cycles that contribute to better use of soil resources (role of plant species, of complex stands and of their management methods in the bioavailability of nutrients and changes in mineral balances)
- modelling of the functioning of soil-plant systems under the effect of global changes and cultural practices, and the spatialization of C, water and nutrient balances.

This research is needed to optimize cropping practices, eg to balance nutrient budgets (organic matter management, use of nitrogen fixing plants, rational fertilization).

- Studies of the efficiency of water and nutrient resource use have shown that in the case of eucalyptus plantations, it is better to maintain intensive, highly productive plantations on small areas, with adequate fertilization, rather than extensive plantations over large areas.
- From the second year after planting, evapotranspiration from the most productive eucalyptus plantations is equivalent to rainfall; as a result, water table replenishment decreases compared to a pasture cover and non-wooded areas therefore have to be kept between plantations so as to maintain watercourse levels.
- In the Sahel, African acacias increase carbon and nitrogen sequestration in the soil and the bioavailability of nitrogen for crops.
- In coffee-based agroforestry systems, the forest cover reduces coffee tree transpiration, by regulating the microclimate, and makes the crop less vulnerable to climate change.

Preparation of a 17-m deep pit to measure root functioning at an experimental site in Brazil.
© J.P. Laclau/CIRAD

Measuring soil respiration in a rubber plantation, Thailand.
© P. Thaler/CIRAD

Studying the impact of a reduction in rainfall and fertilization (K) on the functioning of a *Eucalyptus grandis* plantation, Brazil.
© J-P. Laclau/CIRAD

Partners

French and European projects: Heveadapt, Intens&Fix, Maccac (ANR); Arina (EuropeAid); Carboafrica and Climafrica (EU), etc
Bilateral projects: Soil and carbon balance of rubber ecosystems (PHC Thailand), Eucflux (Brazilian companies)
Research organizations and universities in Europe, North and South America, Africa and Asia
Partners in research and training platforms in partnership: Thailand (rubber); Costa Rica (agroforestry systems); Republic of Congo (eucalyptus); Brazil (eucalyptus, mixed plantations)

National and international networks: SOERE, F-ORE-T, CIFOR, Fluxnet, AsiaFlux, IRRDB, NGARA

For further information

Laclau J-P. *et al.*, 2015. Adaptation and mitigation in tropical tree plantations. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide*. Springer (in press)

See also: http://publications.cirad.fr

Improving agroforestry systems in the humid tropics

The example of cocoa and coffee

© D. Snoeck/CIRAD

In humid tropical zones, agroforestry systems (AFS) combine forest trees with cash crops (coffee, cocoa, rubber, oil palm, etc), fruit trees (cola, avocado, orange, etc) or food crops, or livestock production. These systems are generally natural forests in which some of the original vegetation has been replaced by other perennial species after total or partial slash-and-burn clearing of the forest to plant food crops. After a few years, this results in production systems with multiple outputs, which are managed depending on the cash crops being grown, since they generally provide the major share of farmers' income.

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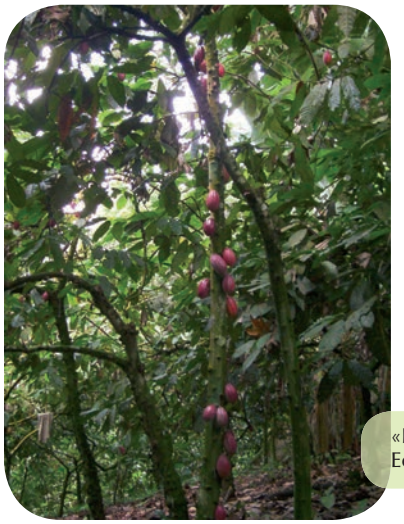
Against a backdrop of reduced cultivable land availability, increasing population pressure, food crises, climate change, and the fact that conventional intensification of agriculture has now reached its limitations, agroforestry practices offer interesting prospects. Improving management of such systems and ensuring their environmental, technical and social sustainability is a major issue for research and development.



