Chapter 16

Agricultural development measured against climate change


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Field of quinoa in the Salar de Uyuni (Bolivia).
Adapted to arid environments and poor or saline soils, quinoa is also highly resistant to cold, frost and wind. Scientists are studying it to test its resistance to climate events.

AAfter being excluded, agriculture is gradually gaining a position in climate policy negotiations. The IPCC Fifth Assessment Report assessed the potential reduction of GHG at between 20 and 60% in land-based sectors (agriculture, forestry and other land use) by 2030. The challenge to the sector is enormous. Greenhouse gas emission must be reduced in agriculture. The latter must also adapt to climate change while responding to food security imperatives. According to the FAO, agricultural production should at least double by 2050 to match population growth.

What are the agricultural models expected for handling these issues? 'Climate-Smart Agriculture' is the name given to project agriculture that can meet all three objectives: mitigation, adaptation and productivity. Supported by those in favour of the incorporation of the agricultural sector in climate policies, the notion covers different views of agricultural development. Between supporters of agriculture centred on technological innovation and those who defend small-scale family or local agriculture used to climatic variability, many pathways for the adaptation of agriculture to climate change are being explored.

One thing is certain. The ecological crisis faced by agriculture in many places in the world, with erosion and decreased soil fertility, water management difficulties, decrease

Cacoa growing in Cameroon is mainly in the form of family farming and is a substantial source of income for the rural population.

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in phytogenetic resources and the disappearance of pollinating insects, together with social problems with growing job losses has ruled out the Green Revolution as the sole model. Using the diversity of the practices of small farmers as local responses to climate variability is also an issue for farming in the South where agriculture consists very largely of small farms with areas of less than 2 hectares. Numerous studies conducted by IRD show the capacity of small farming to respond to climate variations, among other things.

In addition to the climatic impacts and ecological crises felt in many regions of the world, it should be remembered that the agricultural sector is also destabilised by international economic approaches and especially the interest of financial markets in agricultural produce and the hoarding of farmland. In this context of climate change and population growth, the forecast decrease in land reserves and water, increased demand for food and, more recently, a substantial increase in the price of food products have led some countries, multinational corporations and international investors to start a race for land. According to the World Bank, 56 million hectares of land was leased or sold in 2009, with the leading target being sub-Saharan Africa.

The sequestration of atmospheric carbon in cultivated land

Agriculture alone accounts for nearly 12% of global emissions of GHG. Counting deforestation, with one of the main causes being clearance for agriculture, the agriculture and forestry sectors are responsible for nearly a quarter of global emissions.

Furthermore, the agricultural sector is the source of most methane and nitrous oxide emissions as a result of livestock farming and the use of fertilisers. But reducing these emissions is not a priority in the tropics as small farming or family farming is still dominated by crops and makes little use of fertiliser. Nevertheless, this aspect seems to rule out commercial farming for small farms in the south as this would risk causing emission levels to rocket. Thus the main mitigation measure that should be used in the South is aimed at carbon sequestration in soil in order to slow the increase in CO_2 in the atmosphere.

Carbon storage and soil fertility

The maintaining of stored carbon is linked to the quantity of organic matter in the soil. Agronomists know well that soil organic matter ensures the satisfactory functioning and sustainability of agro-ecosystems as it allows storage of the nutrients needed by plants and stimulates biological activity, as it is a source of both energy and nutrients for soil organisms. Organic matter also plays a central role in the structure of soils and

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Farm work in the High Atlas in Morocco.
Water brought to a field in the village of Agremugzen for growing potatoes between plots of barley.

contributes to stability in the face of aggression (rain, compaction, etc.). It thus enhances soil permeability, aeration and moisture retention capacity. Carbon sequestration is thus accompanied by the maintaining of fertility and moisture in farmland. The farming practices that allow carbon storage are therefore often those recognised and set up for sustainable land management that is propitious for the protection of the environment and soil productivity.

Many techniques—and especially traditional ones—have long been known for improving the organic matter content (compost or straw, fallows and grassed strips that stabilise the soil and improve infiltration of water, sediment retention, etc.). The issue in dry regions is that of improving water management while avoiding loss of organic matter, in particular through the use of mechanical techniques such as zaï. This traditional technique found in part of the Sahel (Mali, Niger and Burkina Faso) is a special form of pit farming in which water and fertiliser are concentrated in micro-basins. Other agricultural techniques recommended for several decades within the framework of water and soil conservation also enhance carbon storage: soil cover techniques, agroforestry, etc. Techniques for addressing desertification also contribute to carbon sequestration in the soil.