«Nacional» cocoa tree, Ecuador. © M. Dulcire/CIRAD

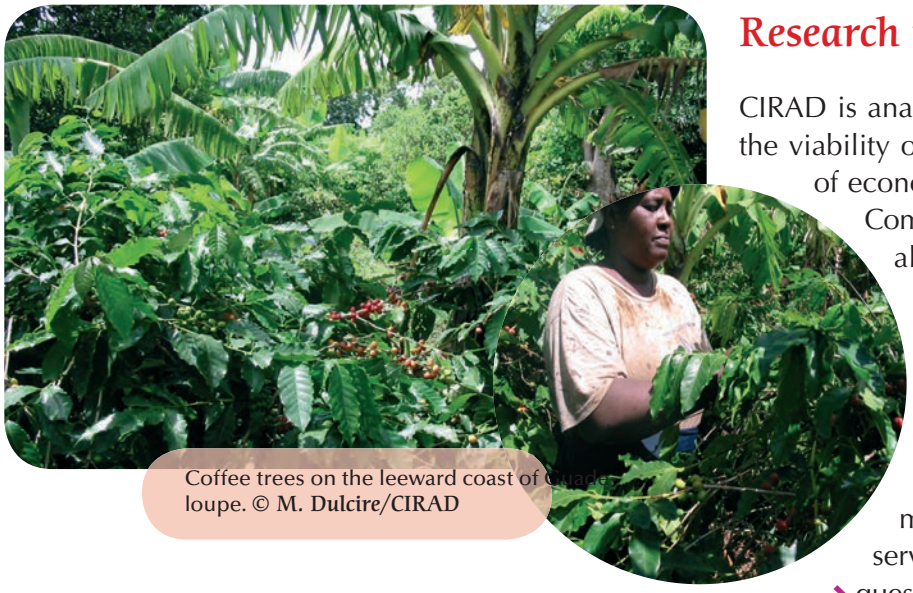
Understanding how they work...

Cocoa- and coffee-based agroforestry systems are traditional production systems, which function in much the same way as forest. Compared to monoculture systems, they produce less cocoa or coffee, but they are more sustainable and environmentally friendly, since they are less intensive in terms of pesticides and chemical fertilizers. Farmers also produce other goods for their own consumption or for sale (various fruits, palm oil and wine, medicinal products, fodder, timber and craft products). Agroforests also provide a range of important environmental services, such as biodiversity conservation, soil fertility preservation, and carbon sequestration. They also play a social and cultural role (family, national and international heritage, landscape appearance and sacred sites).

Cocoa *(Theobroma cacao)* and coffee *(Coffea canephora* and *Coffea arabica)* are understorey species. The shade provided by the other species grown with them is naturally favourable (regulation of the microclimate, supplies of organic matter). However, shade can also have adverse effects, for instance by creating conditions that favour disease development. In cocoa-based agroforestry systems, shade reduces attacks by insects such as mirids, but favours black pod disease. In coffee-based systems, it lengthens the cherry ripening period, which improves coffee quality, but reduces yields. It is thus by adjusting the degree of shade in a plot that farmers can balance the positive and adverse effects of combining other trees with cocoa or coffee.

Understanding and supporting the development of such systems means analysing local know-how and strategies and practices among the different stakeholders involved in the cocoa and coffee supply chains. Research is also looking at innovation processes, changes in supply chains, and the landscape impact of agroforestry.

Intercropping coffee with Erythrina, Costa Rica
© P. Vaast/CIRAD



Coffee trees on the leeward coast of Guadeloupe. © M. Dulcire/CIRAD

Research in response to change

CIRAD is analysing how agroforestry can contribute to the viability of household activity systems in a context of economic, climate and environmental change. Comparative analyses of different local histories allow researchers to:

- measure the impact of agroforestry on household economics, land ownership and the environment;
- assess the flexibility of household activity systems in the face of change (diversification of outputs, biodiversity management methods, use of environmental services);
- question the development models promoted by public policy.

... So as to boost their performance and sustainability

CIRAD is conducting research in several countries aimed at enhancing these multifunctional cropping systems, whose maintenance depends on the management choices made by farmers. The performance of agroforestry systems is being assessed to understand the compromises farmers have to strike between the products and the different services provided by such systems.

Solutions are being tested in response to specific constraints and objectives. The work currently under way is aimed at developing innovative systems in a context of ecological intensification and climate change.

The aim is also to develop tools and methods, on the one hand to assess the ecosystem services provided by agroforestry systems, and on the other hand to design agroforestry intercropping models capable of stabilizing or even increasing incomes among rural households.

Partners

Agroforestry Systems in Africa platform (IRAD, University of Dschang, University of Yaounde 1)
Agroforestry Systems in Latin America platform (CATIE, INCAE, Bioversity International, PROMECAFE, CABI)
Cameroon: IRAD, Institut de recherche agricole pour le développement
Costa Rica: CATIE, Centro Agronomico tropical de Investigacion y Ensenanza
Ghana: Kwame Nkrumah University
Ivory Coast: CNRA, Centre national de recherche agronomique; University of Cocody
Kenya: ICRAF, World Agroforestry Centre; CRF, Coffee Research Foundation
Uganda: University of Makerere

For further information

Vaast P. et al., 2015. Coffee and cocoa production in agroforestry systems: a climate-smart agriculture model. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide.* Springer (in press)

Project AFS4Food, agroforestry for food security:
http://AFS4Food.cirad.fr

Wood, a biofuel to replace fossil fuels

Sugar mill that burns biomass to produce its own electricity and some of that consumed by the nearest town, Tanzania.
© R. Peltier/CIRAD

According to international experts, rational fuelwood use would save more than 1Gt of carbon emissions per year. Over the past ten years, this prospect has led to increased demand for fuelwood worldwide. CIRAD is working with its partners to manage the fuelwood resource sustainably, develop new uses and modernize supply chains.

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Wenge nursery to produce precious wood and fuelwood, Democratic Republic of Congo.
© R. Peltier/CIRAD

The fuelwood of yesteryear

Since time immemorial, forests and the wood they contain have been used to produce energy. However, with the development of fossil fuels in the 19th and 20th centuries, the way in which the world's forests were used generally changed: timber, wood for pulp and panels, leisure, environmental services, etc.

In the 1980s, in both North and South, most national policies were aimed at reducing fuelwood consumption. In Europe, for instance, low oil and gas prices and the guarantee of oil supplies as of the late 1970s saw fuelwood consumption shrink to less than 3% of total energy consumption. At the same time, in Africa, when wood covered more than 70% of the demand for energy on average, most governments adopted strong-willed policies aimed at replacing wood with gas or oil and reducing wood consumption through the use of improve hearths.

Traditional hearth in northern Cameroon.
© R. Peltier/CIRAD

The fuelwood of today

At the dawn of the 2000s, the economic and political world realized the extent of climate change and the double necessity of on the one hand reducing greenhouse gas emissions and on the other storing as much carbon as possible in the form of biomass.

If wood, a renewable resource, is managed sustainably, it is virtuallly carbon-neutral and should theoretically satisfy this dual demand. The renewed interest in wood over the past decade has resulted in increased demand for fuelwood on a global scale. In the North, that demand primarily corresponds to new uses: industrial heat generation and electricity. In the South, domestic uses (above all cooking) are still predominant, but new energy demands have arisen, notably for electricity in rural areas.

The fuelwood of the future

Many experts worldwide consider that fuelwood provides a range of economic, ecological and energy opportunities for countries in both North and South. According to the FAO and the International Energy Agency, rational fuelwood would save more than 1Gt of de carbon emissions per year. The world still has substantial potential sources of wood. However, "source" does not necessarily mean "resource". For wood to emerge (or re-emerge) as an energy resource, it has to be mobilized, managed sustainably and used efficiently, and its use has to be socially acceptable.

Casamance charcoal mound with chimney in Senegal (25% higher yields). © R. Peltier/CIRAD

Lines of research

Very few forests or plantations are currently logged for fuelwood alone. Major research efforts are required to develop plantation and sustainable natural resource (forests and trees outside forests) management models, so as to increase supplies and improve the energy efficiency of supply chains and make wood a modern energy resource for industry, communities and individuals.

In Senegal, charcoal is still the most widely used domestic fuel. © R. Peltier/CIRAD

In this overall context, CIRAD is attempting to come up with answers to several questions on different levels:

- technological: how can we improve the efficiency of the technology used to produce wood and convert it into energy (carbonization, gasification, combustion, electricity generation)?
- ecological: what plantation and logging models can we develop to make fuelwood use sustainable and neutral in terms of greenhouse gas (GHG) emissions?
- socioeconomic: how can producers and supply chains (plantations, markets, transport, processing, consumption, authorities) be organized so as to reduce carbon losses, cut GHG emissions, keep prices accessible for urban consumers and develop rural employment?