Evaluating the quantities of carbon fixed in soil

Although everyone agrees about the sequestration capacity of these different techniques, the question of the quantities of carbon that are actually sequestered is still a subject for debate. Part of agricultural research on soils thus consists of measuring the quantities of carbon in soils according to the management method. The scientists evaluate soil carbon contents according to tillage practices, the type of plants grown and soil composition. This quantification is needed for validating the role that agriculture will play in emission reduction strategies. Another line of work is the development of measurement techniques that are easier to use and cheaper. This is a necessity, in particular in countries in the South (Box 50).

At the international scientific conference on Climate-Smart Agriculture in Montpellier in March 2015, Stéphane Le Foll, the French Minister of Agriculture, called for the launching of a major research programme called ‘4 per-mille’. The figure is used as a symbol, showing that a very small variation in soil carbon stocks (of some 0.4%) can affect the global CO_2 balance. Field measurements made by various IRD research teams in Mediterranean, subtropical and tropical contexts indicate storage variations that are comparable with this 4‰ objective.

Box 50

New techniques for measuring soil carbon content

IRD is recognised as one of the world leaders in the application of near-infrared spectrometry techniques. These are faster and less costly than conventional methods for soil carbon measurement.

There are two classic types of technique for measuring the carbon content of soils.
Both are destructive.
Oxidation methods are based on the direct analysis of organic carbon after oxidation of organic matter using potassium dichromate.
But the latter is a pollutant and very allergenic and the methods were discarded in favour of combustion techniques. These provide accurate determination of total soil carbon (organic and inorganic) but are expensive at about €15 per sample.

Less costly techniques have been developed over the past decade.
They include near-infrared spectroscopy (NIRS) that costs around €1 per sample.
The new methods can be used to work directly on unprepared soil samples (no crushing or sieving) but require calibration using a reference soil database.

IRD is at the cutting-edge of infrared spectrometry application techniques.
Work on soils from dry regions shows satisfactory calibration of spectra in the near infrared is possible for determining soil carbon and nitrogen contents.
In addition, recent work shows that NIRS technology allows satisfactory discrimination between organic and inorganic carbon in soils, which is still a tedious task using conventional methods.
Finally, studies are currently focused on *in situ* measurements that would overcome the uncertainties of sampling.

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Observation of the result of a chemical test to detect the presence of iron in the surface soil horizon (South Africa).
The red colour indicates anoxic conditions favourable for the storage of organic carbon and the denitrification of water.

Box 51

The evolution of soil carbon in soils under conservation agriculture

Within the framework of the RIME-PAMPA international project led by IRD, the Eco&Sols unit works on the evolution of carbon stocks in conservation agriculture soils. This system used in agricultural development programmes is based on three principles: minimum tillage, the rotation of several crops and permanent soil cover. The contribution of plant cover (dead or alive) is in theory capable of increasing the annual input of organic matter and hence the organic carbon content of soils.

Eco&Sols researchers used both conventional methods and those based on near-infrared spectroscopy to measure the evolution of carbon stocks in soils.

Soil samples in Tunisia, Cameroon, Laos, Vietnam, Brazil and Madagascar displayed sequestration capacities of a few hundred kg of carbon per hectare. The level is thus low in relation to the billions of tonnes released by human activities. Nevertheless, the sequestration potential of conservation agriculture could become significant at regional and global scales.

Fieldwork on rainfed rice in Laos.

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The advantages of biodiversity in the face of climate uncertainty

How can crops and forms of livestock farming be adapted to climate change? As it is difficult to make fine forecasts of changes in climate, especially in the tropics, the capacity of adaptation of farming systems must be strengthened rather than performing a search for *a priori* solutions. In this context, the diversity of the plants grown is an advantage insofar as it provides a broad variety of available characters that can be used according to climate conditions. Research conducted by IRD has shown in particular how genetic diversity in millet varieties has allowed adaptation to drought (Box 52). This work also shows the interest of *in situ* breeding making use of local varieties.