Electricity generating station in the town of Andaingo, fed by 60 ha of eucalyptus plantings, in Madagascar. © R. Peltier/CIRAD

Partners

CIFOR, Center for International Forest Research, Cameroon and Burkina Faso; **2iE Foundation,** Institut international de l'eau et de l'environnement, biomass energy laboratory; **University of Liège**, Gembloux AgroBioTech, **BIOSE** department, Belgium; **INRAN,** Institut national de la recherche agronomique du Niger; **FOFIFA,** National Institute of Agricultural Research, Madagascar.

NGOs: Debout Niger, Niger; PARTAGE, Madagascar; Cabinet IdSahel, Mali; Hanns Seidel Foundation and Ibi Village, DR Congo, etc.

Energy industry: TOTAL S.A.; EDF; Lafarge S.A; TPC-Tanzania.

For further information

Gazull L., Gautier D., 2014. Woodfuel in a global change context. Wiley Interdisciplinary Reviews: Energy and Environment. doi:10.1002/wene.115.

See also: http://publications.cirad.fr

Health strategies and policy in a "One Health" context

On the way to the lake, Burkina Faso.
© D. Louppe/CIRAD

Adapting health strategies and policy to climate change fits into a broader context of global change: growing demand for animal products, increasingly globalized trade and the impact of many environmental, socioeconomic and climatic determinants on human and animal health. These factors exacerbate the risks of the emergence, spread and maintenance of parasite-borne and infectious animal and zoonotic diseases.

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Environmental modifications

The climate and its variations have an impact on pathogens (resistance, selection, etc), hosts (immunity, movements including migration, etc), vectors (ecological niches, vector capacity) and epidemiological dynamics. The climate can also influence and modify the rate of transmission and the way in which pathogens are dispersed, contact networks between individuals and between different species, community structures and livestock farming methods, and also biodiversity and its ambivalent role in disease emergence. The diseases most sensitive to climate are parasitoses, vector-borne and water-borne diseases and infectious diseases passed on by micro-mammals. Several of them may occur simultaneously in the event of extreme climate phenomena. Lastly, these diseases are often zoonoses, "diseases and infections that are naturally transmitted between vertebrate animals and humans and vice versa" (WHO).

On a farm, Vietnam. © JC. Maillard/CIRAD

Greater risks of transmission between animals and humans

Climate change can favour contact between wildlife and humans by modifying the natural habitats of the animals that act as pathogen reservoirs and influencing their movements. They may exacerbate food insecurity, which can in turn modify human behaviour, particularly by prompting people to look for alternative food sources, such as bush meat.

The Ebola epidemic in West Africa bears witness in particular to the urgent need to step up the detection and early management of the emergence of zoonoses, and to determine the conditions of transmission between species.

An encounter between a warthog and a zebu. © A. Caron/CIRAD)

Sanitary structures must be strengthened

The gradual or sudden impact of climate change on health systems following extreme events may be direct, as a result of the disorganization of social networks, and/or indirect, due to the increased occurrence of diseases. The climate and its variations may also disrupt sanitary structures and restrict humans' and animals' access to health systems. The analysis, modelling and risk management work being done as part of a global "One Health & EcoHealth" programme set out to implement animal and public health strategies and policies tailored to the changes in the climate. The main priority is to foster interactions between sectors – environmental, medical and veterinary – and transverse communication between the scientists, managers and communities concerned.

Animal health systems are structurally inadequate in the least advanced countries, where they endure rather than anticipate climatic conditions and variations. However, there is real potential to establish early warning systems using information on climate variations, which would serve to improve the way in which epidemics are managed. However, generally speaking, sanitary, environmental and climate data are not gathered simultaneously. Better coordination between sanitary surveillance systems and climate research institutions and centres (CNES, NASA, etc) would facilitate the gathering of data on diseases and climate parameters.

A strategy to be developed with each and every stakeholder

In a "One Health" context, the recommended approach is to:

- prioritize diseases linked to climate variations using conventional methods (expert opinions) or innovative techniques (h-index);
- analyse and map risks;
- combine risk prediction maps with maps of the vulnerability of human and animal populations;
- prioritize target zones and populations prior to intervention: prevention, surveillance, control;
- adapt and strengthen health systems and disease surveillance and control;
- propose appropriate, flexible sanitary policies and regulations.

Education, training and awareness-raising operations for health professionals and scientists as part of a "One Health" approach are another way of consolidating these overall approaches by taking account of climate aspects.

Training in diseases linked to rodents in Asia (ANR project: CNRS-CIRAD). © J. Thanarotewanata/ GREASE

...to improve epidemic prevention and monitoring

Using adaptation mechanisms, it is possible to boost the resilience of the livestock production and health sectors and of territories as regards climate-sensitive diseases. That adaptation means prioritizing diseases, assessing risks, and using risk reduction methods (surveillance, prevention and control) as part of a "One Health" approach. It must also be supported by appropriate legislation.

Vaccination campaign on a semi-commercial farm, Vietnam. © Phan Dang Thang/CIRAD

Partners

Research centres and universities
France: AFD, Agence française de développement; **ANSES,** Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail; **CNRS; ENVT,** Ecole nationale vétérinaire de Toulouse; **INRA,** Institut Pasteur, **IRD.**
Countries: FOFIFA, Madagascar; Universities of Kasetsart, Thailand; Pretoria, South Africa; Zimbabwe.
International
WCS, Wildlife conservation Society; **OIE,** World Organization for Animal Health; **FAO,** Food and Agriculture Organization of the United Nations; **WHO,** World Health Organization.
Networks
Southern Africa: RP-PCP, Production and Conservation in Partnership (http://www.rp-pcp.org),
Southeast Asia: GREASE, Emerging Diseases in Southeast Asia (http://www.grease-network.org)
Caribbean: CaribVET (http://www.caribvet.net/fr)
Madagascar: F&B, Forests and Biodiversity (http://www.forets-biodiv.org)
Indian Ocean: AnimalRisk network (http://www.animalrisk-oi.org)

For further information

Roger F. et al., 2015. The one-health concept to dovetail health and climate change *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide.* Springer (in press)

See also: http://publications.cirad.fr

Ecosystem services

Unique economic and policy instruments

Consultations in Cameroon.
© R. Peltier/CIRAD

Throughout history, economic development has often resulted in the degradation of ecosystems, a phenomenon that has gained pace since the 1970s. However, ecosystems are the mainstay of life on Earth and contribute to the wellbeing of mankind. The ecosystem service concept was introduced in the 1990s to make this clear. In a world in which more than six billion people are looking to feed themselves and fulfil their hopes of a better future, CIRAD faces a major challenge: satisfying demand through crop and animal production while conserving the ecosystems that underlie our very existence. One of the fields CIRAD is working in with a view to solving this problem is research on ecosystem services.

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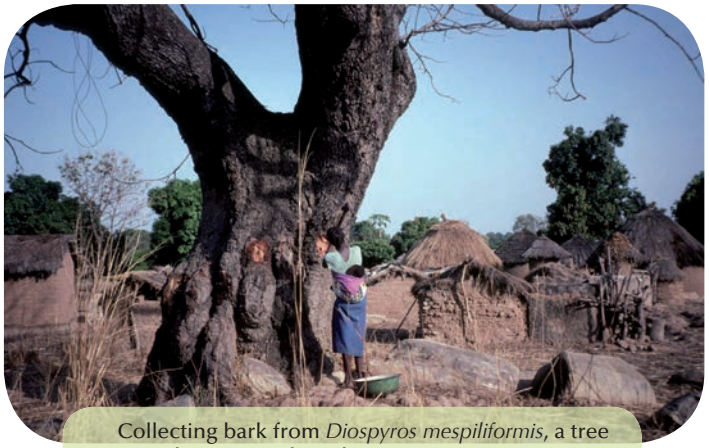
An environmental, economic and policy issue

The ecosystem service concept was developed to satisfy the need to understand the interdependence of ecosystems and society. Ecosystem services are defined as the benefits people obtain from ecosystems. For instance, the leaves and roots of trees control erosion, limit biodiversity losses and maintain river water quality while reducing the cost of water treatment. Tropical forests play a role in the formation of precipitation on a regional level, in the Amazon, the Congo Basin and Indonesia. Genetic biodiversity is a source of medicines, contributes to disease control and sustains genetic potential for the future. Naturally, the aim of the ecosystem service approach is not to reduce nature to its role as a support for mankind. On the contrary, it is intended to help in developing an interdisciplinary approach in which aspects linked to socioeconomic governance and knowledge of biophysical processes are taken into account in a coordinated way, enabling the implementation of strategies on a national, regional and local level, for each and every type of stakeholder.