However, the role to be given to the management of biological diversity in agricultural development is not obvious as selection conducted by agricultural research has favoured pure lines for half a century in order to ensure stable characters in successive

Box 52

The adaptation of millet to climate variation

Following the various drought periods in the Sahel in the 1970s, 1980s and 1990s, researchers at the DIADE unit and their partners have sought to understand how cultivated millet varieties adapted. Their results show how genetic diversity within varieties made possible adaptation to the decrease in rainfall.

What were the effects on cereal crops of the major drought periods that hit the Sahel between 1970 and 1990? IRD biologists addressed this question in the context of climate change. They sought to understand how the varieties of millet, one of the most commonly grown grain crops in the dry zones of the region, adapted to the changes in rainfall.

The scientists were able to compare genomes using two samplings of millet seed grown in Niger in 1976 and in 2003. The results give much information. First, the diversity and types of millet grown changed little over a period of about 30 years. Adaptation was thus not the result of the use of new cultivated varieties by farmers. However, within the same variety, the plants grown in 2003 have earlier flowering dates than those of 1976. The diversity of certain genes of the 1976 seed permitted this change. Thus, many plants of the same species were able to respond to new climate conditions.

The adaptation was the result of coevolution between varieties, the environment and the selection pressure maintained by farmers on their seed stocks. In Niger for example, seed was selected and re-sown by farmers from one year to the next. During drought periods, late rains have a less harmful effect on early flowering varieties. Farmers' *in situ* selection makes it possible to favour the more drought-resistant plants and these are sown again in the following year.

The biologists compared the number of alleles in the genome of the varieties at an interval of 27 years and found that this remained constant. Selection maintained genetic diversity and thus did not affect the capacity for adaptation to new conditions in the future.

A millet market in the Niamey region (Niger).

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Box 53

The traditional farming system in the Rio Negro area, a source of agrobiodiversity

Often criticised, traditional slash-and-burn cultivation does have its advantages. In particular, it ensures a great richness of cultivated plants. The recognition of the Rio Negro Amerindian farming system as an immaterial heritage in Brazil is opening pathways for the use of the remarkable biological resources and knowledge in traditional agricultural practices.

In northwestern Brazilian Amazonia, IRD researchers and various Brazilian institutions have shown within the framework of the PACTA project the great diversity of cultivated plants in the traditional Rio Negro farming system.
More than a hundred varieties of bitter cassava and about two hundred other species or varieties have been recorded. This agrobiodiversity is accompanied by a rich food heritage based essentially on cassava (beer, tortillas, condiments, roasted semolina, etc.).

The existence of this broad range of phytogenetic resources results from agroecological criteria (strategy for resistance to pests and diseases, the staggering of harvests and adaptation of many ecological niches among others) and also cultural and not only farming models of crop management.

In the Rio Negro area, possessing numerous varieties of cassava is something to be proud of, as is taking care of them; there is constant interest and curiosity about the testing of new varieties. The female farmers pass around cassava cuttings, banana plants and seeds of other crop plants all the time. The conservation of plant diversity thus operates at a collective scale covering a radius of several hundred kilometres.
Cuttings and seeds are given, exchanged or passed on according to procedures that depend on the type of plant. Fruit species are passed around mainly among the men and cassava and companion plants more among the women.

The environmental impact of slash-and-burn is usually limited to the annual clearing of less than half a hectare.
It takes about a dozen years for forest cover to become reconstituted in the scarred area.

In 2010, this traditional farming system was recognised as an immaterial national heritage.
For Brazil, it is the first time that such a listing makes explicit reference to the notion of system and concerns a both biological and cultural good. Official recognition opens pathways for making use of the remarkable biological resources and knowledge associated with traditional types of agriculture.
However, it should not be forgotten that these singular types of agriculture are not limited to the technical aspect but also reveal other conceptions of the world and society.

Cassava tubers set out for retting at Santa Isabel on the Rio Negro (Brazil).

© IRD/L. Emperaire

generations. But the recognition of diversity as a source of adaptability contributes to the redefinition by decision makers of certain practices of small farmers whose agrosystems are widely recognised as regards the maintaining of great diversity of species and cultivated varieties.