Collecting bark from *Diospyros mespiliformis*, a tree with many medicinal properties, Ivory Coast.
© D. Louppe/CIRAD

Interdisciplinarity, a source of excellence

CIRAD's specificities, in terms of its history, professional profile and operations (agriculture, development, conservation) and its global partnerships, mean that it has access to scientific expertise and technical solutions in the fields of both biophysics and socioeconomics. That expertise tallies with the various social and spatial scales on which solutions may be found to issues relating to conservation and development in tropical regions. It centres on three main lines of research:

› The assessment, conservation and restoration of ecosystem services

Integrated approaches are being developed to tackle the processes of erosion and of soil fertility maintenance; measuring carbon and carbon flux in tropical forests, agroforests and other cropping systems (including plantations); hydrological regulation in forests and farming systems; and use of biodiversity for pest management. These scientific advances form the foundations of innovative crop management techniques aimed at boosting agricultural and forest production (projects: Acaciagum, TropSoil&Biol&Fertility, Funcitree, Innovkar, Intensifix, Floresta em Pê, Floagri, etc).

› Analyses of policies and instruments to promote ecosystem services

CIRAD has global expertise in terms of analysing the scientific and policy issues that surround the ecosystem service concept: conception and implementation of environmental and rural development policies for the promotion of environmental services; and methodological tools applied to multi-criteria measurement of the socioeconomic and environmental impact of such policies. It also studies stakeholder networks and coalitions involved in promoting such approaches, their alliances and the resulting changes in the different international arenas and the public development aid sector (projects: Serena, Pesmix, Invaluable, Payer pour l'environnement ?, Prigou, Impact certification, etc).

› Modelling and foresight exercises

The science-policy interface is a priority line of research for CIRAD. To this end, CIRAD studies the socio-ecological systems behind the maintenance and restoration of ecosystem services. It addresses and explores the functioning and dynamics of such systems using modelling tools and participatory and foresight techniques (projects: EcoAdapt, Regreening Sahel, Prospective Bassin du Congo, Spiral, etc).

Assessing ecosystem services in highland forest agro-landscapes. © D. Ezzine-de-Blas/CIRAD

Installation to study rainwater flow, Congo. © D. Louppe/CIRAD

An essential approach for sustainable agro-ecosystem management

This expertise, at the interface between targeted and fundamental research, enables CIRAD to help develop and implement new crop management techniques, draft guides to good practice and design agro-ecosystem management plans on a local, regional and global level.

Partners

CIRAD is involved in numerous projects on every continent.

› For further information

M. Pedrono *et al.*, 2015. Impact of climate change on ecosystem services. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide.* Springer (in press)

Project websites:
http://inco-acaciagum.cirad.fr
http://inco-innovkar.cirad.fr
http://www.serena-anr.org
http://pesmix.cirad.fr
http://www.programme-repere.fr
http://www.afriseb.net

Life cycle assessment

Elucidating the links between agriculture and the environment

Defining systems and describing practices with producers.
© C. Bessou/CIRAD

Life cycle assessment (LCA) serves to assess the environmental impacts of human activity along a supply chain. In the case of tropical cropping systems, researchers are working to understand and model emissions into the environment, and the links between those emissions and their impacts depending on the different systems. Cropping system LCAs have shown that the impact on climate change varies significantly according to the crops, environments and practices involved. LCA serves to steer production systems in order to reduce their environmental impacts. However, it is not always easy to make the appropriate choices.

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A simple framework for a multitude of scientific challenges

Life cycle assessment is based on a conceptual framework that defines the environmental impacts of a product as the linear resultant, along the production chain, of the contribution to various impacts of the resources used and the substances emitted. The resulting methodology comprises four standardized stages (ISO 14040 2000-6):

- definition of the objectives of the study and the system;
- inventory of flows entering and leaving the system;
- characterization of impacts;
- interpretation of results.

LCA poses various challenges for scientists as regards:

- defining a system that is representative of the function being studied, taking account of the variability of practices, soils and climate conditions;
- modelling biogeochemical processes at the soil-plant-atmosphere interface, and the transfer mechanisms behind emissions into the environment;
- characterizing the impact chains linking emissions and environmental impacts;
- allocating impacts to different products, notably in crop rotations or agroforestry systems;
- analysing the results and their uncertainties so as to steer production methods towards agro-ecological systems.

Cocoa-oil palm-coconut agroforestry systems: complex systems and flows.
© T. Tran/CIRAD

Jatropha. © A. Benoist/CIRAD

What are the results for tropical crops?

Since 2009, CIRAD has been compiling a database, LCA-CIRAD©, on products from southern countries: palm oil, coffee, rice, *Jatropha*, cotton, tomatoes, beef, etc. LCA results serve to pinpoint and improve the practices and conditions behind greenhouse gas (GHG) emissions.

In Mali and Burkina Faso, researchers supplemented their studies of the prospects for developing *Jatropha curcas* as an energy crop with an environmental assessment based on LCA. Their work showed that in a West African context, the yield response to fertilizers of *Jatropha curcas* appears to be limited, hence the additional GHG emissions resulting from fertilizer applications would not be cancelled out by the improvement in yields.

In Asia and Latin America, a study of the GHG balance for palm oil clearly demonstrated the virtually prohibitive risk of setting up plantings on peat soils. Moreover, GHG savings can be made by planting on degraded soils or grasslands, by capturing the methane emitted during effluent treatment or by optimizing fertilizer applications.

Spreading effluent in an oil palm planting. © C. Bessou/CIRAD

Greenhouse tomatoes. © D. Grasselly/CTIFL.

Flooded rice paddies. © C. Bessou/CIRAD

In Thailand, an LCA study on rice highlighted the determining role played by the irrigation management method in methane emissions. It is recommended that the fields be allowed to dry out occasionally and urea applications be limited, since they are another source of environmental impact: splitting applications and digging in fertilizers are recommended in order to limit GHG emissions.

In France, LCA has been used to compare the impacts of agricultural products depending on their origin. For instance, there is no clear-cut difference between producing eating tomatoes in France and importing them from Morocco: importing them minimizes the impact on climate change, but maximizes the impact on water resources. This demonstrates the importance of considering every impact category so as not to overlook a pollution transfer, but also illustrates the difficulty of certain decisions.

Prospects

CIRAD transfers its knowledge and expertise in terms of LCA to its partners in the South via training and appraisals. Its researchers are also contributing to the drive to promote LCA within national and international scientific communities.

Above and beyond environmental impacts, it is also vital to take account of the social and economic impacts of a given supply chain in order to steer development decisions. CIRAD is also conducting research into these aspects.

Lastly, despite all the questions surrounding the improvement of LCA, it is still one of the most comprehensive, coherent ways of estimating the impacts of human activities on the environment, and particularly on climate change.

Partners

Field PT Smart, Indonesia
Life Cycle Sustainability Assessment Lab, Thailand
Projects
SOCLE (ADEME), AGRIBALYSE (ADEME), SPOP (ANR)
Networks
ELSA: http://www1.montpellier.inra.fr/elsa
ELSA-PACT industrial chair (IRSTEA)
Indonesian LCA Network: http://indonesian-lca-network.org
Asia LCA agrifood network: http://lcaagrifoodasia.org

› For further information

Bessou C. et *al.*, Lifecycle analysis to understand agriculture-climate change linkages. *In:* Torquebiau E. (ed.). *Climate change and agriculture worldwide*. Springer (in press)

See also: http://publications.cirad.fr

CIRAD in a nutshell

CIRAD is a French research centre that works with southern countries to address global agricultural and development issues. Its activities involve the life sciences, social sciences and engineering sciences, applied to agriculture, food and rural territories. It works hand-in-hand with local people and the local environment, on complex, ever-changing issues: food security, natural resource management, inequality and poverty alleviation.

CIRAD has a global network of partners and of twelve regional offices, from which it conducts joint operations with more than 100 countries. Its bilateral partnerships fit in with multilateral operations of regional interest. In France, it provides the national and global scientific communities with extensive research and training facilities, primarily in Montpellier and the French overseas regions.

CIRAD is:

A staff of 1650, including 800 researchers (some 300 on assignments in the Tropics), almost 5 million euros spent on PhD courses, more than 400 PhD students supervised each year, 60% of them from southern countries, 800 researchers and technicians from all over the world received and trained each year, an annual budget of 203 million euros in 2015.

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