Through many studies on small farming in the South, IRD contributes to better understanding of local innovation and experiments leading to the diversity of cultivated plants. The example of the research carried out in the Rio Negro drainage basin in Brazilian Amazonia shows clearly how agricultural practices and knowledge generate and maintain considerable biodiversity (Box 53). Through the diversity of the food resources that they generate, such farming systems also form a lever to ensure the food sovereignty of populations.

Practices that adapt to climate variability

As is highlighted by the examples of agrobiodiversity mentioned above, farmers' strategies and practices are far from being immutable, but adapt to changes in the climate and the environment. The large amount of work carried out by IRD in sub-Saharan Africa also shows how a rural population that is very dependent on rainfed agriculture has had to handle a change in the rainfall regime over the last 60 years.

Within the framework of the ESCAPE project run by IRD, thousands of surveys conducted in Senegal, Niger and Benin show that farmers clearly perceive the changes in climate and adapt to them. In Senegal for example, the rains have returned for about 15 years and farmers have changed the millet varieties used, going back to those grown before the start of the great droughts (1960), outstripping the models that would have advised them to do the same thing! Adaptation strategies are complex nonetheless. With the same perception of the change in rainfall, researchers observed many trajectories responding to different constraints and in particular to the economic situation.

Numerous strategies are also used in the Andes to reduce climate risks. Farmers mix several types of crop plant in the same field, cultivate numerous plots to optimise exposure to the sun and spread the risks of frost or adjust sowing dates and the varieties grown to adapt to the changes in rainfall.

The capacity for local farming practices to adapt to climate and environmental changes is often not recognised by those who believe in a productivity approach. Work on beekeeping in Morocco clearly shows the tension between strategies with emphasis on productivity and those favouring robustness in the face of climate uncertainty (Box 55).

Box 54

The agroecosystem in the Niakhar zone is becoming diversified with the return of rainfall

Researchers working within the ESCAPE project led by IRD show that farmers in the Niakhar groundnut area in Senegal have adapted to the climate variations of the past 60 years. With the return of rainfall at the end of the 1990s, the agroecosystem was diversified, with revised use made of the practices that existed before the drought years.

Small family farming in Senegal must ensure food security for a rapidly growing population and adapt to new climate, environmental and market constraints (droughts, extreme events, decrease in soil fertility and biodiversity, shortage of land and the destructuring of the groundnut sector)—while using mainly rainfed systems and tools several centuries old. In this difficult context, farmers have succeeded in extending the limits of their agrarian system and have developed strategies to prevent land saturation through crop intensification, extension of cultivated land, the adoption of certain innovations, the development of a migratory system, etc.

New opportunities have emerged since the beginning of the 21st century. On the one hand urban markets have grown and on the other rainfall has increased to levels close to those prior to the great droughts. The single agrarian model used at the beginning of the 20th century was affected considerably by environmental and economic crises.

In the Niakhar area, the agroecosystem is following diversified agricultural pathways but also using old practices and forms of organisation, especially now that abundant rainfall has returned. The reintroduction of livestock farming, the development of cattle fattening, the beginning of the regeneration of acacias, the return to the cultivation of long cycle millet and market gardening are clear signs of these changes. They reveal reactiveness, flexibility and capacity for the diversification of the **socio-ecological** and production **system**.

However, farmers also perceive the fragility of these innovations that are at risk from climate and market uncertainties. For example, Serer farmers have cautiously started to grow long cycle millet (that requires more rain) but without replacing short cycle grain completely. The scenarios drafted by climatologists confirm these fears, forecasting more extreme precipitation events (violent storms) and even higher temperatures in the near future.

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Harvesting and storage of ears of millet in the Niakhar region (Senegal).

Box 55

Moroccan beekeeping in the face of climate uncertainty

Beekeeping is particularly sensitive to variations in climate. For example, poor flowering can decimate entire colonies of bees. Researchers of the GRED unit and their Mediterranean counterparts are examining how beekeepers in southern Morocco are handling climate uncertainties and the increased demand for honey.

Beekeepers in southern Morocco have always been able to handle climate risks with the help of the Saharan honeybee.
This subspecies of *Apis mellifera* is economic in terms of water and honey and can withstand variations in temperature.
However, colonies can be decimated to a considerable extent in very dry years when flowers are rare.
The population of these bees recovers very rapidly when conditions are favourable again. This is possible thanks to their swarming capacity.
Under conditions of uncertain flowering in a semi-arid environment, beekeepers work with this extreme variability in numbers. As much as 90% can be lost.
In difficult years, the stock is partially conserved both by beekeeper who supply a few hives with honey, figs or dates and by wild swarms that occupy and survive in natural cavities.

Beekeeping in Morocco has changed scale and practices over the past decade to meet growing demand.
Beekeepers have adapted to the market and also to climate deterioration in two main ways: by the more or less systematic feeding of bee colonies or by taking hives to reliable flowering areas as they are irrigated (orange groves for example) and also to places with spontaneous occasional but massive flowering periods (euphorbia steppes in southern Morocco or thyme vegetation areas in the mountains).
However, both these forms of adaptation are subjects for controversy within the profession.
Migratory beekeeping has favoured genetic hybridisation that reduces the ecological advantage of Saharan bees under difficult climate and ecological conditions.
Feeding is criticised for its little-known effects on the health and strength of the bees.

Today, the two systems seem to be mutually opposed in a classic 'the ancients versus the moderns' face to face. But mutual recognition, interactions and persistence side by side would ensure greater stability, stemming from diversity itself.
The issue is in particular that of reintegrating environmental adaptation qualities in bee selection whereas agronomic research today favours criteria of productivity and of docility.

Collecting a swarm of wild bees in an argan tree at Jbel Ghir (southern Morocco).

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Irrigated rice fields
on terraces
with dammar agroforest
in the background
(Sumatra, Indonesia).

Technical solutions to strengthen adaptation capacity

Projections of climate change and its impacts suggest that times will be hard for tropical agriculture if climate warming reaches +2°C. A new phenomenon in its rapidity and scale, might such an increase exceed famers' reactiveness threshold? The agronomic research sector is exploring solutions for strengthening the adaptation capacity of small farming, such as the search for techniques or varieties that improve the resistance of farming systems to drought.

Old practices such as agroforestry are also being updated. This system is found from the humid tropics to semi-arid regions. In a context of climate change, the main advantage of agroforestry is that it lowers local temperatures by several degrees. The shade given by trees also reduces the evapotranspiration of crops. The combination of trees and crops improves carbon sequestration and has many other useful ecological features (erosion control, fertility and infiltration of moisture). In a context of uncertainty, the diversity of the resources generated by crops and also by forests (timber and other forest products) is also an economic strong point.

Beyond agronomic research, innovation pathways are also focused on the development of economic facilities such as access to loans and insurance and also information systems and climate warning systems.

Box 56

Fungi to the aid of degraded ecosystems

In 2005, eleven African countries launched the 'Great Green Wall', a vast tree-planting project running from Dakar to Djibouti and aimed at combating the desertification of the Sahel. In the research work mobilised by the project, that of IRD shows the importance of symbiotic microorganisms in the rehabilitation of degraded environments and the resistance of agrosystems to drought.

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Aerial view of a GMV project forest nursery at Widou (north-east Senegal).

In the Sahel, deforestation causes soil degradation and even desertification in some strongly degraded zones. The Great Green Wall project was launched in 2005 by eleven Sahel countries to fight this phenomenon and encourage tree replanting in a strip 15 km wide and 7,000 km long. A committee of specialists on trees and arid environments that included IRD scientists was asked to determine the most suitable techniques and to choose the species best matched to the context of the Sahel.

The researchers recommended in particular the use of mycorrhizal symbiosis, a natural phenomenon of association between a plant and a fungus. The fungus plays a capital role in water and mineral supply for the host plant through the uptake of nutrients in the soil with little mobility, such as phosphorus, and transporting them to the host.

Although it is agreed that optimum plant development is attained when mycorrhizal infection is high, there have been only a few studies under real conditions in arid and semi-arid regions.

In particular, the scientists showed during studies conducted in Senegal and Morocco that the introduction of fungi using facilitating or 'nurse' plants adapted to the environment is more effective than the biotechnological approach with mass inoculation of a high-performance strain of fungus. This *in situ* management allows the development of a richer, more abundant mycorrhizal community.

When the management of fungi present in the soil is successful, symbiosis improves plant growth in degraded soil in arid environments, in particular thanks to better use of water resource, conferring greater resistance to water stress.

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